LEADING EDGE
January 2015
NAVAL SURFACE WARFARE CENTER, DAHLGREN DIVISION

INTEGRATION & INTEROPERABILITY

MISSION ENGINEERING

AIR WARFARE - INTEGRATED AIR AND MISSILE DEFENSE

BALLISTIC MISSILE DEFENSE

COUNTERING IRREGULAR CHALLENGES

CYBERSPACE OPERATIONS

ELECTRONIC WARFARE

EXPEDITIONARY WARFARE

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NAVSEA WARFARE CENTERS DAHLGREN

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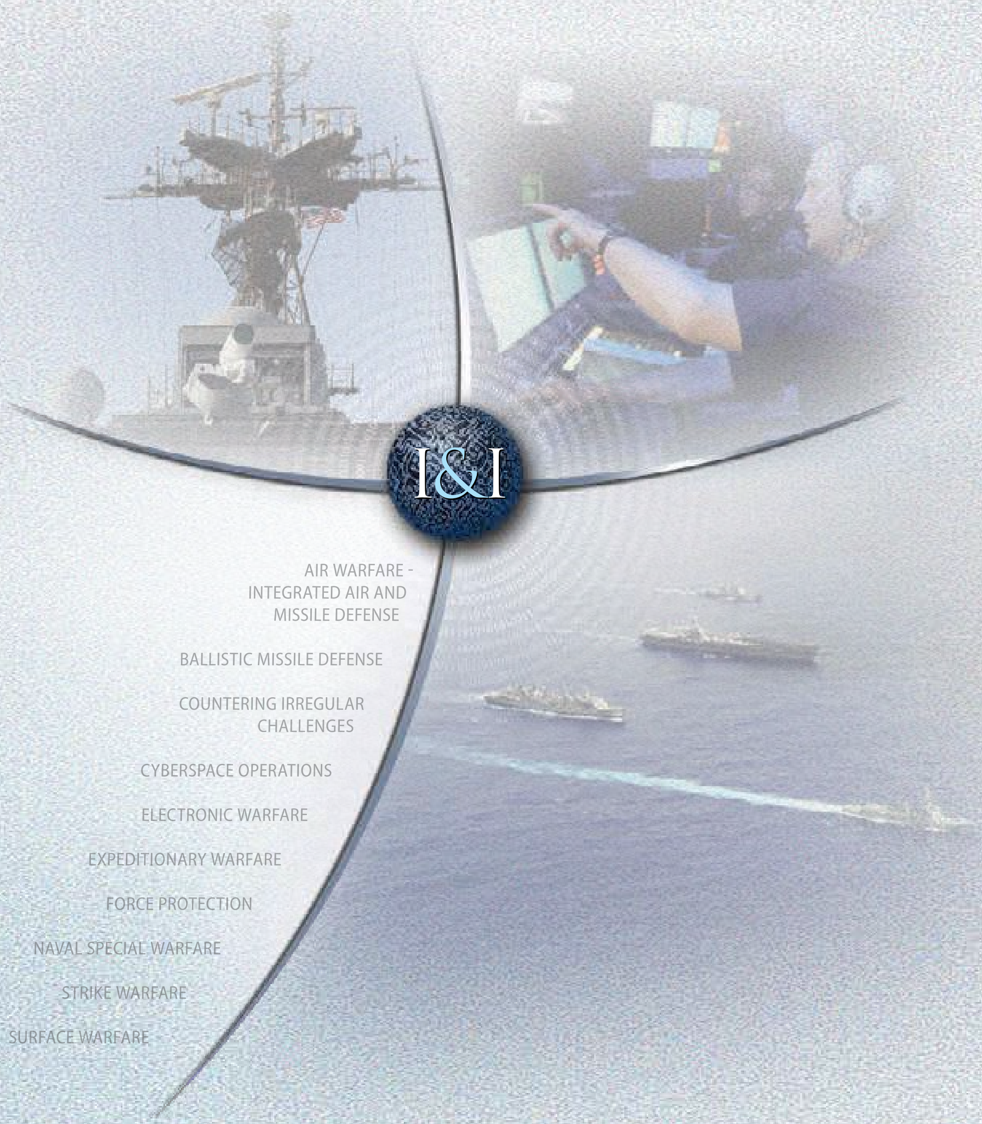

Introduction

Leading the Charge in Surface Warfare Mission Engineering

Naval Surface Warfare Center, Dahlgren Division (NSWCDD) leads the technical integration and interoperability (I&I) of highly complex systems of systems that make up our nation's Surface Warfare capabilities. A highly motivated workforce of scientists, engineers, and technicians routinely orchestrate the full set of mission kill chains that make up surface warfare, each of which is composed of hundreds of components across tens of systems fielded potentially on multiple sea-based platforms. This challenge would seem daunting if it were not for our strong legacy in mathematics, the traditional engineering disciplines, information sciences, and most notably, a holistic systems engineering approach to capability development and sustainment. Envisioning a new capability that exploits a technological development from the laboratory is only the first step of a highly disciplined engineering process. Integrating that new capability with the existing capability to safely and effectively expand the technological advantage of our warfighters at sea is also a critical step. Our mission engineers and architects are committed to maintaining a mission focus throughout the development of the myriad of piece parts, to the final test, certification, and delivery of an integrated whole.

This edition of the Leading Edge features articles describing NSWCDD's work in pioneering integrated solutions for the Surface Navy as part of the overall Navy I&I Enterprise. This edition is structured to highlight our specific contribution to the two primary areas of focus, Developmental I&I and Operational I&I. You will see that we have parlayed our traditional systems engineering disciplines that develop highly integrated and interoperable shipboard combat and weapon systems with an expanded view to the overall warfighting mission at the Naval and Joint Force levels. By aligning more closely with the operational community, the technicians and the tacticians are now working much more closely together to a common mission goal. A much greater focus on "Technical-to-Tactical" is evolving across the Navy Enterprise, and we at NSWCDD are quickly ramping up to answer the call for Surface Warfare.

I invite you to explore the Integration and Interoperability edition of Leading Edge and learn about how we are implementing these game-changing concepts into our mission engineering. I am proud to be Commander of one of the Navy's premier research and development facilities for integration and interoperability and am confident that NSWCDD will continue its legacy as the leader in Warfare Systems Development and Integration.

At NSWC Dahlgren, we turn ships into WARSHIPS.

Captain Brian R. Durant
Commanding Officer
Naval Surface Warfare Center
Dahlgren Division

Integration & Interoperability Edition • January 2015 Subject-Matter Leads

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Mission Engineering Integration and Interoperability (I&I)

By Dr. James D. Moreland, Jr.

The complex and now highly integrated machines of naval warfare continue to evolve enabling higher precision, more effective power projection and safer defensive postures for the Fleet. The interconnectedness of our own social fabric is finding its way into our ships, airplanes, submarines, networks, tanks, and the very weapons they deliver. This paper identifies the critical events that have occurred as a direct result of the Chief of Naval Operation's (CNO) Integration and Interoperability (I&I) Summit on 9 December 2010 to include the development of the Vice Chief of Naval Operations' (VCNO) I&I Activity which is driven by a formal charter. The Naval Systems Commands (SYSCOMs) are charged to place an increased emphasis on assessing the I&I of warfare systems to support current and future readiness for critical mission threads. The assessment of naval technologies, systems and/or capabilities requires a system-of-systems (SoS) approach to analyze the impact of making these naval investments across the diverse domains of surface, undersea, air, land, and networks as well as maritime coalition force integration. These assessments are executed following a systematic, quantifiable, and iterative approach referred to as Mission Engineering which combines the structure of Systems Engineering and the tactical insights of operational planning. The findings are captured in "effects/kill chains" to clearly identify operational needs based on the way we plan to fight through mission threads captured in our Combatant Command's Operational Plans (OPLANs) and Contingency Plans (CONPLANs). Mission Engineering emphasizes capability-based assessments to produce integrated warfighting capabilities that can be translated into specific programmatic guidance for strategic programs. The technical baselines developed will interject warfare system details into the Planning, Programming, Budgeting, and Execution (PPBE) System and Naval Capability Development Process (NCDP) to drive the Program Objective Memorandum (POM) for today's readiness and the future capabilities of our naval force. The overall objective of this I&I Activity is to provide responsive, credible analyses and engineering to inform decision makers of the results, insights, and alternatives of organic naval warfare capabilities for the integration of these capabilities within joint warfighting campaigns enabling more effective civilian and military leadership decisions.

To achieve the naval enterprise goal of having its major systems interoperate to create warfighting capability requires an accountable governance structure with mission-level processes and tools. Naval material acquisition traditionally delivers piece parts of warfighting capability (e.g., radars, weapons, command and control systems) and the platforms that deliver these piece parts to the fight (e.g., ships, submarines, airplanes, tanks, etc.). In today's acquisition process, these individual programs are matured independently with the resulting negative effect of integrating SoS when delivered to the Fleet. Developments and purchase contracts are many times sub-optimized for programmatic business and production purposes. The time between the initial vision of an integrated warfighting capability and the realization of all the necessary piece parts coming from various program offices can span many years or even decades. An additional long-term mission focus activity must be appended to the acquisition process to assure the integrated warfighting capability originally envisioned is actually delivered. A mission-based emphasis is required to focus across the entire developmental timeline from describing, integrating, testing, and finally delivering warfighting effects at best value across representative operational environments. Since these developments can take a long time to be realized, there is a critical need for factually informed, data-driven mission thread assessments from OPLANs and CONPLANs to continually describe and reconfirm warfighting gaps.

Mission architectures serve as the bridge for tactical-to-technical understanding by describing warfighting capabilities in a functional context and, most importantly, to set detailed force-level engineering requirements. These requirements need to be actively tracked through decomposition into Programs of Record (PoRs), validated, and certified at Fleet delivery. In addition, technical reference designs are needed for the major interface implementations, and mission-based testing is required to provide independent operational assessments of mission capabilities across systems. These elements are the enablers to support decision-making and governance for warfighting effects, ensuring the naval systems are integrated and interoperate to create the needed warfighting capabilities to effectively execute mission threads. While it is absolutely necessary to define the effects/kill chains and to govern these products, there also needs to be government control and accountability of major weapon system interfaces across the warfighting domains of surface, undersea, air, land, and networks. Specifically, defined technical reference designs delineating how interoperability needs to be achieved across diverse domains is crucial for mission success as measured by desired effects criteria.

Definitions

The following definitions provide contextual information for critical terms used in this article and throughout this edition of Leading Edge magazine.

Integration: The composition of a capability by designing and assembling elements in a way that allows them to work together to achieve an intended purpose.

Integrated Capability Technical Baseline: An architecture that consists of a list of functions and some indication of their interfaces or Information Exchange Requirements and interactions with each other and with functions located outside the system's boundary. Establishing this baseline facilitates a shared understanding across multiple products, organizations, and disciplines with respect to mission needs.

Integration Readiness Level (IRL): A systematic measurement of the interfacing of compatible interactions for various technologies (components) and the consistent comparison of the maturity between integration points.

Interoperability: The ability of two or more systems or components to exchange information and to effectively use the information that has been exchanged.

Interstitial Space: The interstitial space consists of the logical information characterizing the relationships between system integration. It is where the interface requirements and characteristics between elements are exercised. Characterization of the interstitial space enables insight into higher level system behaviors.

Mission Engineering (ME): Planning, analyzing, organizing, and integrating current and emerging operational concepts for the purpose of evolving the end-to-end operational architecture and capability attributes, across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) spectrum, including anticipated Blue Force (BLUFOR) and Opposition Force (OPFOR) behaviors, that are needed to inform the communities of interest involved in fulfilling mission needs statements.

Systems Engineering (SE): An interdisciplinary approach and means to enable the realization of successful systems. This structured, quantifiable, iterative and transparent development approach integrates all the disciplines and specialty groups into a team effort that proceeds from system conception through disposal covering the complete life cycle of a system.

Purpose

The I&I Activity is a concerted approach to develop recommendations for functional end-to-end accountability for I&I sequential activities that incorporates warfighting capabilities assessment; gap and solution recommendations across the DOTMLPF spectrum; adjudication, resourcing and acquisition of solutions; successful Fleet implementation; validation of solutions; and a workable governance. This new approach incorporates a mission focus on integrated capability development into the traditional SE "V" as depicted in Figure 1.

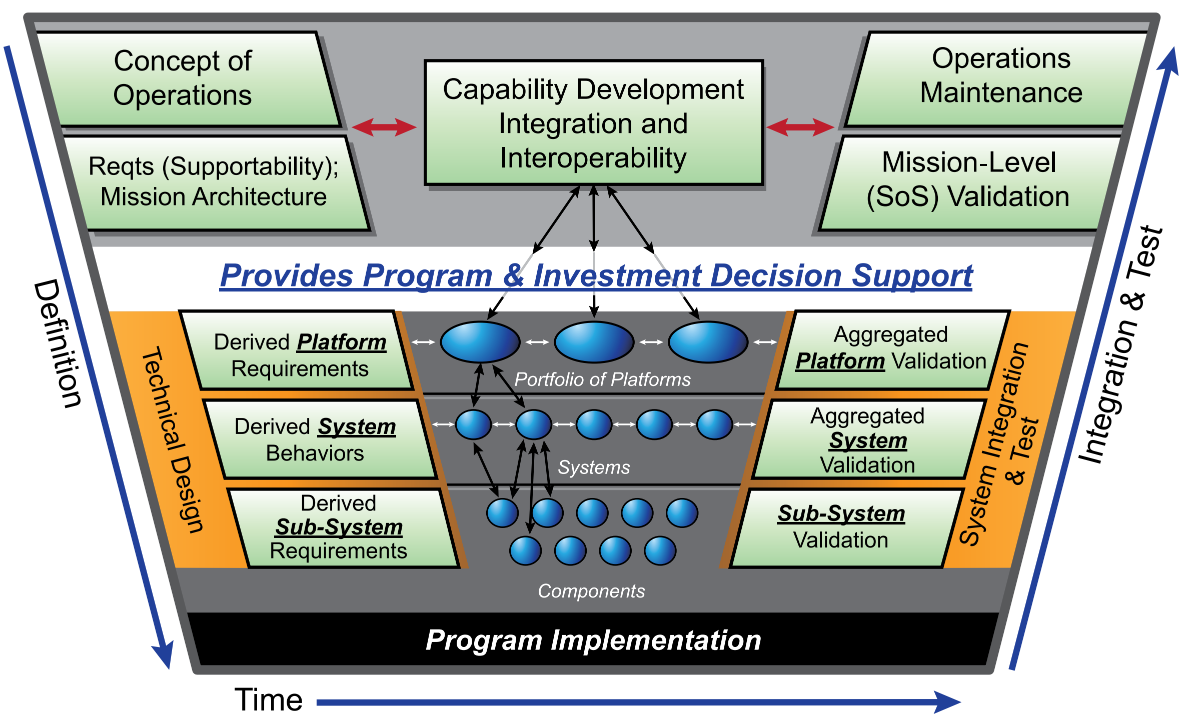


Figure 1. Mission Engineering Within the Systems Engineering "V" Model

Background

On 9 December 2010, the CNO hosted a summit on I&I. During the summit, the concept of an approach to I&I was briefed that would provide for sequential activities as a proactive means to: identify shortfalls in current capabilities (Warfare Capability Baseline); develop comprehensive solution recommendations to identified operational gaps (Capability Solution Management); and process the results within the Department of the Navy (DON) for approval, execution, and implementation in the Fleet. The critical outcomes of this summit are identified below:

Integration and Interoperability
Summit Outcomes

- Sharpen our focus on creating Integrated Warfighting Capabilities
- Develop/Institute formal governance approach for creating Integrated Warfighting Capabilities
- Promote awareness of existing capabilities in our Warfare Centers (people and facilities) to create Integrated Warfighting Capabilities
- Obtain agreement to adjust some Acquisition processes to ensure interoperability requirements are emphasized

An update on the progress of developing an effective approach to I&I was briefed on 20 April 2011 during the CNO Executive Group (CEG-V) meeting that included a proposed sequence of critical steps and the associated roles, responsibilities, accountability, and products for each step. Commander United States Fleet Forces Command (CUSFFC) and VCNO directed a war-game to assess the functionality of the I&I approach presented at the CEG-V, with a specific focus on organizational alignments, accountability, and capability to pass results between critical steps. Leadership direction was to evaluate the ability to achieve executable results within the framework of existing processes. The war-game was conducted 13-16 June 2011 and consisted of three and a half days of mission analysis and course of action (COA) comparisons that revealed findings and recommendations on how to institutionalize I&I activities and influence positive behavior change within the naval enterprise. The war-game objectives were set as shown below:

Integration and Interoperability
Wargame Objectives

- Identify and align supporting processes and expertise required to address effects/kill chain capability shortfalls
- Provide for development of notional DOTMLPF integrated capability recommendations and actions to address shortfalls
- Demonstrate a methodology to effectively address the products from each step of I&I activity, leveraging the available USN processes for capability development and implementation
- Define the concept of a warfare mission area owner

Over 40 war-game participants were drawn from across the naval enterprise providing expertise in Systems Engineering, testing, operations, acquisition, and governmental processes. Where possible, the I&I approach leverages existing DON processes (e.g., Joint Capability Integration and Development System (JCIDS), Capability Based Assessments (CBA) process, NCDP, Programming, Planning, Budgeting and Execution (PPBE) System and the Analysis of Alternatives (AoA) process). Specific focus areas were accountability and expertise within each step, and product wholeness of each deliverable. For the purposes of the war-game, all I&I organizations executed their respective roles within existing resources, recognizing that full execution of I&I within DON may require individual organizations to realign resources and re-prioritize current efforts.

Executing the I&I Activity

The information and products developed under the I&I Activity provide naval leadership with current capabilities and future requirements, thus equipping decision makers with the information necessary to better prioritize limited resources. This naval leadership charge focused on conducting end-to-end mission thread assessments of critical warfare mission areas and to rectifying the identified operational gaps.

The recommended fixes would be drawn from the entire DOTMLPF spectrum to consider all possible solution sets. These solution sets must then be synchronized across the individual elements of the spectrum to conduct complete and rigorous integrated warfighting capability transformation.

The I&I Activity execution plan takes into account a holistic approach to include operational, developmental, and conceptual execution states. Operational I&I focuses on near-term investments to execute quick returns to the naval force and serve as the foundation for future interoperability enhancements. Developmental I&I emphasizes mid-term investments to build on the "as-is" foundation and strives to produce a highly interoperable naval force by 2025. Finally, Conceptual I&I drives long-term research and development (R&D) investments to help guide the science and technology (S&T) efforts necessary to design, create and implement a future naval force network that is fully interoperable with the joint force.

In order to solve complex integration and interoperability challenges early in the systems engineering life cycle, it has become apparent that these issues need to be addressed during experimentation and test on the left-side of the Systems Engineering "V" Model. This requires the ability to execute mission threads in a representative operational environment. Since the integration of new and legacy systems is required, a live/virtual environment must be developed to incorporate modeling and simulation (M&S), Hardware-in-the-Loop (HWIL) and virtual testbeds to include virtual worlds. Agent-Based M&S techniques and frameworks has become a critical research and development area for investigating the behaviors between systems, which provides insights on emergent behaviors not characterized in requirements. Likewise, virtual worlds and virtual testbeds have been developed to provide a representative environment for

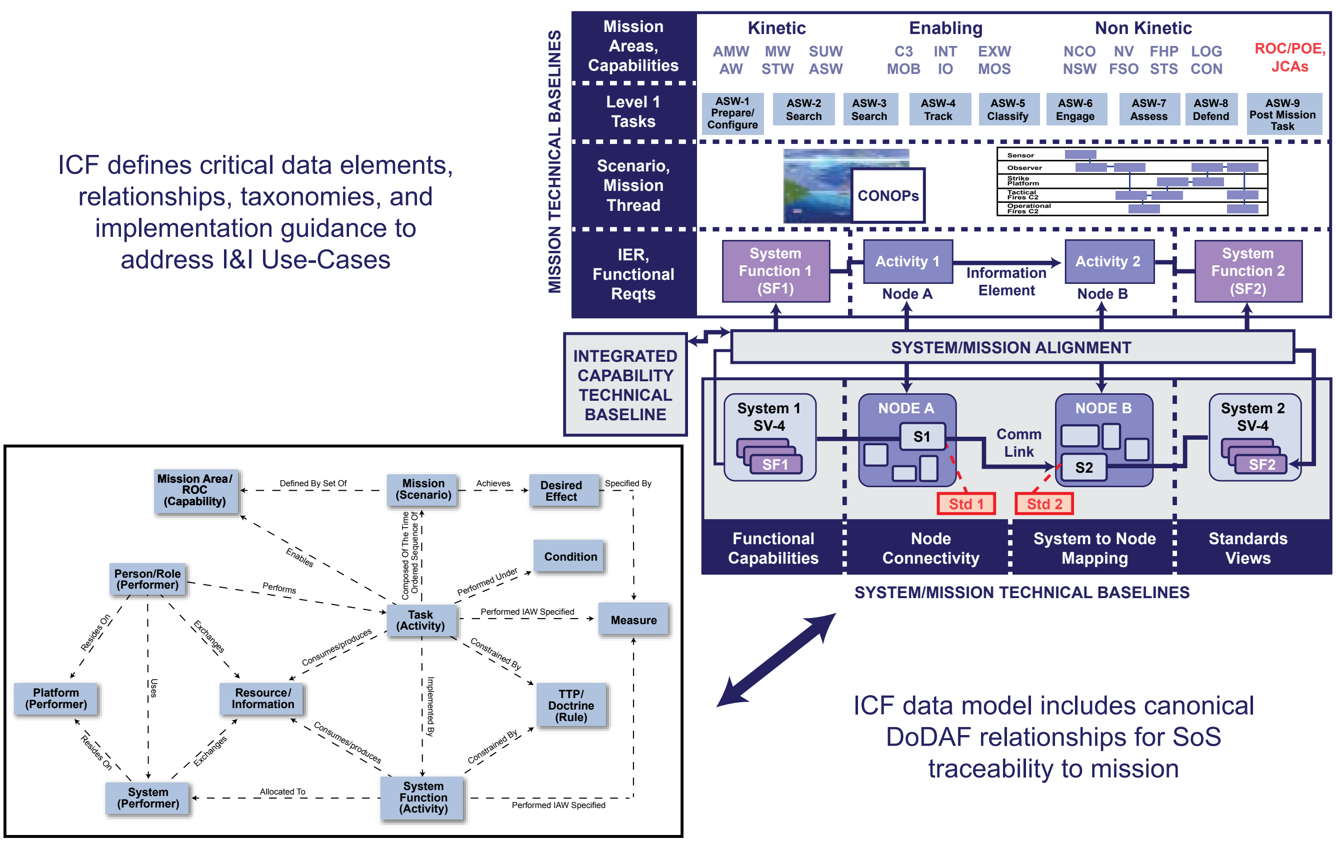


Figure 2. Integrated Capability Framework - Meta Data Structure

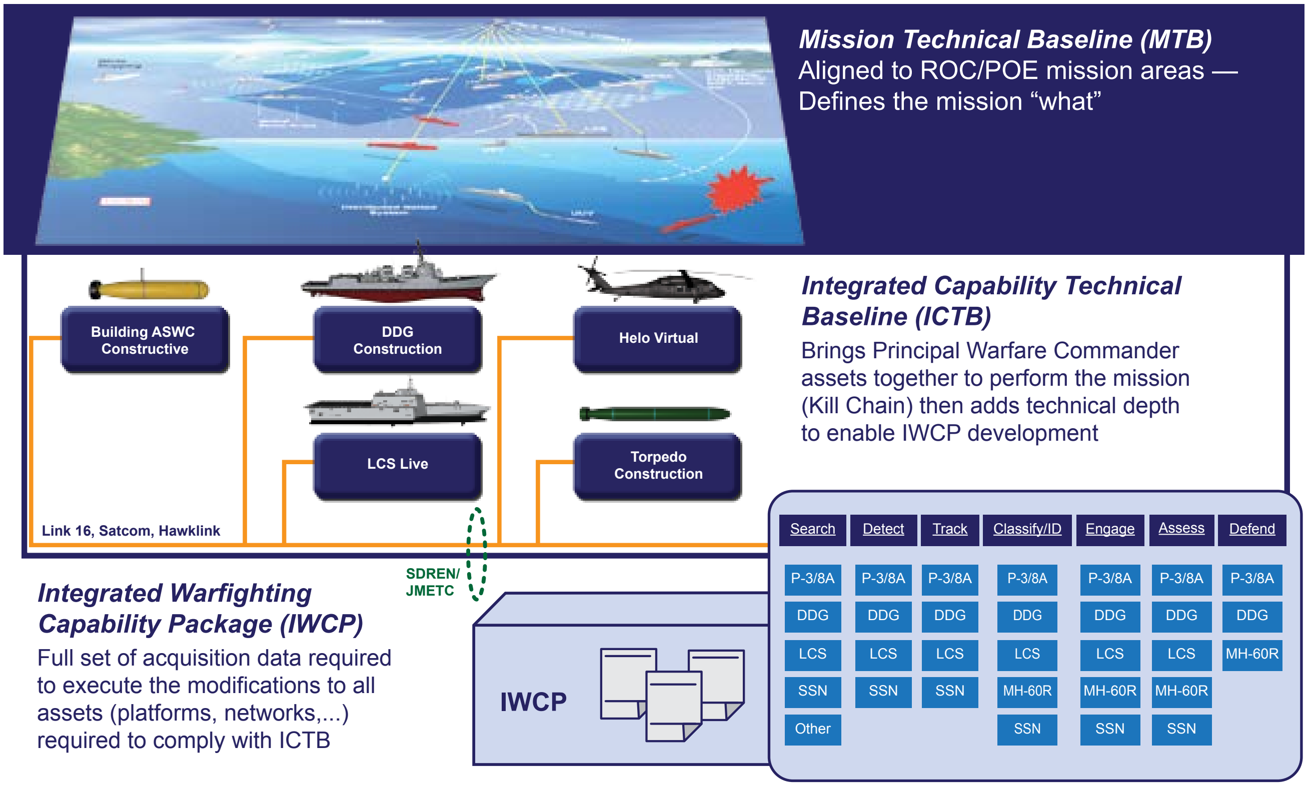


Figure 3. Mission Level Technical Reference Products

both training and the development of mission-level requirements. This ability to evaluate I&I during early engineering development better prepares the acquisition community for success during final operational test, which has now been transformed into mission-based test.

A foundational element of working across many mission-based products is a structured metadata structure to relate and store crucial information for easy retrieval in a tool agnostic way. The I&I team has developed an Integrated Capability Framework (ICF) to define cross-domain relationships as shown in Figure 2. This framework develops the contextual relationships across the naval enterprise, which allows for an effective working relationship and better understanding of roles and responsibilities when working between technical disciplines and tactical tribes.

This metadata structure needs to support the alignment of crucial technical baseline elements of the I&I Activity. These technical products define the mission requirements and engineering development details across programmatic boundaries through the appropriate architecture products with an emphasis on effective mission success. The goal is to define the required SoS linkages to provide an integrated warfighting capability as illustrated in Figure 3. These products serve as the technical reference documents to drive synchronization.

Operational I&I

This aspect of I&I addresses the near-term factors associated with current warfighting capability gaps. The process provides critical decision-making information through a feedback loop to the acquisition process on capability delivered according to the methodology in Figure 4.

The assessment of naval technologies, systems and/or capabilities requires a system-of-systems (SoS) approach to analyze the impact of making these naval investments across the diverse domains of surface, undersea, air, land, and networks as well as maritime coalition force integration. This assessment is

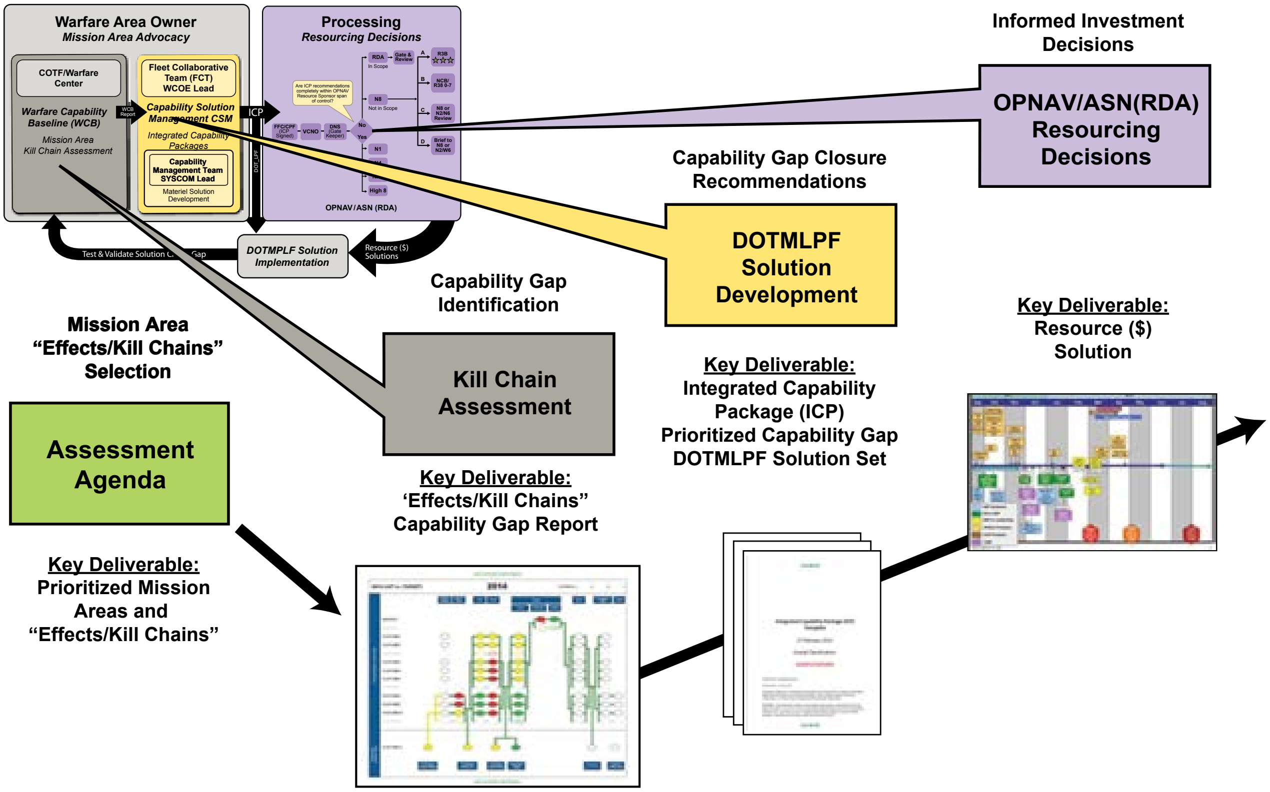


Figure 4. Integration and Interoperability Activity Methodology

accomplished through the development of effects/kill chains to illuminate capability advantages and disadvantages of the alternatives; consider joint operational plans; examine sufficient feasible alternatives; characterize key assumptions, variables, and sensitivities; as well as assess technology risk and maturity. Figure 5 shows an example of a notional Air Warfare (AW) effects/kill chain which consists of eight mission tasks (plus three sub-tasks) and six C3 nodes as illustrated by the rectangles.

The second phase of this process identifies proposed DOTMLPF solution sets to fix the degraded/broken effects/kill chains according to Fleet priorities. The Warfare Centers of Excellence serve as the lead for these solution sets, which are documented in an Integrated Capability Package (ICP). The subject matter experts across the DOTMLPF spectrum collaborate on solutions considering important trade offs across that spectrum as well as the synchronization of modifications across the spectrum elements.

An example of this collaboration is the Naval Integrated Fire Control Counter Air (NIFC-CA) project, which was officially recognized as a joint venture in 2002. This system-of-systems engineering effort extends the Naval Theater Air and Missile Defense battlespace to the maximum kinematic range of our weapons. The capability focuses on targets beyond the detection range of the shooter, including Engage-on-Remote (EoR) and Over-the-Horizon (OTH) targets. Formal scoping and structure were required based on detailed examinations using effects/kill chains and operational test data to determine operational needs for Fleet leadership. A critical governance element of this formal integrated warfighting capability structure involved the decision to direct Program Executive Office – Integrated Warfare Systems (PEO IWS) to establish a NIFC-CA Systems Engineering and Integration Project Office to integrate across the elemental programs in support of the development and acquisition of a NIFC-CA capability. This instantiation of a formal NIFC-CA project began with the critical elements identified in Operational I&I, namely the

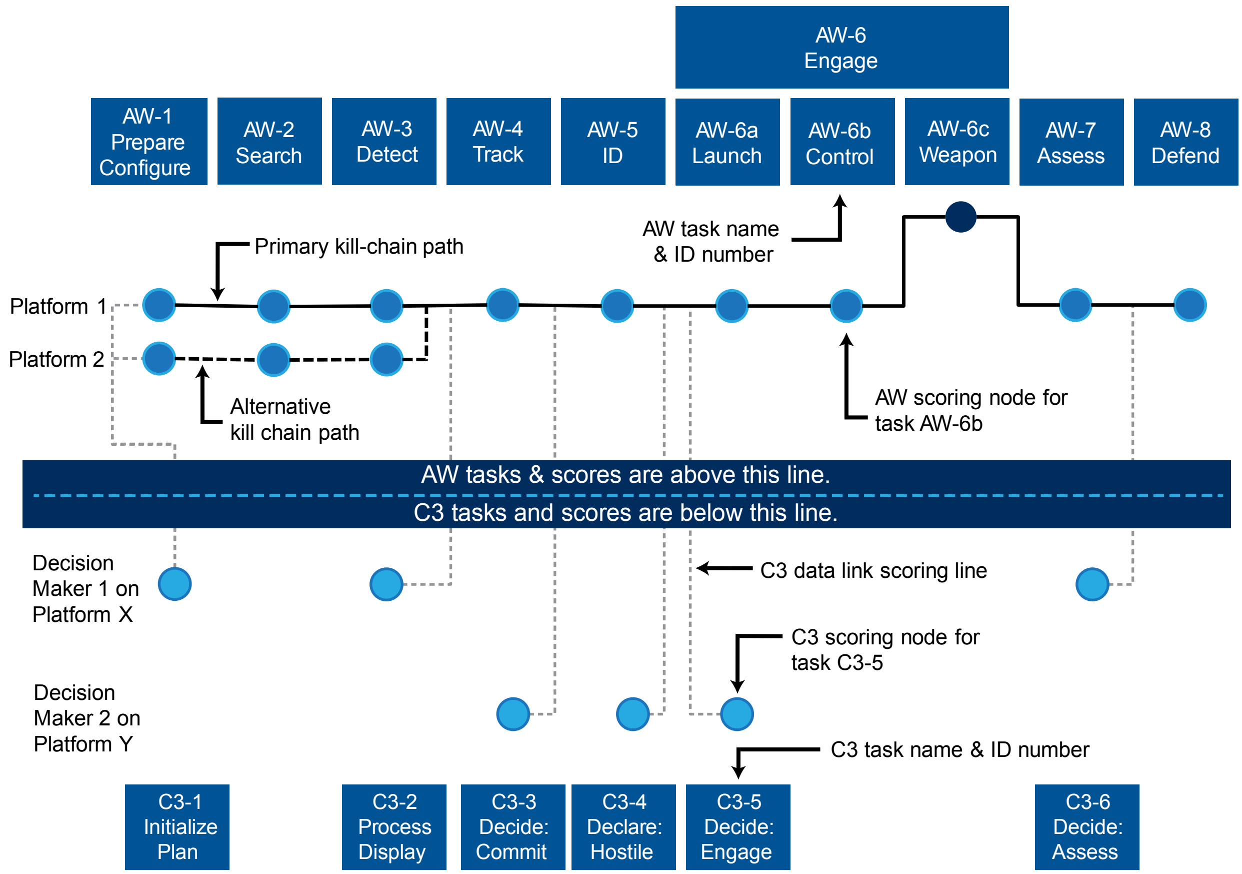


Figure 5. Notional Air Warfare Effects/Kill Chain

determination of facts-based operational gaps and recommended solution sets across the DOTMLPF spectrum and warfighting domains.

Developmental I&I

In today's environment, most technical decisions driving the POM are based on the advertised performance of a system as a prediction of what should be versus data-driven measurements obtained during operational evaluations representing ground truth of what is. These operational evaluations can provide a higher level integrated Technology Readiness Level (TRL) of the system in context with the real environment and therefore the I&I of multiple systems to achieve a warfighting capability. What has been missing is the inclusion of the Integration Readiness Level (IRL) into the modulus where the interaction between systems is evaluated to recognize the activity resident in the interstitial space between systems where SoS behaviors are realized. This bridge between tactical and technical operations provides additional technical depth to existing Front End Assessment (FEA) products to ensure accuracy in determining capability gaps and therefore acquisition decisions on what needs to be procured for Fleet readiness. The overall objective is to produce a data-informed Warfighting Capability Plan as part of the PPBE System to eliminate financial waste, increase competition, and procure more relevant products.

Another critical element toward improving the acquisition process is to provide good linkages between the left and right sides of the SE "V" and prepare for increased technical emphasis on mission requirements. The scientists and engineers engaged in the I&I Activity are currently taking the lessons learned in evaluating today's independent systems on the right side of the SE "V" (refer to Figure 1) to better inform the left side of the SE "V". This is accomplished through DASN RDT&E initiatives by modifying the Systems Engineering Technical Reviews (SETRs) and acquisition Gate Review Requirements to identify problems early in the development process and therefore drive toward better success in the production of I&I systems while gaining more pre-Milestone B trade space. In addition, the SoS Guidebook is being updated to incorporate mission-level SE operational objectives and designated technical authorities. These efforts are also providing the naval workforce with more experience in understanding ME and the production of SoS capabilities versus myopic views of individual systems, which may or may not affect the overall capability. A major part of this education has come from the development of the Mission Level Assessment and Evaluation (MLA&E) process, which is an engineering approach to an iterative Fleet/Acquisition capabilities-based methodology by which operational needs are defined through warfighter-validated mission architectures that influence Joint/Fleet rehearsals, exercises and experiments.

Continuing with the NIFC-CA example thread, Developmental I&I elements play a crucial role as NIFC-CA executes as a capabilities-based acquisition project, levying minimal requirements onto the component systems while deriving SoS capability from the federation of these independent systems. Multiple programs must be tightly synchronized across both actual development and future acquisition strategies. In today's environment, this approach has matured into the execution of three effects/kill chains called From the Air (FTA), From the Sea (FTS), and From the Land (FTL) with the challenge of keeping all in sync on a daily basis. The NIFC-CA project exploits capabilities inherent in existing systems, optimizes current and emerging technologies in component system upgrades, integrates them and performs effects/kill chain tests, therein forming an interoperable SoS to maximize future air defense capabilities. Early in the effort, the emphasis was to support system definition and architecture development, performance prediction, performance assessment, system test and risk reduction efforts, system analysis, modeling and simulation, and capability demonstrations in order to drive the acquisition decisions in the PPBE system. This project also facilitated the development of the concept of operations with the warfighter to maximize effectiveness when deployed with the Fleet.

Conceptual I&I

Conceptual I&I concentrates on the longer range objectives to establish government-controlled trade space to enable more affordable and flexible weapons systems. The naval environment is implementing Open Architecture (OA) as an overarching strategy to acquire, upgrade and maintain weapons systems using an evolutionary approach to achieve commonality. Conceptual I&I takes into account acquisition law, program delivery schedules, and supportability from both a financial and personnel resources perspective. This convergence of business practices and technical design agility is producing modular systems with greater success in the I&I of complex systems. A challenge and significant part of this future direction involves the linkage between new and legacy components/interfaces to facilitate rapid development and effective I&I between systems.

In order to reduce the total ownership cost (TOC) of weapons systems, it is essential to design and develop systems based on cross-domain solutions with a move away from platform-centric capabilities. Sharing data and building modular systems is essential to leverage across programs (buy once and reuse) with the ultimate objective to reduce cycle time for transitioning new capabilities to the operational environment. The success of the Open System Architecture (OSA) depends heavily on an innovative and well-educated workforce. The naval enterprise must produce a workforce that is well versed in identifying and managing cross-domain and life cycle dependencies, understanding and responding to adverse vendor behaviors, ensuring that competition yields the desired results, and incorporating OSA best practices as an integral part of program management.

Force level security and safety are being investigated as part of Conceptual I&I under the auspices of the Naval Ordnance Safety & Security Activity (NOSSA), incorporating and utilizing the Weapon

System Explosives Safety Review Board (WSESRB) and its current processes. This is essential to ensure that the resultant distributed effects/kill chains will perform effectively and safely across all SoS component systems. Key to Conceptual I&I are discovering and documenting how best to review and assess the I&I characteristics of weaponized systems to understand safety risks; identify hazards and causal factors; assess monitors and mitigations; assess test and validation; and issue I&I safety findings or actions. According to systems engineering best practices, common taxonomy, processes, tools, and objective quality evidence shall be injected into naval policies and guidance, into SETR criteria and the Probability of Program Success (PoPs)/Gate Review process and metrics.

The critical areas of investigation for the I&I Activity are illustrated in Figure 6.

These areas of investigation were addressed in a SYSCOM Mission Level Technical Authority Summit held on 9 December 2013 to synchronize processes and approaches for the execution of these complex initiatives across the SYSCOM communities. This event provided reviews and in-depth discussions on the critical elements of the I&I Activity and set the path forward.

Recurring actions sponsored by the Program Executive Offices (PEOs) are driving change in the way we do business based on this facts-based approach concentrating on end-to-end execution of mission threads. Discussions have focused on the coordination of the Capability Phasing Plan (CPP), Surface Warfare Technical Requirements Group (SWTRG), I&I Activity, and Warfare Improvement Program (WIP) processes. As part of this coordination, detailed discussions are occurring with the Major Program Managers (MPMs) to discuss the execution of the I&I process and the critical output products driving the POM.

As demonstrated within the NIFC-CA project, successful management of acknowledged SoS systems engineering projects requires reaching across organizational boundaries to establish a capability-based endgame. NIFC-CA is charged with bringing

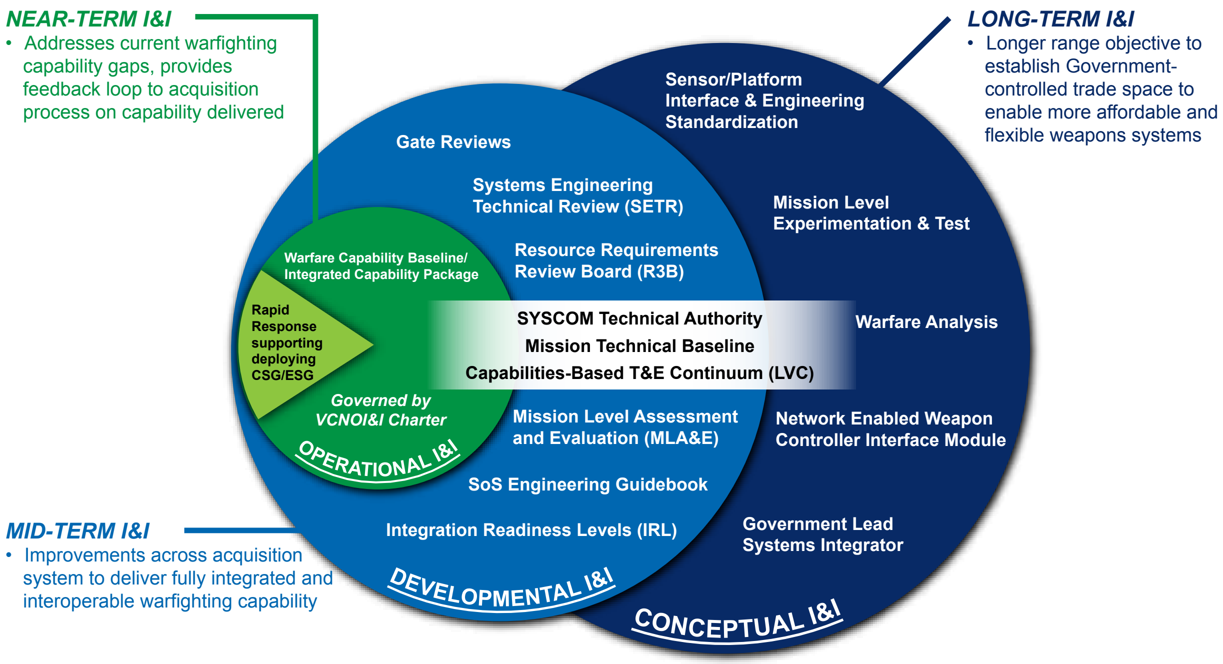


Figure 6. Intergration and Interoperability Activity Critical Areas of Investigation

together independent major defense acquisition programs (MDAP) as component systems of an integrated warfighting capability. The NIFC-CA DODAF architectures, in the form of Integrated Capability Technical Baselines, have proven to be powerful tools for capturing the functionality, communications, and essential information of this acknowledged SoS. These products serve as the authoritative source of information to capture conceptual systems engineering ideas and guide tasking to form actual engineering products. NIFC-CA has implemented the key systems engineering and software engineering techniques, including modularity, open architecture, abstraction, and information hiding which are critical to Conceptual I&I activities. These techniques were applied during the functional allocation and distribution process resulting in a system that is far more extensible, allowing dramatic evolution and innovation in the future.

Conclusion

An increased emphasis has been placed on accessing the I&I of warfare mission capabilities through the effective and efficient integration of current and future systems. These assessments are being accomplished through the development of effects/kill chains to identify I&I issues between the critical warfighting systems across mission areas. This is being accomplished through the assessment of effects/kill chains for specific tactical situations (TACSITs) threads within joint Operational Plans. The future vision of this mission-level analysis capability is to interject warfare system technical details into the major acquisition processes to drive the POM for future naval integrated warfighting capabilities.

It is absolutely necessary to define operational gaps through effects/kill chains and to govern these, but also needed is government control and accountability of major weapon system interfaces and integrated capability reference baselines. The naval environment's annual acquisition budget is founded on a "commodity" philosophy and is driven by a fast-paced environment where rapid decisions must be made without adequate time to determine the second-order impacts (interoperability, non-synergy of material procurements, operational capability imbalances, etc.) the acquisition decisions within the POM. Although the commodities are continually manipulated, rippling effects may aggregate consequences upon warfighting capabilities that are exercised by the Fleet at the force-level and therefore require investigation. The goal is to maintain technical and operational cohesiveness across mission areas in a fiscally constrained environment while increasing the overall capability for the warfighter. Adding a structured mission focus to the acquisition process will serve the I&I needs of integrated warfighting well. We don't acquire commodities the way we fight, but we MUST engineer for the way we fight. ⚓

Ms. Mary Lacey
Deputy Assistant Secretary of the Navy Research, Development, Test & Evaluation

Introduction

To ensure the future technological superiority of our Fleet and Force, it is critical that prudent Department of the Navy (DON) Research, Development, Test, and Evaluation (RDT&E) investments provide combat effectiveness, affordability, and improved reliability and maintainability in our current and future weapon systems. With increasing fiscal pressure, it is imperative that the DON balances tactical and strategic investments across all accounts, ensures RDT&E investments target the correct warfighter missions, and expeditiously transition technologies and capabilities to Fleet and Force operators. The basic concepts of Integration and Interoperability (I&I) prompt us to look across the effects/kill chains to see how systems really work together in an operationally relevant environment. Through the rigor of experiments, testing, data-driven assessments, and review, the DON is looking for game-changer innovations that effectively integrate technology and systems to provide affordable solutions for our Sailors and Marines.

The Navy is aggressively pursuing I&I with the goal of maintaining technical and operational cohesiveness across mission areas while increasing the overall integrated warfighting capability for the warfighter. Front-end assessments based on operational evaluations that include the I&I of multiple systems ensure accuracy in determining capability gaps and lead to better acquisition decisions. A data-informed Warfighting Capability Plan is not limited to material solutions, but posits solutions across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Policy (DOTMLPF-P) spectrum. This approach couples rigorous analyses, coordination, and collaboration to produce holistic views across domains and functionalities. We are also modifying the Systems Engineering processes, particularly Technical Reviews and Gate Reviews, to identify disconnects early in the development process and thereby drive better success into the production of integrated and interoperable systems.

Even more critical than the processes and tools we put in place to enable systems integration and interoperability are our people. I&I analysis is largely an inherently governmental function and to truly understand the technical dimension of the military problem, our workforce must be engaged in technical work. For that reason, in concert with OPNAV, the Assistant Secretary of the Navy for Research Development and Acquisition (ASN(RDA)) is relying on our technical workforce—civilian and military—to lead and conduct I&I analyses. We are investing particularly in our Warfare and Systems Centers to do hands-on work to ensure the capability and capacity the DON needs are available. The I&I activity is shedding light on the technical requirements and organizational governance that must be satisfied to successfully deliver system of systems capability. ⚓

DEVELOPMENTAL

INTEGRATION & INTEROPERABILITY

Maintaining Technical and Operational Cohesiveness Across Mission Areas

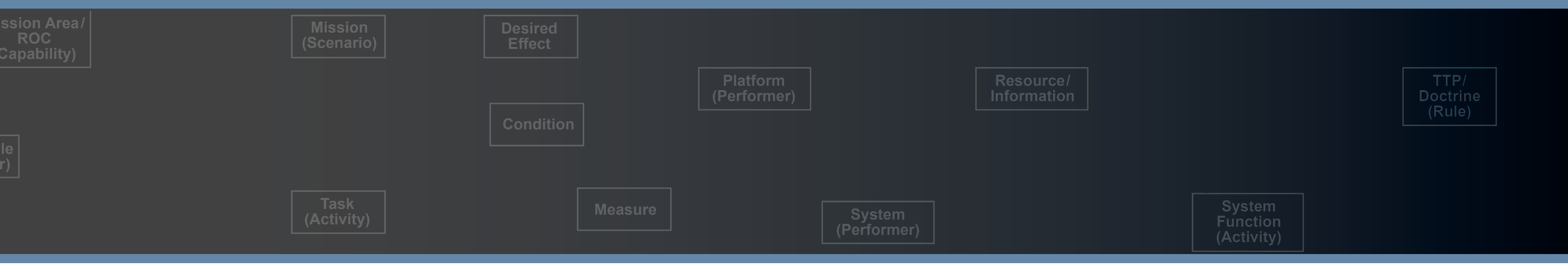
Integrated Capability Framework:

Building a Metadata Structure for Diverse Products

By Stephen R. Haug

There are many producers and users of architecture data in the Integration and Interoperability (I&I) community, including operational mission planning, testing, training, acquisition and development, capability analysis and definition, cost analysis, and many more. No matter the purpose, the architecture created must include sufficient detail to meet the needs of the intended users; it must be created to enable communication and collaboration between the various users of the architecture, including the intended users and the unknown future users. This is especially important given the increasingly collaborative and net-centric nature of Navy and Joint missions. Missions performed by the Navy are rarely performed by a single ship or aircraft; rather, they are usually performed by operators using multiple systems on multiple platforms simultaneously.

There are many frameworks[1] with different data models and taxonomies (languages) that attempt to enable architecture definition, but most fail to address all issues associated with defining architectures. Many times, frameworks use terms that are not understood by all users or the frameworks focus on one user at the expense of others. Each user has unique needs, but in order to integrate capabilities, the user processes must occur in collaboration across Navy operational, acquisition, test, training, and engineering stakeholders. To solve these issues, a cross System Command (SYSCOM) team created the Integrated Capability Framework (ICF)[2] that leverages existing frameworks and is intended to be the common, overarching framework that drives and ties together each of the user processes.



ICF Creation

The first step in creating the ICF was to understand the needs of the various users. The ICF team identified a set of expected users of the ICF (both as architecture creators and users of ICF compliant architectures) and interviewed representatives from those positions and communities. After analyzing interview results, as well as other input from the I&I community, a few common themes emerged:

- Architectures must be built with consistent taxonomies.
- Architecture data must be from authoritative sources.
- Architectures must be based on missions as understood by the operational Navy.
- Architectures must contain a minimum set of data and views to be useful in defining a mission-based architecture made of people, platforms, and systems.
- System and mission architectures must be able to be mapped to each other.

Simultaneously, the ICF team evaluated the existing frameworks and taxonomies, as well as the Navy and DoD policy and guidance that constrained the ICF solution. One constraint identified was that all architectures created in the DoD are required to be Department of Defense Architecture Framework (DODAF) compliant. Similarly, the Department of the Navy (DON) Chief Information Officer (CIO) has issued an Architecture Development Guide (ADG) that constrains how DODAF architectures are created.

ICF Solution

The first issue addressed by the ICF was the common taxonomy. Without a common language, including the types of architecture data, the relationships between the data types, and the authoritative source of definitions of that data, architectures cannot be commonly understood or used by all parties. The DODAF Meta Model (DM2), which defines a number of types of data and relationships in architectures, was evaluated to determine the minimum set needed to fully define a mission-based architecture, including a determination that no additional relationships are needed. The resulting data model is shown in Figure 1. In the diagram, a commonly understood term is the first item in each data type block, and (as needed) the DODAF term is provided in parentheses. A definition for each data type is provided in Table 1.

In addition to defining the minimum data set needed for fully defined mission architecture, the ICF includes authoritative sources for the terms and definitions for each type. Without that common definition, architectures cannot be easily understood by all parties. As an example, consider the term used for a sweetened, carbonated beverage. According to the Harvard Dialect Survey[3], more than 12% of the country uses the term "coke" to refer to all soft drinks, but a person in the northeast U.S. (where "soda" is the much more common term) may not understand an architecture that used "coke" to refer to anything but Coca-Cola®.

Similarly, without a common data model and taxonomy, architectures cannot easily be used in combination with other architectures. Using the same example, if an architecture was created for a soft-drink dispensing system that was to provide six dispensers of "coke," and an architecture was created for a restaurant that needed a "Coke" dispenser, putting the two architectures together may not result in the desired effect. Even worse, if the restaurant architecture called for a "soda machine," the "coke dispenser" may not even be considered.

To identify the appropriate authoritative sources, the ICF team evaluated existing taxonomies for each type of data to identify an authoritative source, taking

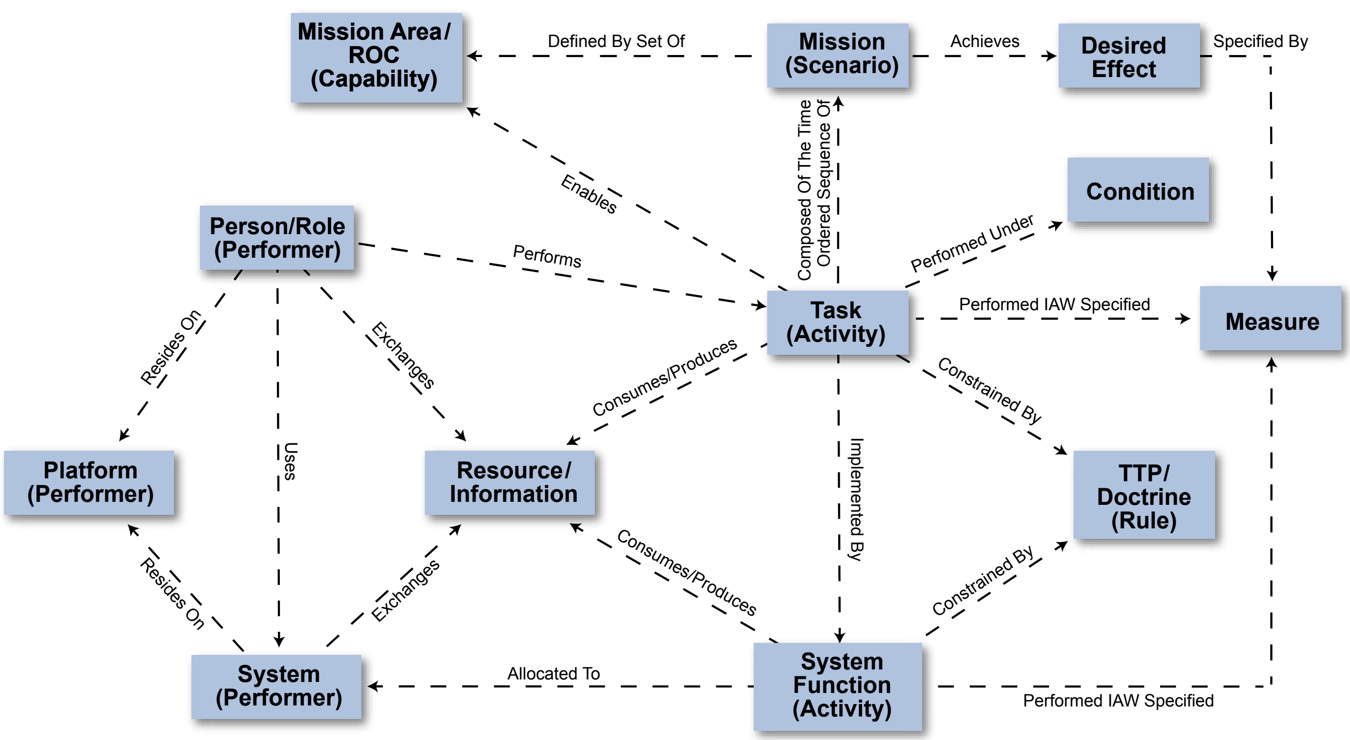


Figure 1. Integrated Capability Framework Data Model

DATA ELEMENT	DESCRIPTION	TAXONOMY/SOURCE
Mission Area/Required Operational Capability (ROC) (Capability)	The abilities needed to execute specified courses of action, organized into the specific segments of the overall Navy mission.	Mission Areas and Required Operational Capability/Projected Operational Environment Statements (Office of the Chief of Naval Operations Instruction (OPNAVINST) C3501.2K)
Task (Activity)	Work, not specific to a single organization, weapon system or individual that transforms inputs into outputs or changes their state. (DODAF)	Navy Tactical Tasks (NTAs) as assigned to platforms/systems/organizations in Navy Mission Essential Task Lists. Note that detailed scenarios may require extending the leaf level activities defined in the NTAs.
Tactics, Techniques, and Procedures (TTP)/ Doctrine (Rules)	Fundamental principles by which the military forces or elements thereof guide their actions in support of national objectives. (JP 1-02) The constraints placed on any Task or System Function in performance of a mission scenario.	Operational Plans (OPLANs), Navy TTP
System Function (Activity)	Work assigned to a specific system that transforms inputs to outputs or changes the system state. (DODAF)	Joint Common System Function List (JCSFL)

Table 1. Data Element Descriptions and Authoritative Source

into account policy and guidance. An important factor in each choice was the appropriate "owner" of the taxonomy. For example, Tasks (Activities), are performed by operational Navy personnel – the enlisted and officer Sailors out in the Fleet. As such, it is appropriate to use a taxonomy in use in the operational Navy, the Universal Naval Task List (UNTL), rather than one made by acquisition personnel. A sample of the resulting ICF taxonomy is provided in Table 1.

Once the minimum data set and the authoritative sources were defined, the ICF team defined a minimum set of products or views into the data. Each product is built from a subset of data in the ICF Data Model, and from the authoritative sources. In addition to the prerequisite Overview and Summary Information (AV-1) that defines the scope and purpose of the architecture, the ICF identifies two major sets of products – the Mission Technical Baselines (MTB) and the System/Platform Technical Baselines (S/PTB). The list of products is shown in Table 2, including a description and the DODAF terminology.

MTB products are based on a Tactical Situation (TACSIT) definition of the mission to be performed, which includes key details such as the desired effect of the mission, the required capabilities, the tactics and rules of engagement (ROE), the tasks to be performed and the measures of performance (MOPs) for each task in support of the desired effect. Also in the TACSIT are the information that must be exchanged, and the system functions needed in support of the operational tasks. It is especially important to capture the ROE and the tactics as the Fleet expects to execute the mission, since these can greatly affect ordering of tasks and who performs them; the ability of the force to meet the desired effect; and even which systems are critical in support of the mission. As an example, if only command nodes are permitted to declare a target hostile, then the communications systems and networks on all platforms become critical systems for the mission even for a self-defense engagement, a detail that could be easily overlooked without the ROE.

The S/PTB products define the following: the platforms and systems that are expected to be part of the

ICF MISSION TECHNICAL BASELINE PRODUCTS
1. Concept of Operations (CONOPs)/OV-1/TACSIT
2. Required Capabilities/CV-2, CV-4, CV-5, and CV-6
3. Organizational Relationships Chart/OV-4
4. Mission Thread/OV-6a and OV-6c
5. Information Exchange Requirements (IERs)/OV-3
6. Functional Requirements/SV-5a

ICF MISSION TECHNICAL BASELINE PRODUCTS
1. Functional Capabilities/SV-4 and SV-7
2. System to Node Mapping/SV-1
3. System/Node Connectivity View/SV-2 and SV-6
4. System/Interface Standards/StdV-1

Table 2. ICF MTB and S/PTB Products

mission; the functionality each must provide and the associated MOPs; the platforms on which each system resides; and the communications between each system and platform.

In order to fully define and evaluate the mission and identify potential interoperability issues, the systems and platforms in the architecture should be specific whenever possible. Instead of generically defining a carrier, helicopter, or radar, the specific hull number, aircraft type, and systems should be specified. Otherwise, details like different data link implementations or different radar performances can be overlooked, and the analysis of mission capability or interoperability of the systems would then be incomplete.

Identifying the owner of the views, is just as necessary as identifying the data and views needed. The view owner has the most understanding of the data in the view and is empowered to make the decisions about the views. For example, the operational view products in a mission-based architecture define the mission from the perspective of the warfighter, including the desired effect, tactics, environment, chain of command, tasks to be performed, etc. In order to be representative of actual Navy operation, this data must all be owned and defined by the Fleet, e.g., organizations like Fleet Forces Command (FFC), Pacific Fleet (PACFLT), the Operational Test and Evaluation Force (OPTEVFOR), and the Warfare Centers of Excellence (WCOEs). Similarly, system view products must all be owned by the program managers who are responsible for producing the platforms and systems.

The final step in creating the ICF compliant mission architectures is to combine the MTB with the several S/PTBs to create an Integrated Capability Technical Baseline (ICTB). Creating the MTB and S/PTBs using the data model and authoritative sources, is significantly easier than when using individually defined terms. As an example, since the MTB defines the required system functions using the Joint Common System Function List (JCSFL), and the S/PBT products define available system functions using the same list, matching needed functionality to provided functionality is possible. Work will still be needed to fully integrate the products, of course. For example, an MTB that says it needs a system to "Acquire and Track Targets" (JCSFL number 2.1.39) will require more analysis to determine what kind of target and how well it must be tracked (e.g., an E2 Hawkeye, designed for air/surface tracking and command and control, will likely be of little use in detecting submarines). However, having all sensor systems that are capable of acquiring and tracking targets as defined in the JCSFL use that term and definition enables discovery

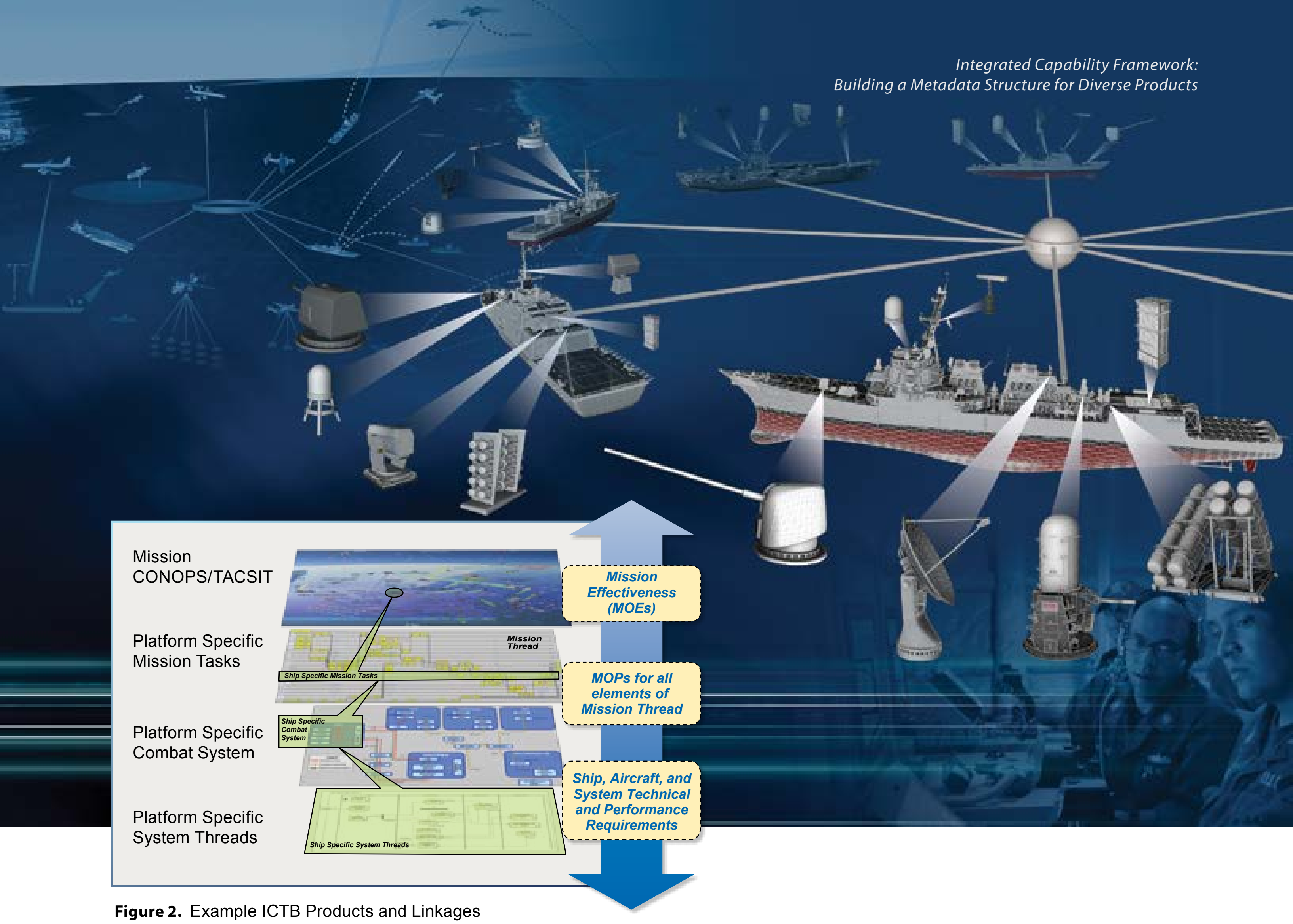


Figure 2. Example ICTB Products and Linkages

of systems that can perform the function – something that is much more difficult if each architecture uses different terms. Figure 2 depicts an ICTB with linkages between the products.

Having a completed ICTB then enables the definition and analysis for the operational, testing, training, and acquisition and development communities that are not easily performed otherwise. For example, a simple analysis can determine if physical communication paths exist among the S/PTBs to enable the operational information exchanges identified in the MTB; more detailed analysis can identify if the communication bandwidth is sufficient, and if there are redundant paths for the data. This analysis can be used to identify additional system requirements to the acquisition community or the need to change the information plans or available platforms/systems for the operational community to complete the mission. Further analysis can begin to identify I&I issues such as how specific platforms and systems will be used, how specific missions enable analysis to determine where functionality is duplicated in the force; or where the same data is transferred via more than one communication path, which can lead to interoperability issues.

The completed ICTB also enables a more complex analysis. As illustrated in Figure 2, each system on each platform has performance requirements defined for the functionality performed. Each system function supports an operational task that has a measure of performance supported by both the system function and the operator, and each operational task measure is linked to the desired effect of the mission being performed. Having this complete linkage allows the Fleet mission planner to evaluate the ability of the force to achieve the desired effect and to define the operator performance level requirements for each supporting system. Having a completed mission thread with those same measures of performance allows the training community to develop training curricula, and the testing community to develop test scenarios to measure system performance and operator proficiency. Similarly, the ICTB allows analysis of the systems, platforms, and sailors to enable definition of gaps linked to Fleet need, as well as defining new DOTMLPF solutions, including prioritization and definition of new and modified systems.

Conclusion

Using the ICF for creating architectures enables all users to more effectively and efficiently perform their tasks and improves collaboration. From the Fleet perspective, use of the ICF enables more complete definition of warfighter need and more effective collaboration with the acquisition community. As the MTB owners, the Fleet will be able to more easily and completely communicate to the acquisition community how they intend to execute the missions, input that is critical for all types of analysis. The acquisition community is already required to generate DODAF-compliant architecture products. Using a mission-based approach in compliance with the ICF and Fleet-owned mission architectures help ensure that the architectures are useful for all communities, with little to no extra cost. Definition of system requirements, analysis of systems, and system test all benefit from having relevant operational scenarios to help ensure completeness and correctness. The ability of the Fleet to use ICTBs will enable definition of training requirements and curricula, and evaluation of operator proficiency. Finally, use of the ICTBs will enable complete, accurate analysis of mission capability, identification of potential interoperability issues, and DOTMLPF solutions to gaps in mission capability. ⚓

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System of Systems Engineering Guidance

By William F. Ormsby

Every day, all around the globe, U.S. Navy officers and sailors make decisions to accomplish their assigned missions. The decisions are influenced by the capabilities possessed by the units assigned to the mission. As defined in the Chairman of the Joint Chiefs of Staff Instruction (CJCSI 3500.01G; 15 March, 2012) a capability is:

> *"The ability to achieve a desired effect under specified standards and conditions through a combination of means and ways across doctrine, organization, training, materiel, leadership and education, personnel, facilities and policy (DOTMLPF-P) to perform a set of tasks to execute a specified course of action."*

This multi-faceted capability construct has served as a model for Naval Operations and materiel procurement for many years. However, as attrition warfare has been replaced by network centric operations, including cyber warfare, the complexity of engineering effective weapon systems has grown. Engineering guidance has evolved to handle the increased complexity. For example, the highly compartmented system engineering disciplines used

to develop the Submarine-Launched Ballistic Missile (SLBM) in support of the Strategic Triad Concept are obsolete for systems used in more modern and collaborative combat scenarios. System of Systems (SoS) engineering guidance responds to: the deficiencies in traditional system engineering practices; the resulting Fleet's dissatisfaction with strike-force interoperability; and the crucial need for integrated sensor, weapon, and command and control (C2) systems that support coordinated decision-making in dynamic threat environments.

The Deputy Assistant Secretary of the Navy (DASN) for Research, Development, Test, and Evaluation (RDT&E) Chief Systems Engineer (CHSENG) is the naval technical authority within the acquisition structure for ensuring compliance with overall Department of the Navy (DON) Enterprise Architecture (EA) policy along with integration and interoperability of current and future DON acquisition programs. The DASN has the responsibility to provide guidance for SoS engineering processes to translate mission operational requirements into measurable and testable mission performance requirements. The office of the Assistant Secretary of the Navy Research, Development and Acquisition (ASN (RD&A)) Naval System of Systems Engineering Guidebook Version 3.0, was developed to aid Program Managers and System of Systems Engineers in the performance of their duties. It is intended to support the Naval acquisition community, particularly Program Executive Offices (PEOs), Systems Engineering Integrated Product Teams (SEIPTs), and Mission Area Systems Engineers in implementing capability-based acquisition in accordance with SECNAVINST 5000.02.

This article describes the latest version of the SoS Engineering Guidebook including recent updates made by a national technical team of subject matter experts composed of Naval Sea Systems Command (NAVSEA), Naval Air Systems Command (NAVAIR), and Space and Naval Warfare Systems Command (SPAWAR) personnel. The guidebook promotes a shared understanding among engineers developing various warfare systems, of effects desired by operators who employ those collective systems in accordance with a chosen course of action. This concept of "starting with the end in mind," a common mission model, leads to fewer inconsistencies in system designs and reduced costs associated with integration of systems conceived to deliver mission enhancements. Excerpts from the guidebook are highlighted in this article to stimulate greater efficacy in acquisition and improved operational readiness in support of National Security.

Integrated Capability Framework (ICF) – Justification for and Nature of Changes

The SoS Engineering Guidebook V3.0 substantiates its content and value by describing Carrier Group issues first identified in 1998. It was determined that target track information being passed between platforms resulted in track ambiguity (1 threat aircraft with 3 different tracks and 3 different IDs) which negatively impacted Battlegroup interoperability (see Figure 1). As a result, initial policy was set in place to ensure Warfare Systems are fully developed, mature, reliable, and have completed interoperability testing in a systems of systems environment prior to deployment. The current guidebook recognizes that no amount of end item testing will make a system more interoperable, and that modern mission modeling techniques can be used to preclude system designs that would lead to similar interoperability issues.

In late 2010, the Chief of Naval Operations (CNO) hosted a summit on Integration and Interoperability (I&I) where he was briefed on a concept for improving acquisition practices that would resolve many issues that were degrading Fleet readiness. Subsequently, actions were taken to convene a Multi-SYSCOM team to define and validate an Integrated Capability Framework (ICF) that formalizes a core set of data elements, relationships, and taxonomies, as shown in Figure 2, that improve efficacy of integrating systems into Fleet missions. The ICF includes: Department of

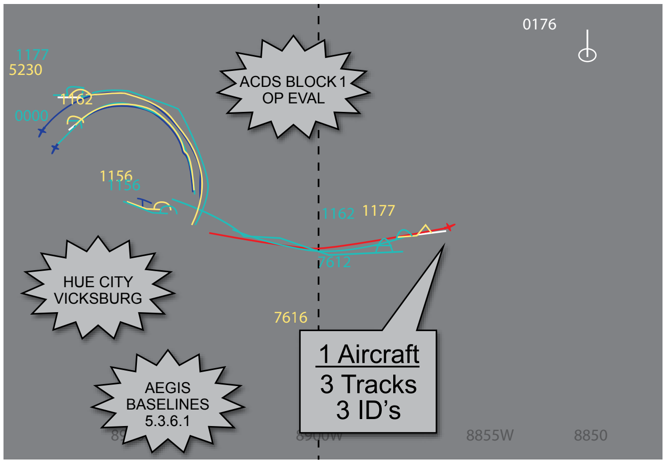


Figure 1. Battlegroup Interoperability Deficiencies

Defense Architecture Framework (DODAF) models to distill the critical context required to decompose mission-level requirements into SoS and component system functional and performance requirements; implementation guidance and associated roles and responsibilities for interaction with the Fleet to authoritatively capture Fleet needs; references to authoritative sources, data taxonomies, and common standards for capturing the complex relationship

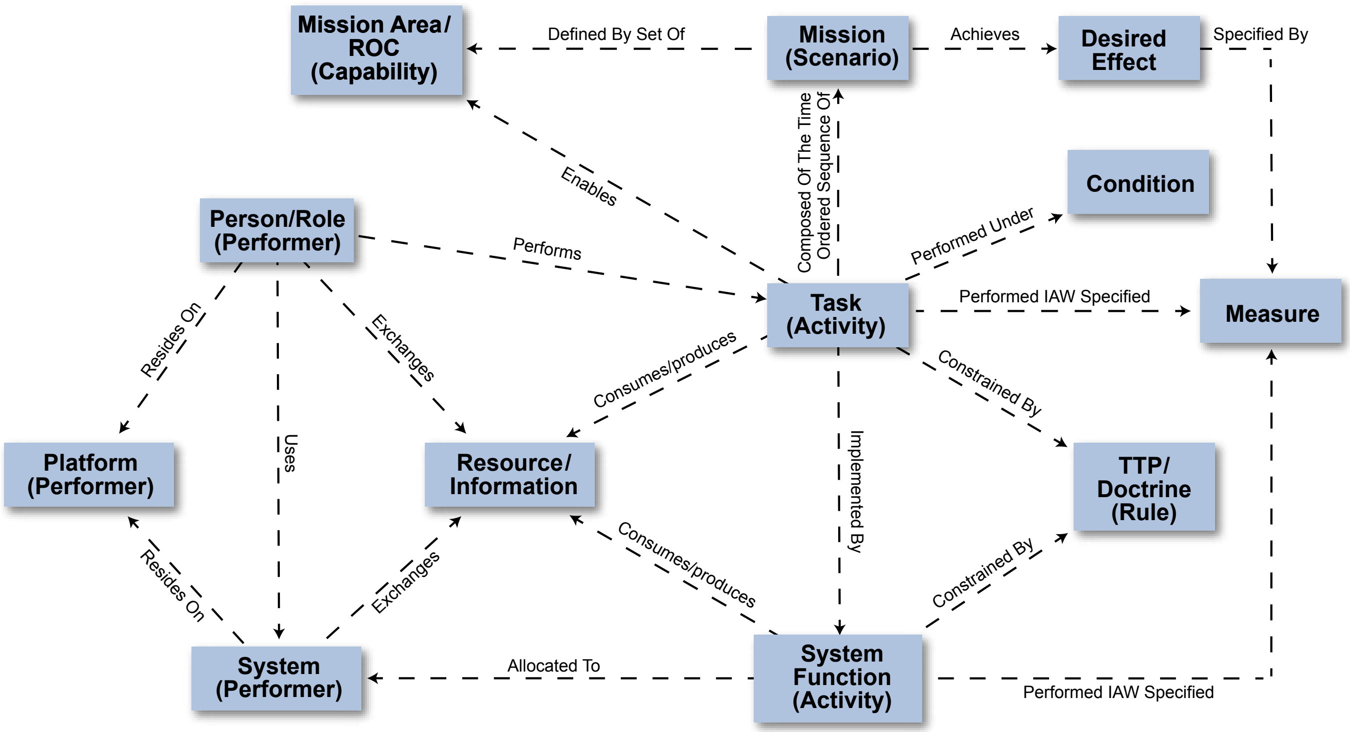


Figure 2. Integrated Capability Framework Data Model

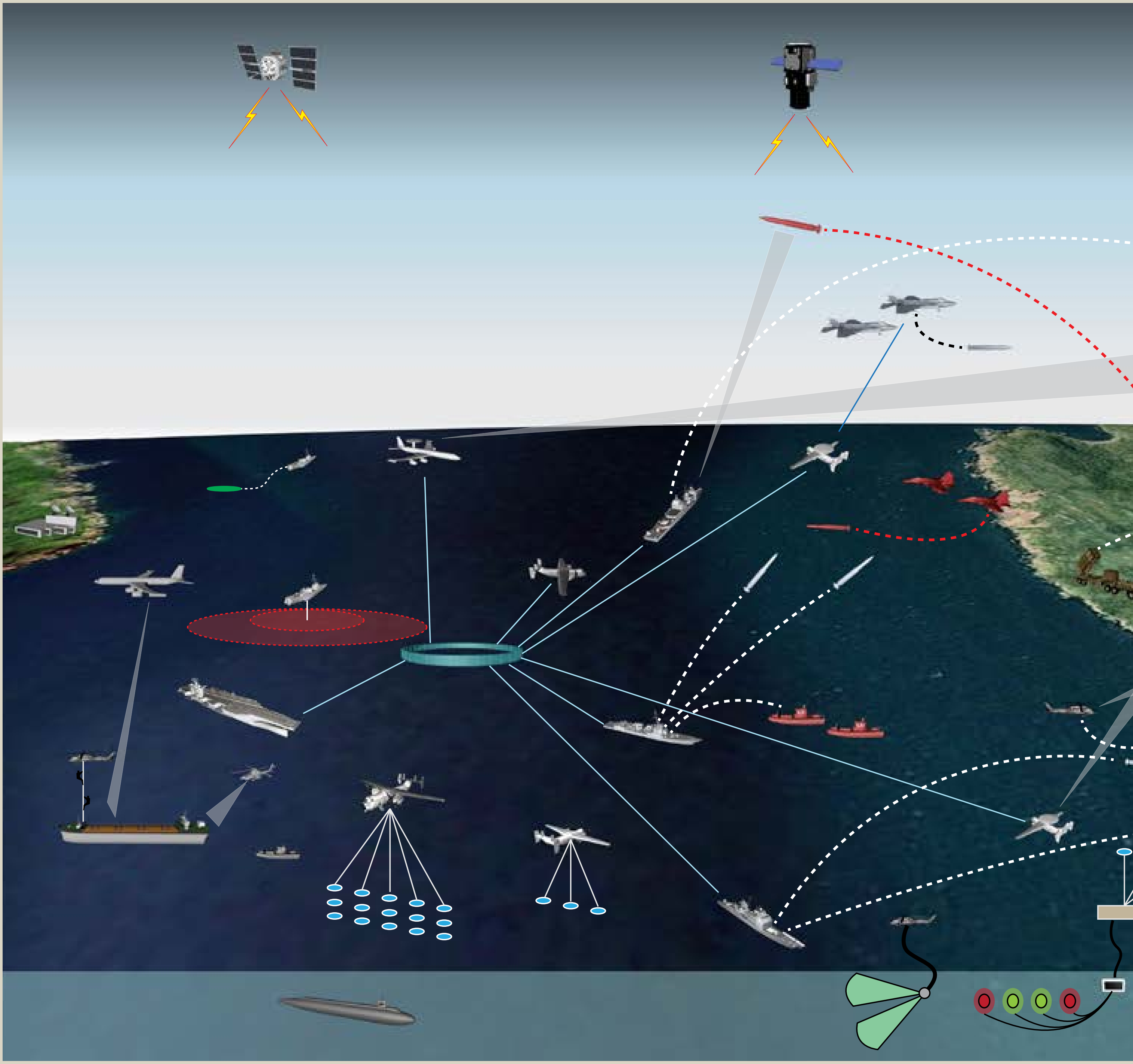
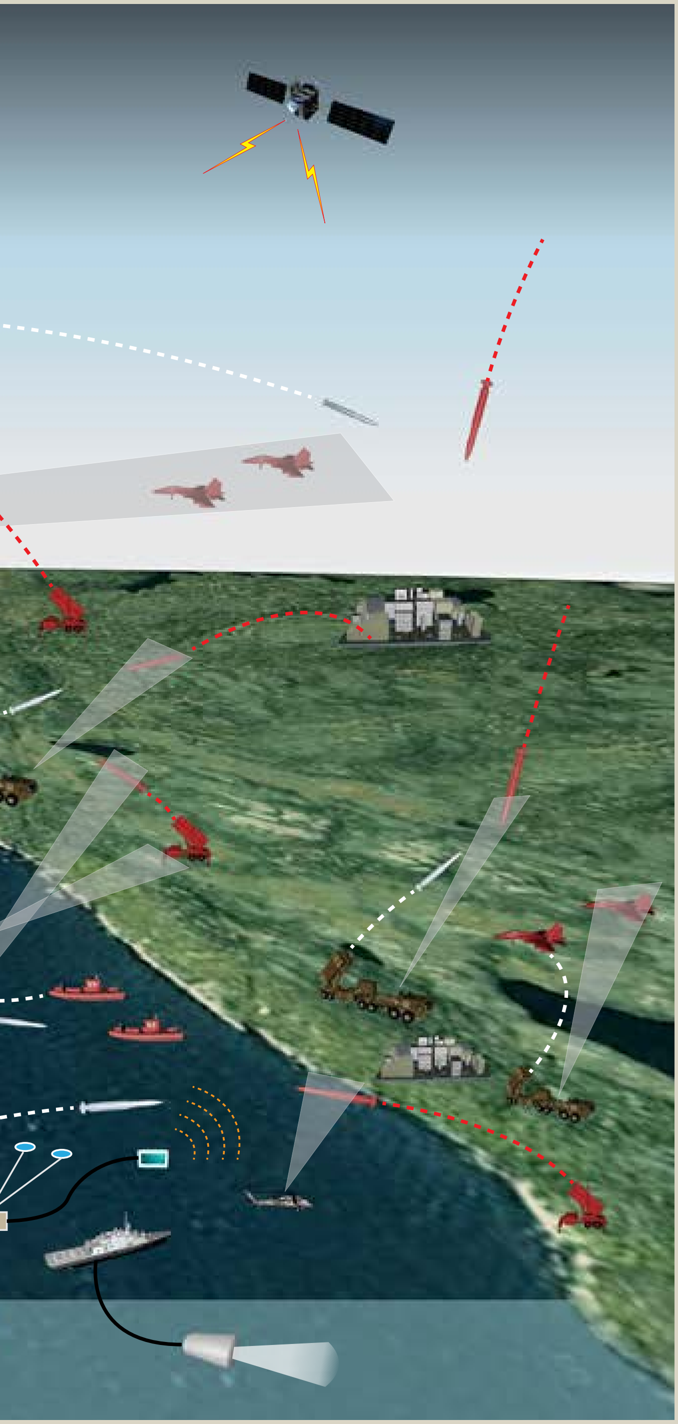


Figure 3. Universal High-Level Operational Concept Graphic *(Operational View OV-1)*



between the ICF products, across platforms, systems, and components.

Improving warfighting capability in a measureable way requires identification of all types of data that contribute to the measure. The ICF Data Model includes the relationships and dependencies between data types and can be shared with various stakeholders. Cursory review of the ICF Data model reveals SoS engineering disciplines are less about the system and more about the data related to the system, either directly or indirectly. The number of relationships among these twelve data elements, each of which consists of multiple items, exposes the complexity of SoS engineering. That is, decomposition of system behaviors (i.e., functions and timing) requires contextual details of all eleven other data elements. Modern tools help manage the complexity, and the SoS guidebook describes methods for modularization that allow data collection that results in a mission model with maximum cohesion and minimal coupling. The ICF Mission Model development focuses on:

- Describing the mission in operational language through development of Concept of Operations (CONOPS) and Tactical Situation (TACSIT) description documents;
- Describing the capabilities required to accomplish the mission;
- Modeling the activities, resource exchanges, and system functions that are used to accomplish the mission.

A historical example of mission decomposition provides a basis for understanding updates to SoS engineering guidance. Figure 3 is a universal high-level operational concept graphic (Operational View, OV-1). Such a graphic, together with a textual description of a concept for operational mission performance, is often considered the initial step in mission modeling. In the 1950s, the mission was to keep the Soviet Union at bay. The CONOPS for this mission required the United States to have thousands of nuclear warheads and three ways to deliver them on target. The three legs of the nuclear "triad" included: heavy bombers, Submarine-Launched Ballistic Missiles (SLBM), and land-based intercontinental ballistic missiles. Three technologies "saved the Navy's bacon."[1] Miniaturized warheads, solid propellants, and very high accuracy gyros made it possible for the Navy to start the Polaris SLBM Program. Policy in the 1950s established fire control (FC) of the SLBM capability as an inherently government function, and the SLBM FC system has continued to be developed by government scientists and engineers at Naval Surface Warfare Center Dahlgren Division (NSWCDD) ever since.

Over the years, the Polaris Program evolved to the Poseidon Program and then to the Trident Program, each with greater targeting accuracy requirements. SLBM engineering disciplines were thus influenced by:

- Geodesy, that branch of applied mathematics which determines the shape, curvature, and dimensions of the earth;
- Geopotential, the potential of the earth's gravity field;
- Satellite Geodesy, the use of artificial satellite techniques to measure the distance between launch locations and target locations and the gravitational forces on ballistic missiles during flight.

Within this context, the platforms and systems represented in Figure 3 that are relevant to SLBM become apparent and performance measures are understood. An expectation is created for a description of an information exchange (Department of Defense Architecture Framework (DODAF), OV-3), together with the technical standard profile (DODAF, TV-1), that codifies the conditions that govern ballistic missile trajectories, bounds the maneuvers of submarines relative to ballistic missile targets as a function of launch location, and influences the designs of fire control and guidance systems.

To characterize the mission, one must fully understand and characterize the environment upon which the mission will be exercised. Continuing our SLBM example, Figure 4 illustrates the TV-1: the World Geodetic System (WGS84), "a model of the world" that resulted from years of data collection. It shows that the earth is not perfectly spherical; rather certain locations (blue) are below the reference ellipsoid, and other locations (orange) are above. The undulations for given launch and target locations are easily calculated and enable achievement of required accuracy.

Today we are dealing with new threats and with inter-dependent missions. The advances of U.S. adversaries, such as mobile missile launchers; the Navy transformation to network-centric operations, including use of unmanned air vehicles (UAVs); and multi-mission requirements have created capability dependencies that require greater collaboration with the Fleet. More iteration between the ICF data elements is anticipated to discover the dominant parameters of missions. The success of the SLBM Program confirms the return on investment in a commitment to "modeling the world" and the need for collecting data over long periods. Operating on what we simply believe to be true (spherical earth) can hinder the development of the required precision for the machine operation to achieve mission success. Future data collection will be conducted in accordance with capability-based modeling practices that describe dependencies and enable predictable mission performance across kill-chains.

The nature of changes described in the SoS Engineering Guidebook fulfills the Navy I&I Charter to provide more informed input into the existing Planning, Programming, Budgeting and Execution, and Joint Capability Integration and Development System processes. The changes leverage existing end-to-end effects/kill chain gap analyses efforts and requires collaboration among operational and acquisition subject matter experts. The guidance enables a disciplined assessment of I&I gaps at the mission level and development of holistic (i.e., DOTMLPF) recommendations to inform investment decisions. The changes mandate development and use of authoritative mission models to ensure the system requirements are complete, consistent, correct, and testable. Version 3 of the guidebook also describes activities to govern the evolution of mission models to converge the designs and implementations of all systems across an effects chain.

One basic tool to help characterize parameters within the ICF is the use of Modeling and Simulation (M&S). Models and simulations should continue to be used as needed to support requirements definition, analyze the Force Package configuration and design, and mitigate identified risks through engineering analyses. M&S supports the assessment of functional and performance characteristics, integration and interoperability, network throughput and bandwidth, supportability, and Human System Integration (HSI) issues such as maintainability, usability, operability, and safety. Moreover, M&S provides the ability to predict SoS performance as specified before system design and testing.

Managing the System of Systems Acquisition

The guidebook describes the desired, iterative nature of systems development noting that the verification feedback loop at each level of the system life cycle is the mechanism for providing development control. Iteration of the design reduces the risk of developing a system that does not meet the needs of the user. As stated in the Defense Acquisition Guidebook, "The ultimate purpose of the System Engineering (SE) processes is to provide a framework that allows the SE team to efficiently and effectively deliver a capability to satisfy a validated operational need." Claiming that current derivation of system functionality is done at the discretion of the individual Program Managers, the guidebook promotes significant use of venues that take system engineers into Fleet operations, where DOTMLPF capabilities and limitations are experienced first-hand.

The collaboration on mission-based test design and Fleet Exercise and Experimentation events (FLEX) are highlighted as advancements in mission engineering. These venues are fleet-led and fleet-driven, and they establish fact-based assessments of baseline capability

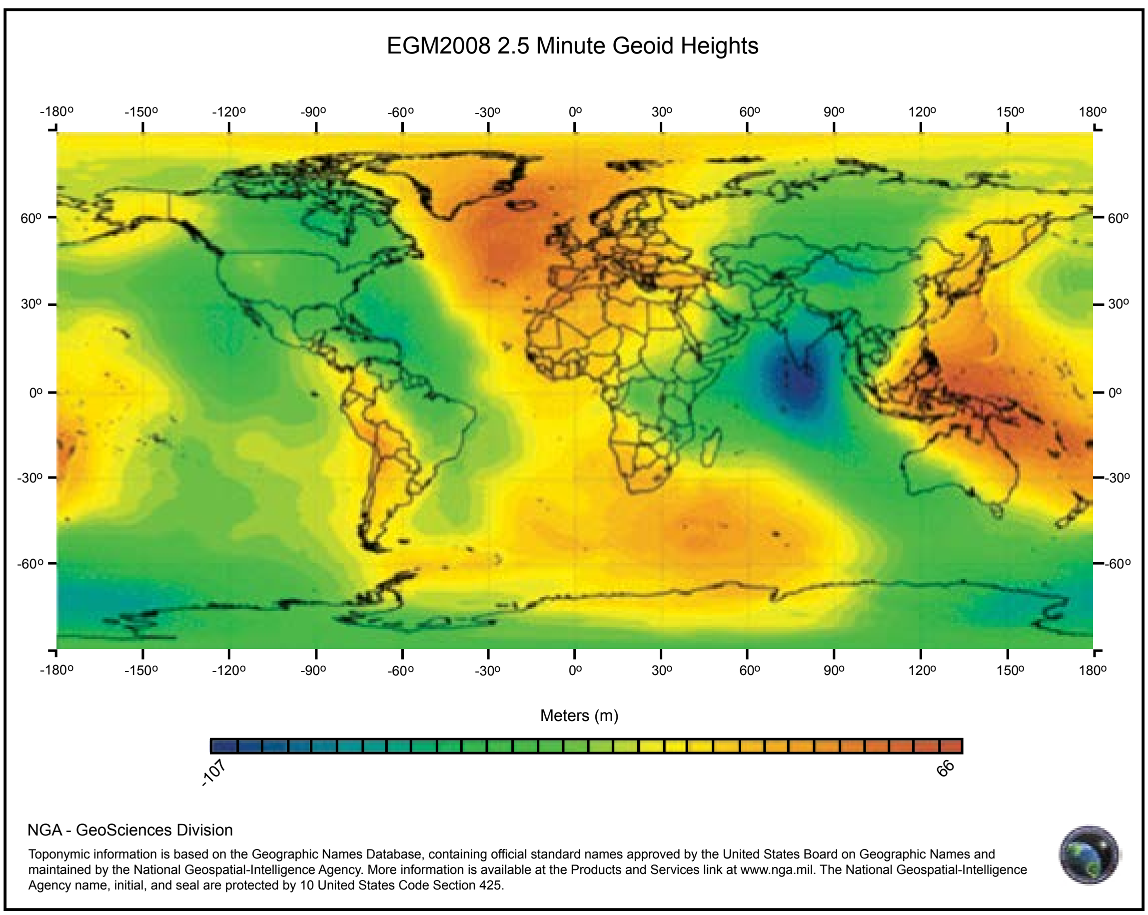


Figure 4. EGM2008 2.5 Minute Geoid Heights[2]

and fully vetted evaluations of concepts of future capabilities. Figure 5 portrays a mission engineering life cycle and shows how I&I activities exploit an ICF to provide continuity of Fleet insight throughout the life cycle of all systems in an effects chain.

While a naval governance process for a mission-level system of systems has not yet been established, the guidebook prescribes business processes that would govern the execution of those practices to ensure integrity in the acquisition of horizontally integrated capabilities. It defines the attributes of a governance process that will provide mission engineers the top-down authority to exercise the disciplines described in the guidebook. The governance is based on the premise that PEOs, PMs, and system engineers recognize the dependencies among the many systems employed in a kill-chain to achieve a desired operational effect. Furthermore, the program manager's number one responsibility, "to deliver systems to satisfy validated warfighting requirements at optimal life-cycle cost,"[3] is best achieved through governance described here. The roles of organizations identified in Figure 6 are defined in the SoS Engineering Guidebook to achieve the goals of the Navy Integration and Interoperability Charter, which was signed and promulgated by the Vice-CNO on December 19, 2012.

The Navy I&I Charter endorses a business process for the organizations to interact from a mission area effects/kill chain perspective, to develop integrated solution recommendations, to inform investment decisions, and to verify all system dependencies have been implemented. Figure 7 illustrates the temporal aspects of an effective I&I battle rhythm that follows the traditional DoD two-year Program Objective Memorandum (POM) cycle with overlap from cycle to cycle.

The information required from mission engineers to support effective I&I governance becomes clear during the mission decomposition activities. Figure 8 illustrates such activities at the various organizational levels (vertical) and in the integrated capability phasing timeframes (horizontal).

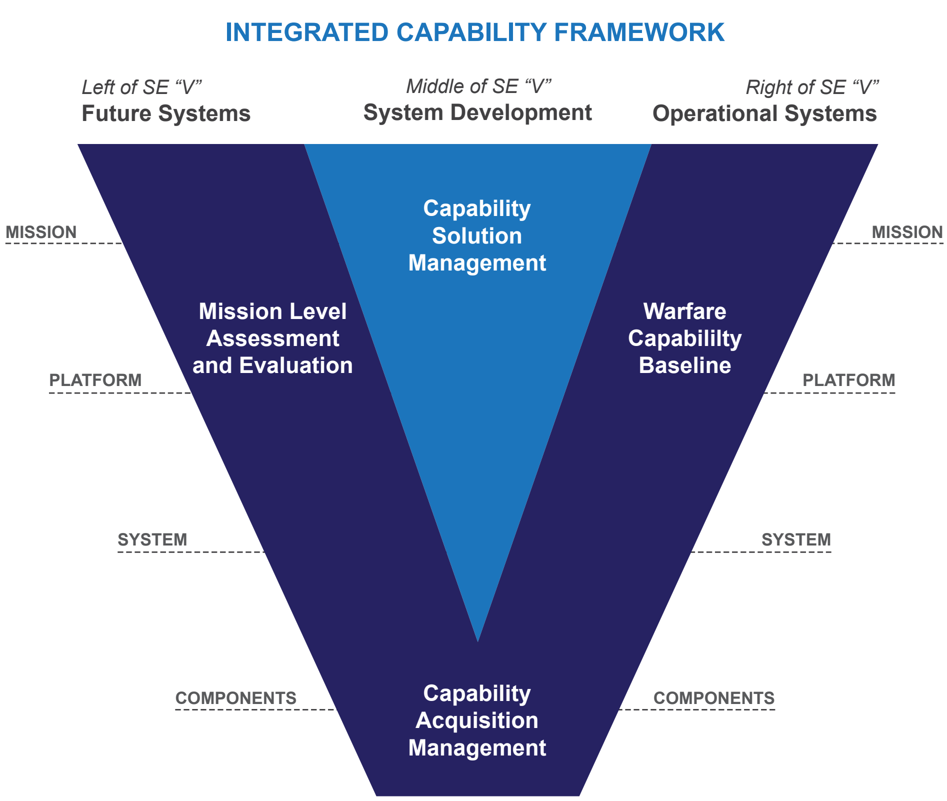


Figure 5. Mission Engineering Life Cycle

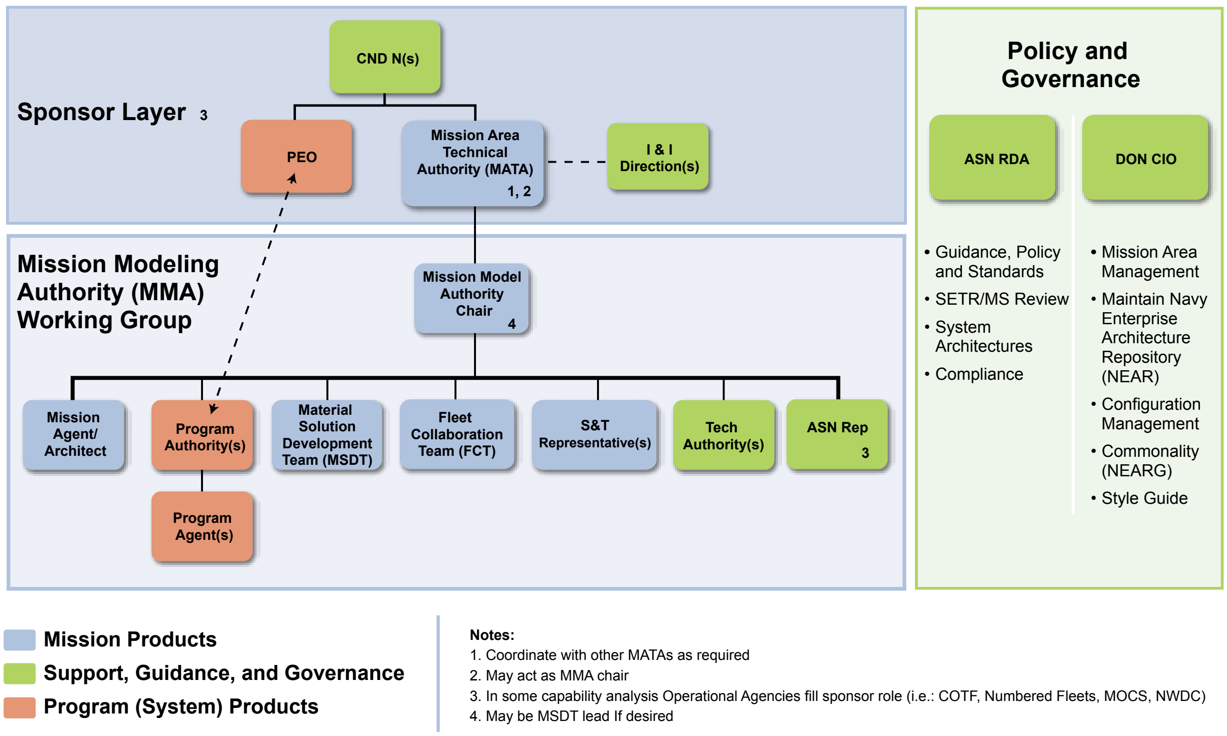


Figure 6. DON Architecture Organization

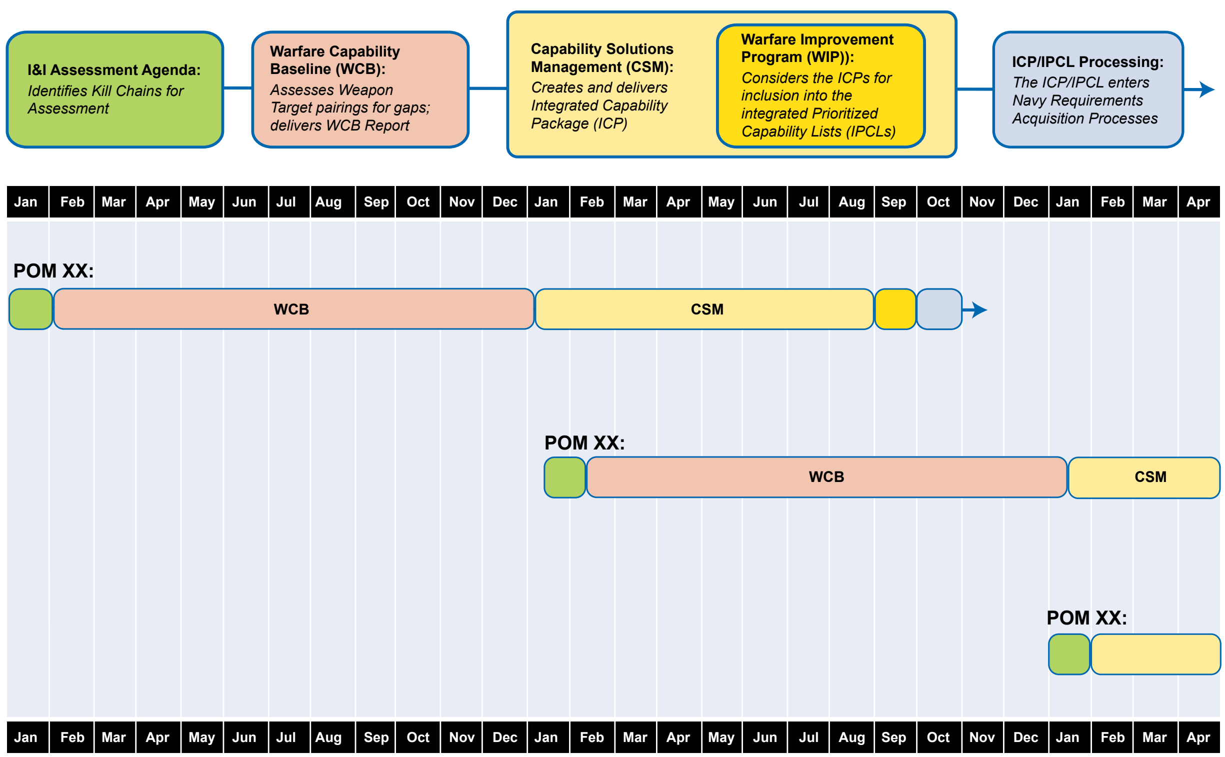


Figure 7. Notional I&I Battle Rhythm

Examples of past activities are described below to illustrate the data collection activities highlighted in Figure 8, and the use of data to support acquisition decisions.

Develop Baseline System Architecture and "To-Be" System Phasing Options: In the early 1980's, NSWCDD scientists and engineers used the WBS-72/84 model, which was developed for SLBM, in work with the Naval Research Laboratory (NRL) in developing optional constellations of the Global Positioning System (GPS). The GPS architecture, i.e., the number of satellites; the number of orbital planes; the inclination of the orbital planes; and the angular separation of satellites in each plane, was evaluated to ensure reliability and availability of the system. While the first GPS Block I satellite was launched in 1989, GPS modernization continues to meet growing military, civil, and commercial performance and accuracy needs. The use of GPS-enabled capabilities is critical to modern combat operations, especially those employing UAVs.

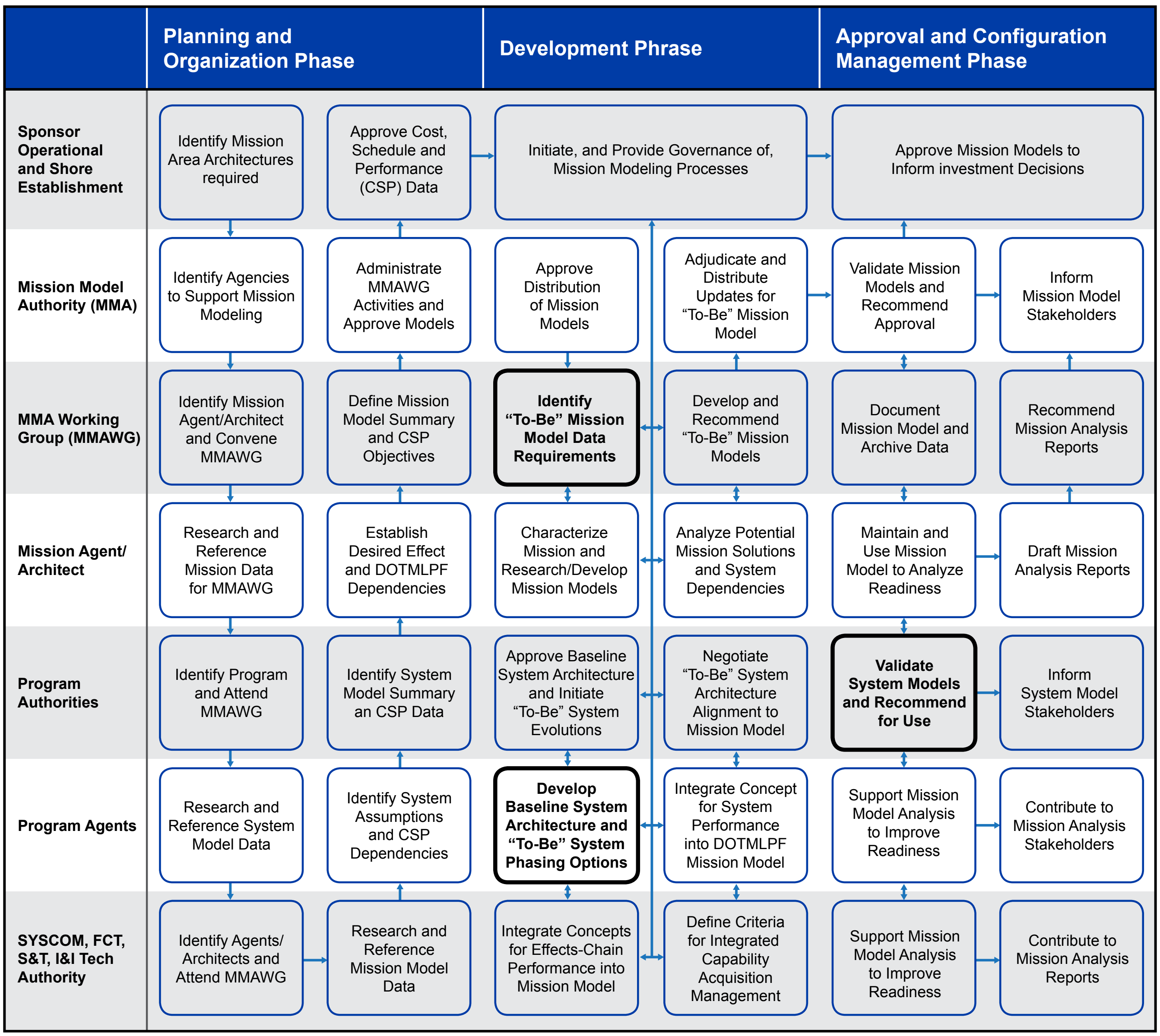


Figure 8. Organizational Interactions Required for SoS Engineering Governance

Validate System Models and Recommend for Use: In the mid 90's the Navy was adrift waiting for entrance criteria to be met prior to an SLBM readiness assessment event. Policy held that "demonstration and shakeout" (DASO) tests must be preceded by fire control simulations and guidance system simulations that produced the same predicted outcome. Until current mission engineers at NSWCDD were consulted, the cause for different M&S predictions was unknown. Mission engineering data was used to reveal discrepancies between guidance system design specifications and source code implementation. Once the source code implementations were represented in FC models, the simulations produced DASO predictions that met entrance criteria and the readiness assessment commenced.

Identify "To-Be" Mission Model Data Requirements: In the summer of 2000, the National Missile Defense (NMD) Joint Program Office (JPO) was scheduled to report to Congress with a "Deployment Readiness Review." A primary question to be answered, which was posed by Army and Air Force operational test agencies, was, "are we deploying bulldozers to the right location (for placing anti-ballistic missiles (ABMs))?" Engineers at NSWCDD who had access to requirement specifications for all five NMD components validated the physical architecture of the NMD system of systems in three steps. First, they partnered with civilian Army and Air Force test engineers to get the "as-is" ground-based test data and in-flight test data that characterized baseline limitations. Second, they used specifications for "to-be" NMD performance requirements to develop credible M&S of the specified SoS. Third, they collected measures of effectiveness from simulations that exercised new information exchanges to employ NMD capabilities against stressing scenarios.

The historical anecdotes provided above are unique in detail, but serve to convey the broader benefits of mission modeling and simulation. However, there is a recognized deficiency in number and comprehensiveness of mission architectures. The cause, from the perspective of this author, is that DODAF architecture development has been "for compliance" and "in isolation." As a result, comprehensive, coherent, and accurate mission models are not available to simulate and predict outcomes of alternative Courses of Action (COAs) for modern combat operations.

With promulgation of the Navy I&I charter—and like the SLBM Fire Control function—integration of individual contractor-delivered systems is now recognized as an inherent government function. As such, Multi-SYSCOM mission engineers will collaborate with the ultimate purpose of delivering more interoperable capabilities. The SoS Engineering Guidebook V3.0 provides a vital tool for managing acquisition activities to develop and use common mission models, across multiple PEOs, to evolve operational readiness. ⚓

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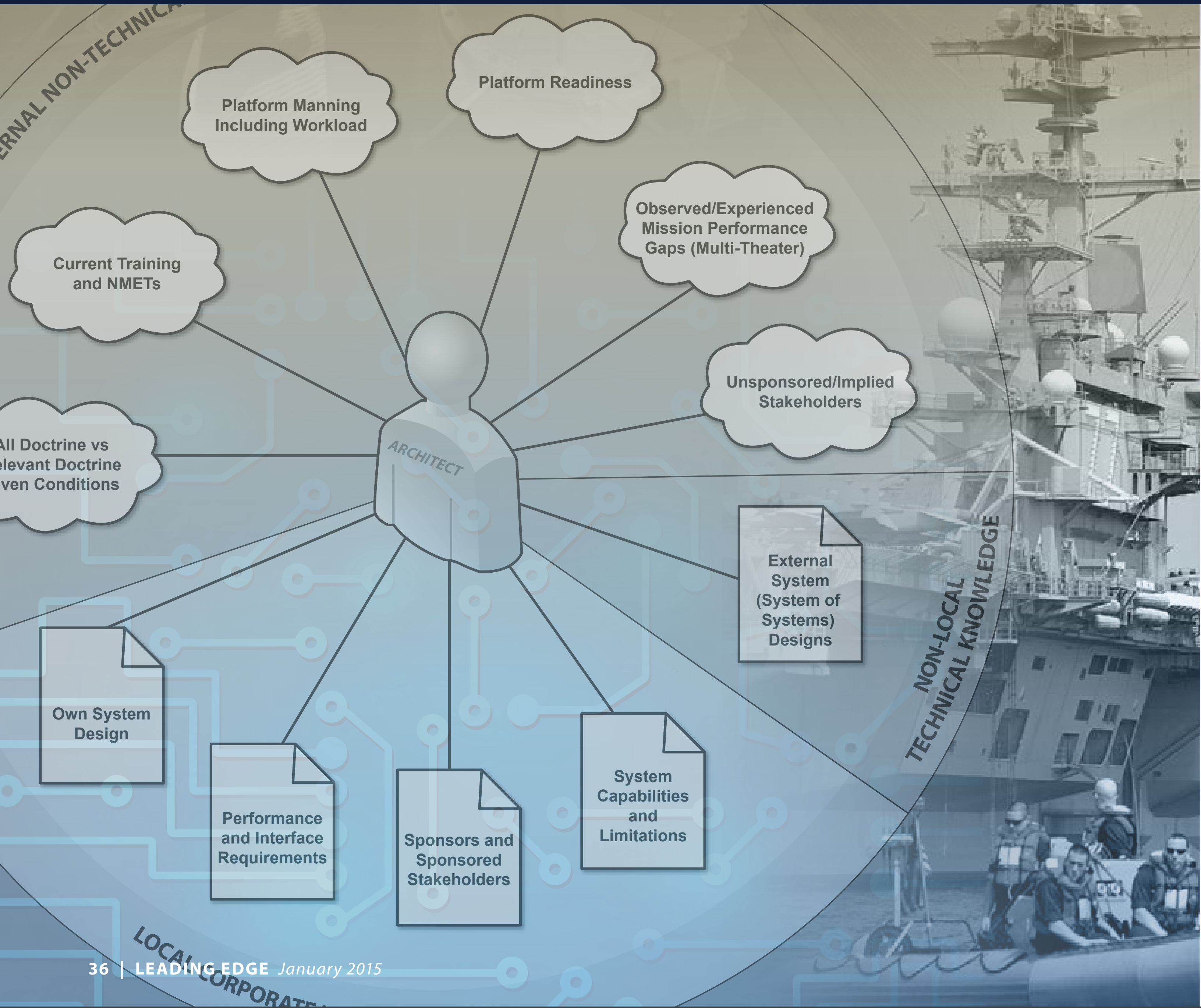
Integrated Mission Baselines:

Using Fleet-Owned, System Command Serviced Architectures to Improve System Integration and Interoperability

By Joseph Pack



Current acquisitions require the use of architectures during both the design and integration phases of development in accordance with a series of Department of Defense (DoD) and civilian publications that regulate system development and engineering best practices. Within specific development communities, such as communication and networking, architectures are used far more effectively because of their obvious benefits in managing diverse resources and data types across complex enterprises. However, for many Navy weapons, sensors, and combat systems, as well as other future technologies, architectures have been used more frequently to maintain compliance with current acquisition regulations than to aid in predicting and mitigating future interoperability problems that risk degrading Fleet readiness or preventing an emerging technology from improving Fleet readiness to its full potential.

The objective of Navy integration and interoperability (I&I), as articulated in the Vice Chief of Naval Operation's-endorsed I&I charter, is to improve existing acquisition practices by establishing a Navy organization that better works across acquisition communities and program offices. This is accomplished in part by encouraging data management and exchange throughout organizations that have traditionally experienced stovepipe behavior. Architectures, being proven effective for integrating diverse data types and relationships, can be used to realize the I&I objective of improved data sharing.

This article will examine the application of developing mission reference architectures that focus on capability and operationally driven models. The application of such models ranges from simplifying collaboration between the acquisition community and the Fleet, to providing validated mission context toward systems and modeling development.

System Architecture and Mission Architecture Integration Using Integrated Mission Baselines (IMBs)

Traditional use of architectures has focused on system, system-of-systems, and software architecture, with emphasis on the material aspects of a given enterprise or on the satisfaction of interfacing and resource exchange requirements. Mission architectures are fundamentally different from these forms of architecture in their focus on the Fleet's desired effect and the operations required not only to achieve the desired effect but also on a mission's doctrine, training, and conditional constraints. These differences are more clearly understood by observing different architecture types articulated in past and present Department of Defense Architecture Framework (DODAF) specifications.

An "integrated architecture" is said to be a product where all architectural viewpoints and models uniquely define and consistently interpret data. Architecture is said to be integrated when it meets the following criteria:

- The architectural objects common to more than one view are identical or linked by underlying data relationships.
- All objects that have relationships across views are linked by underlying data relationships.

For many, if not most system architectures, these definitions sufficiently describe the level of integration built into their products, and for good reason. System architectures exist to adequately describe an individual system's full functionality, physical configuration, and employment. This implies a level of independence from a larger enterprise that makes anything more than an integrated architecture of limited value to component engineers and systems analysts.

However, an integrated architecture does not physically exist in absence of a larger enterprise. Both physical configuration and employment strategies for a given system are informed by the larger Navy enterprise architecture. This larger architecture is referred to as a "federated architecture," defined in DODAF v1.5 as a product that "allows the architecture user a means to examine the enterprise from all aspects of the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) concept." This implies that even though a system architecture may exist at the integrated architecture level, it is dependent on the information contained in a larger federated architecture. For systems developed for strategic and tactical applications, a larger federated architecture is represented through mission area architectures owned by senior uniformed leadership and the numbered Fleets as depicted in Figure 1.

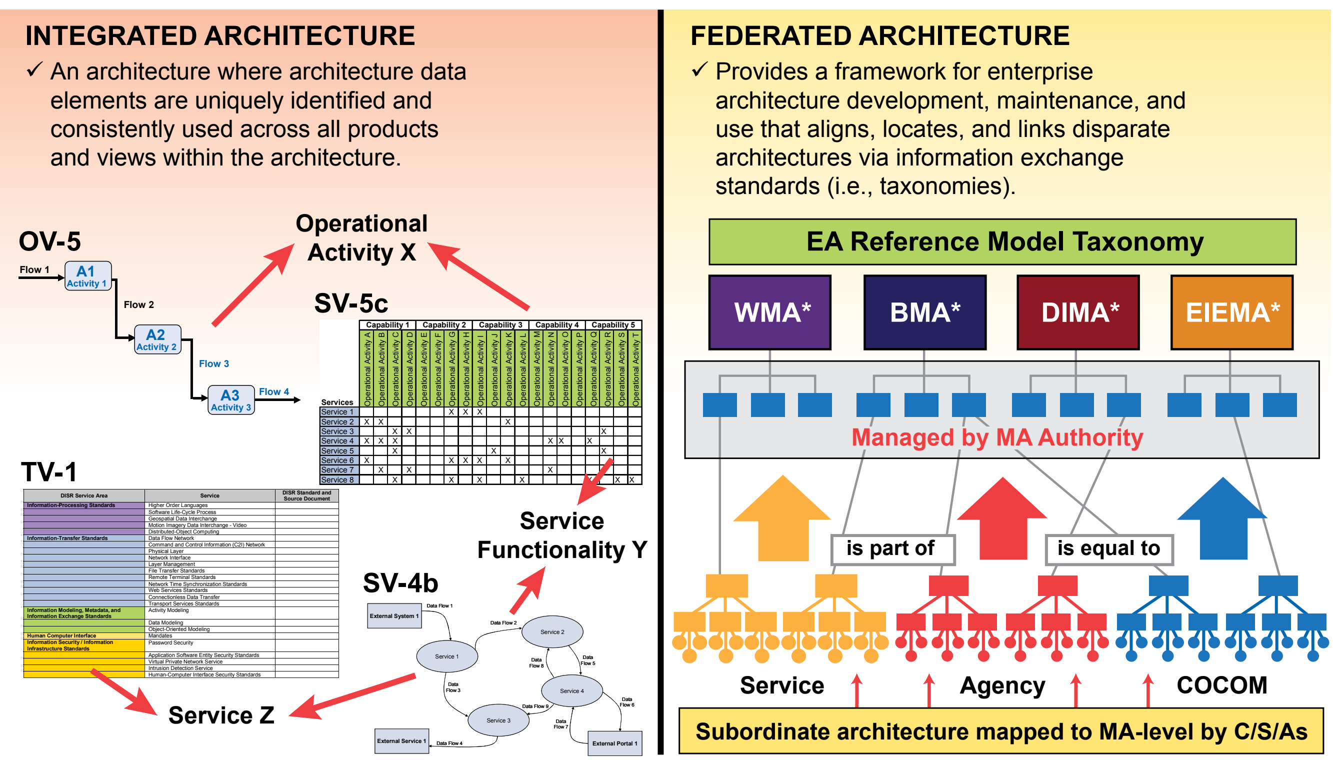
While system architectures contain the entire functionality of a given system and a description of its use, in context of its design-to-platform or system-of-systems, mission architectures contain the partial functionality of multiple systems required to achieve a given desired effect or mission outcome; both products rely on information from the other. Mission architecture informed from the design-to-functionality and performance from the system architecture, and the system architecture must adhere to the strategic and tactical employment schemas articulated in the mission architecture, as illustrated in Figure 2.

This relationship identifies the requirements for systems engineers to support mechanisms that allow for both the information publishing and subscribing to some form of federated mission architecture. One such mechanism is the IMB.

Definition

An IMB is a mission-based reference architecture that models the capabilities and activities required to achieve a desired effect for a particular mission and set of environments or conditions. Similar to reference architecture in software engineering practices, an IMB is used as a template to begin production of a fully federated architecture using platforms and systems that span multiple program offices, platforms, and DoD services. By serving as a reference across multiple organizations, an IMB serves as a mechanism whereby disparate system architectures originating from different organizations may converge on a common understanding of how a mission is executed by the Fleet.

Architecturally, the IMB is heavily reliant on Capability Viewpoints (CVs) and Operational Viewpoints



* **WMA** — warfighting mission area, **BMA** — business mission area, **DIMA** — DoD portoin of the intelligence mission area, **EIEMA** — enterprise information environment mission area

Figure 1. Integrated vs Federated Architecture as Modeled in DODAF V1.5

(OV). Selected viewpoints focus on defining the mission to be executed; the complimentary capabilities required to complete the mission; activities required of personnel, platforms, and organizations for each activity; and doctrinal constraints placed on mission execution by virtue of relevant conditions (e.g., environmental, geopolitical) and locations.

The role of an IMB is to serve as the Fleet-owned and endorsed mission reference for system employment and enterprise readiness evaluation. The significance of Fleet ownership is nontrivial. Current mission architectures, if produced at all, are the result of data collection efforts on the part of system commands (SYSCOMs) and program offices. When each program office is responsible for its own mission architectural development, the potential exists for multiple interpretations of the same mission, as illustrated in Figure 3. The material risk to the Navy is the deployment of multiple systems into the Fleet built on non-standard battlefield interpretations, resulting in inconsistent or unpredictable mission performance. More often than not, this inconsistency or unpredictable mission performance results in a degraded Fleet readiness until sufficient interoperability mitigation strategies can be developed, vetted, and implemented. The use of Fleet-owned IMBs enforces a level of consistency among program offices that mitigates this risk, as illustrated in Figure 4.

Structure and Use-Case

Throughout fiscal year 2013, an I&I-funded effort sought to define, construct, and investigate IMB

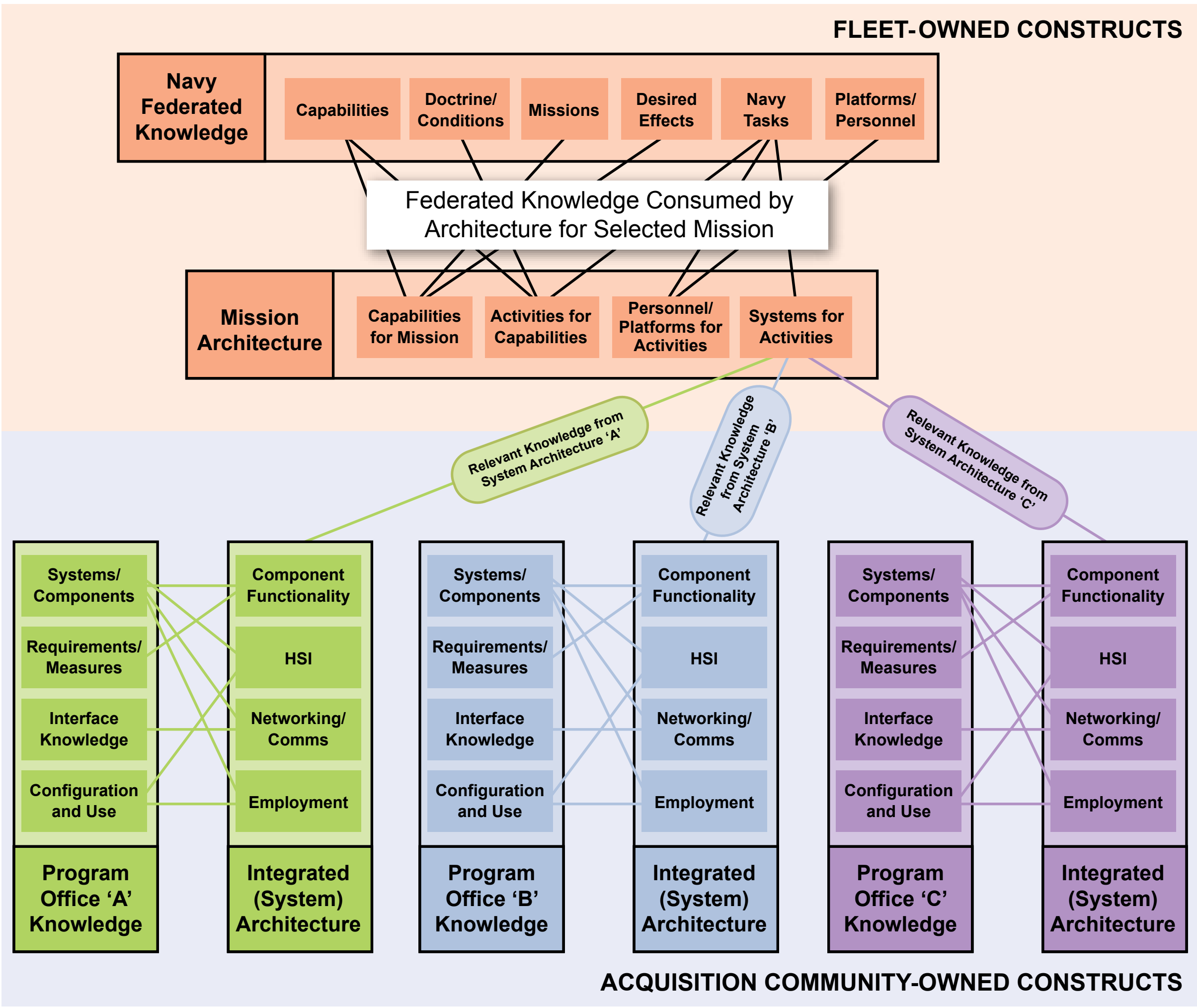


Figure 2. Fleet and Acquisition Community Construct Data Ownership

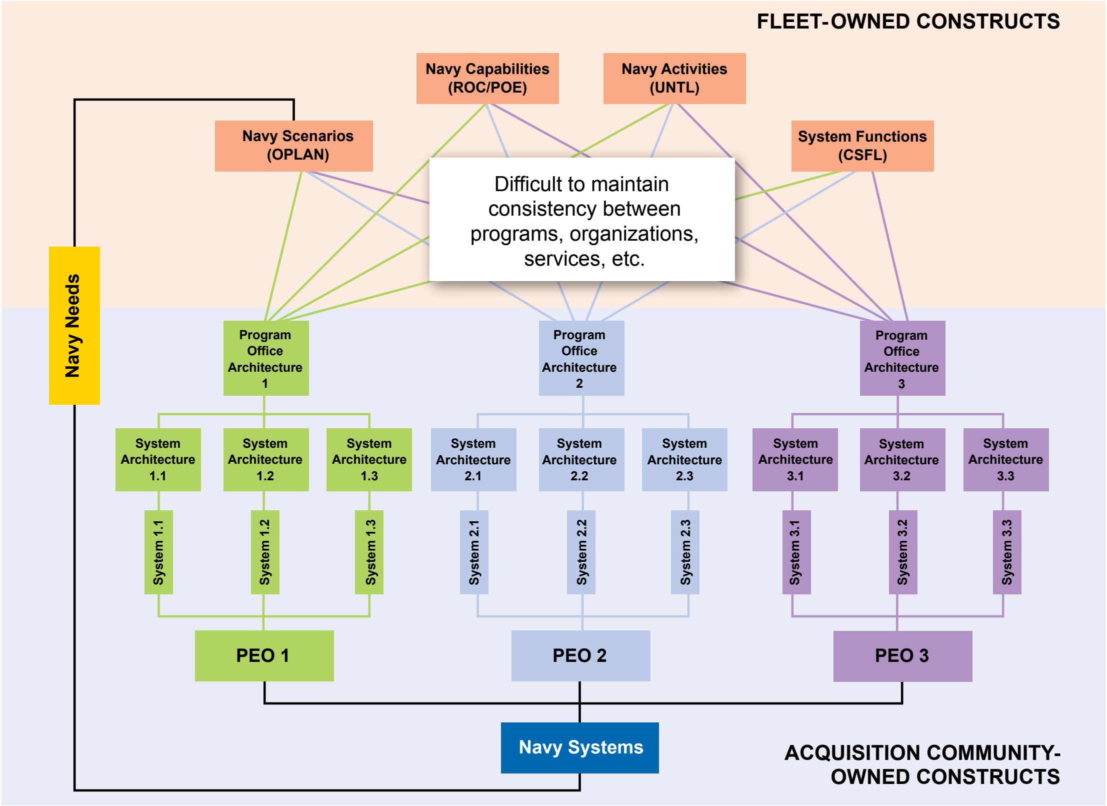


Figure 3. Communicating Data Needs Absent a Common Data Management Environment

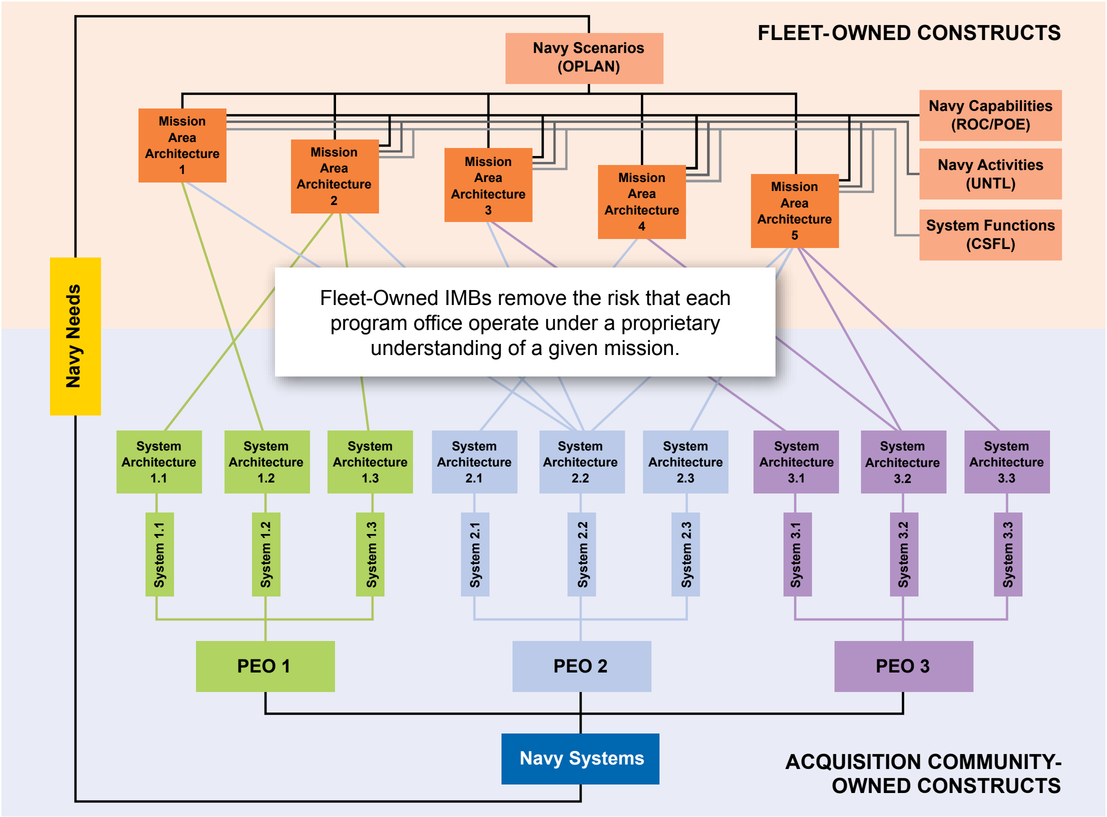


Figure 4. Communicating Data Needs with a Common Data Management Environment

usage. The Naval Surface Warfare Center, Dahlgren Division (NSWCDD), took the lead by developing a surface warfare IMB, focused on missions typical of Littoral Combat Ships. Architecturally, the IMB consisted of the All Viewpoint (AV), CV, and OV products in Table 1.

The selection of IMB viewpoints focuses on accurately capturing data elements from the Integrated Capability Framework Data Model that sufficiently and distinctly identifies what the Fleet is trying to accomplish, how it is trying to accomplish it, and which agencies, operators or performers are required to accomplish it. Figure 5 depicts these elements.

The architectural approach taken to create the products in the surface warfare IMB followed a methodology developed for the sole purpose of modeling Navy missions called the Capability-Based Modeling Methodology (CBMM).

VIEWPOINT	ACRONYM	PURPOSE
Overview and Summary Information	AV-1	Provides a brief overview of information contained within the product.
Integrated Dictionary	AV-2	Architecture data repository with definitions of all terms used in all products.
Capability Taxonomy	CV-2	A hierarchy of capabilities which specifies all the capabilities that are referenced throughout one or more Architectural Descriptions.
Capability Dependencies	CV-4	The dependencies between planned capabilities and the definition of logical groupings of capabilities.
Capability to Operational Activity Mapping	CV-6	This view describes the mapping between the capabilities required and the activities that enable those capabilities.
High-Level Operational Concept	OV-1	High-level graphical/textual description of operational concept.
Operational Node Connectivity Descriptions	OV-2	Information and resources exchanged between nodes and the relevant attributes of that exchange.
Organizational Relationships Chart	OV-4	Organizational, role or other relationships among organizations.
Operational Activity Taxonomy	OV-5a	Taxonomy of all activities included in the given architecture - useful for identifying the operational scope of the architecture.
Operational Activity Mapping	OV-5b	Mapping of relationships between tasks that helps to identify the required sequence of events that may take place given a known initial set of conditions.

Table 1. Integrated Mission Baseline Core Models

Fleet-First Architectural Methodology

The importance of using CBMM instead of other common methodologies is due to its focus on Fleet capabilities. CBMM was developed based on the theory that most Fleet stakeholders can be categorized into one of three domains: Fleet Capability, Operational, and Technical (see Figure 6). The relationships between these domains aid in identifying necessary authorities for sources of data as well as potential consumers.

The CBMM primarily focuses on the Fleet's desired effect; without this, the mission would not exist. Therefore, it is the Fleet's desired effect that is often the most well-defined part of a mission, especially since the method of mission execution and performance of relevant systems may be highly variable on external factors not fully realized before the mission is executed.

For this reason, the CBMM encourages initially establishing a capability taxonomy to accurately characterize the nature of the Fleet's desired effects. Following the capability taxonomy, architecturally called a CV-2, architects can begin identifying dependencies between capabilities (CV-4) and activities required for successful achievement of a capability (CV-6). Only after capabilities have been properly characterized and mapped can OV and System Viewpoint (SV) creation begin.

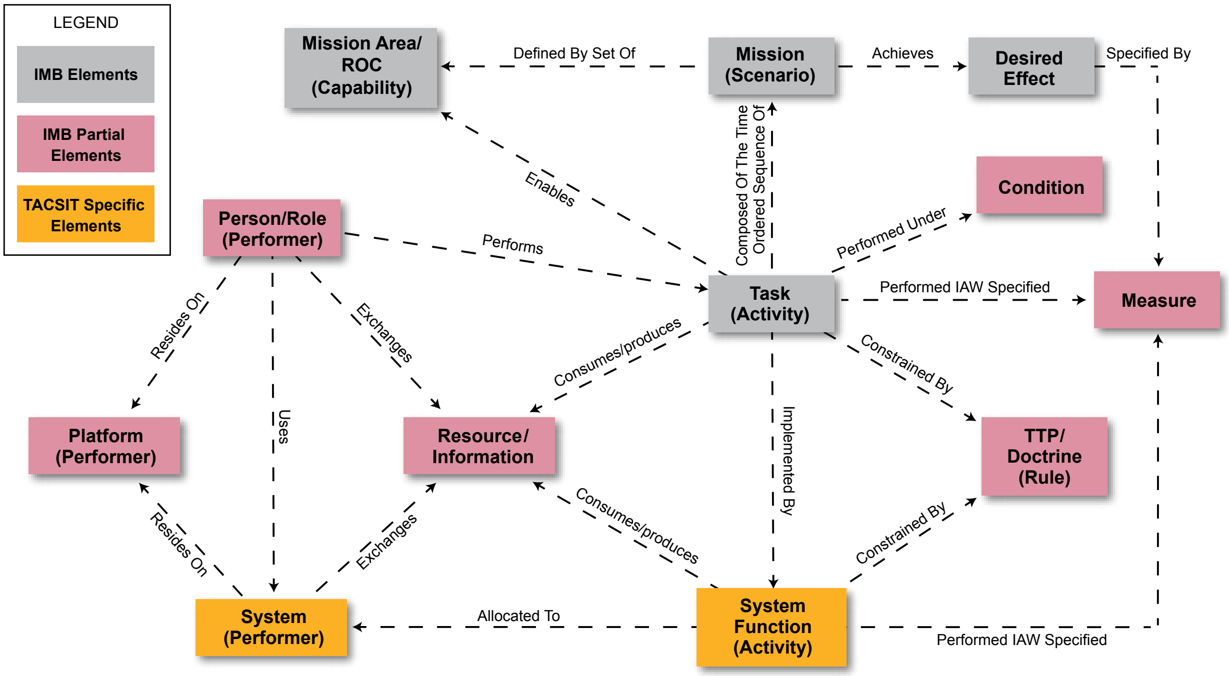


Figure 5. Integrated Capability Framework Data Model Highlighting Integrated Mission Baseline Data Elements

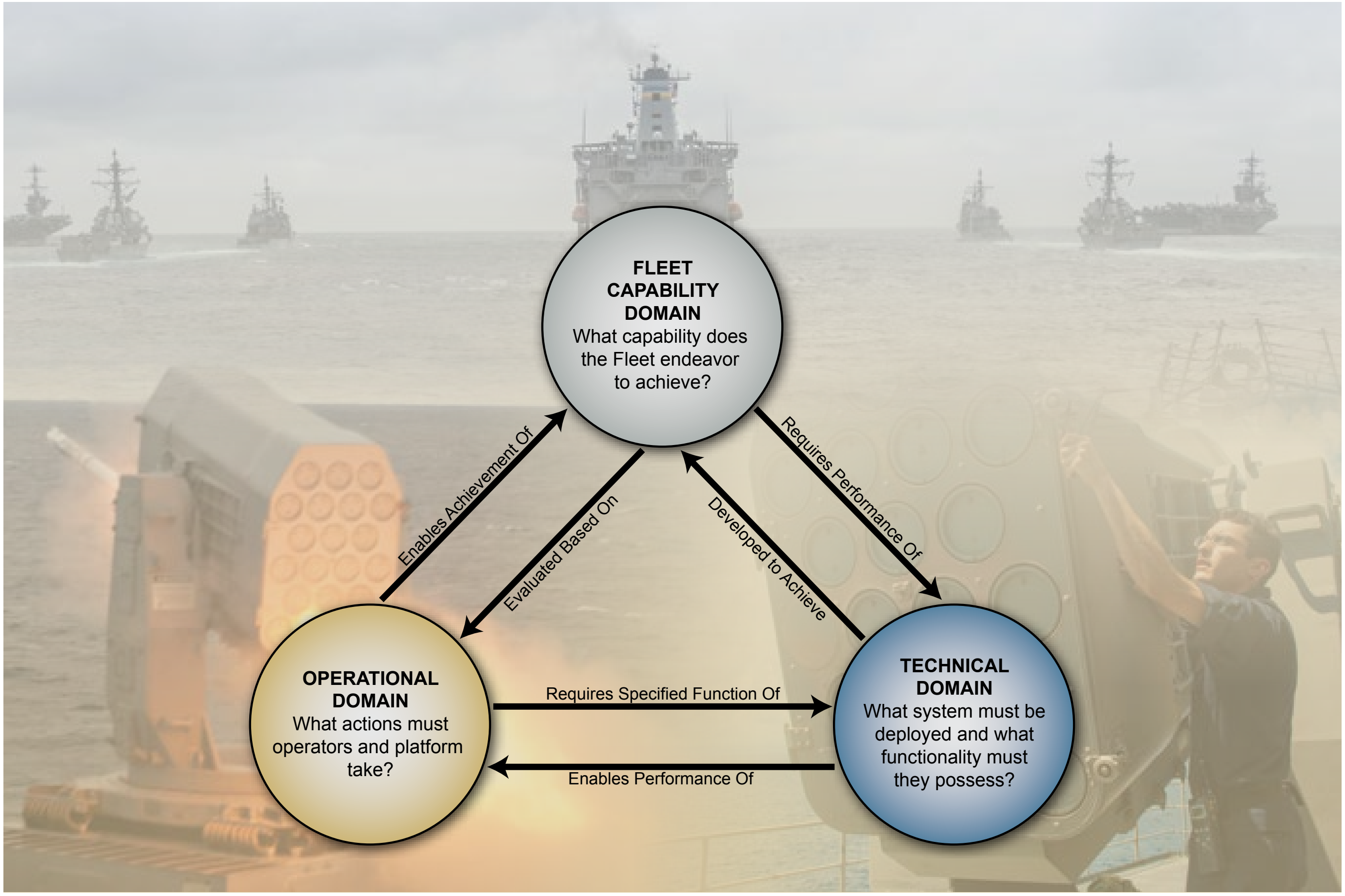


Figure 6. Capability-Based Modeling Methodology Acquisition Triad

This approach forces architects to focus on the Fleet first rather than a particular system or systems. It puts Fleet-owned data, such as doctrine and current rules of engagement, in front of an engineer's understanding or a program office's interpretation of the missions of interest. Because of this Fleet-first approach and because of the genesis in AV and CV products, the CBMM serves as an efficient method of architectural development for a mission baseline-level reference architecture.

Impacts to Architecture Development

As with most models, modeling languages, and engineering tools, architectures are only useful if designed for the correct purpose. Currently, many program offices, SYSCOMs, and Fleet organizations use architectures for communication, collaboration, and compliance. These purposes, while important for the daily function of all Navy organizations, do not lend themselves to achieving goals set forth in the DODAF regarding integrated and federated architectures.

Improvements to Current Architecture Development

Architectures are currently required by both the Joint Capability Integration and Development System's acquisition process and the latest iteration of DoD Instruction 5000.02E, "Operation of the Defense Acquisition System." Though required, the proper generation, use, and governance over architectures has traditionally been ambiguous. Programs interested in acquiring a new system, making modifications to an existing system, or attempting to transition a new technology, use mission architectures to map system functionality into Navy operations using DODAF viewpoints. As mentioned earlier, mission architectures represent a form of federated architecture under the DODAF construct and, as such, require the architects to understand not only their specific system focus but also systems used throughout the entirety of the mission as well as how operations are conducted by the uniformed organizations of interest.

Under the previous, non-I&I-informed system, it was up to the individual program offices or field components to develop, verify, validate, and exploit their mission architectures. For SYSCOMs, this required architects to compile data from numerous internal and external sources. Some sources of information were known and others were combined through known associations and professional contacts. Even today, system data tends to be better understood, as are sponsors, direct users or stakeholders identified by the sponsor, as well as initial performance requirements and capability analyses. The SYSCOM-level engineer may not understand without proper integration with Fleet components the latest tactics, doctrine, training (including relevant mission essential tasks), personnel or manning, platform readiness and availability, and other relevant geopolitical information critical to the successful employment of a new system or technology.

To the individual architect, this may not seem like any more of a burden on one party than another (see Figure 7). However, there are numerous programs—all reaching out to the same (or similar) organizations— asking for common data for each independent architectural effort, as shown in Figure 8. The result is a risk of overburdening data requests on relevant Fleet components and redundant manpower investments by the Navy. There is also a risk that two independent programs attempting to address a common mission area or environment may base their architectures on data originating from disparate sources, which often results in different solutions or inefficiently integrated products into a common mission area. Figure 8 illustrates how multiple architectural efforts, when accessing common data sources, can create unnecessary complexity and additional task loading on Fleet organizations.

If architects were to use an IMB established and maintained by the new I&I organization and owned by the Fleet, the Fleet would not be overburdened by redundant requests for data. Common use of single data sets also allows for more consistent data gathering and exchange among architects spanning across different and distinct Navy programs, as shown in Figure 9.

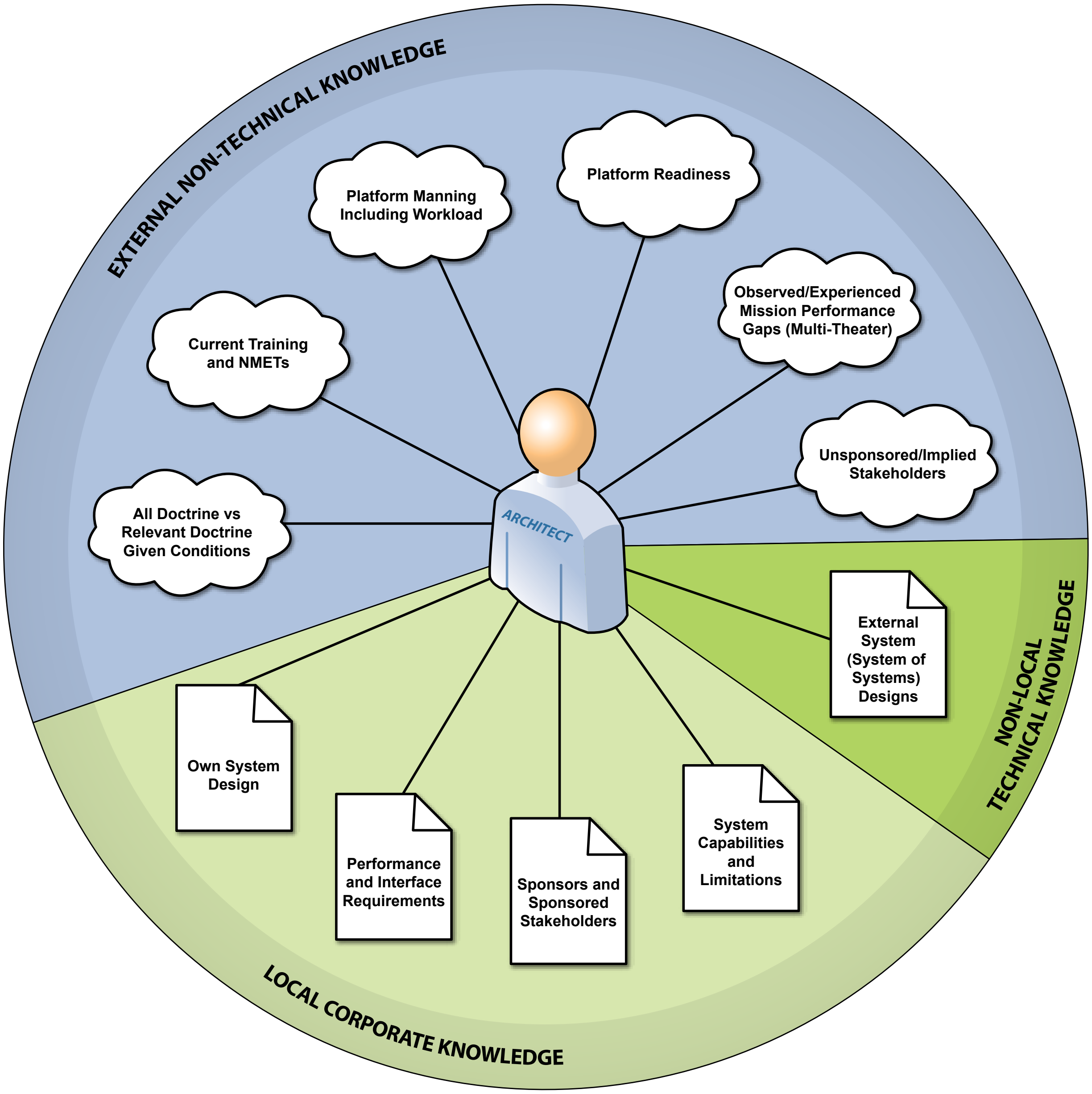


Figure 7. Data Sources Consumed and Managed by the Mission Architect

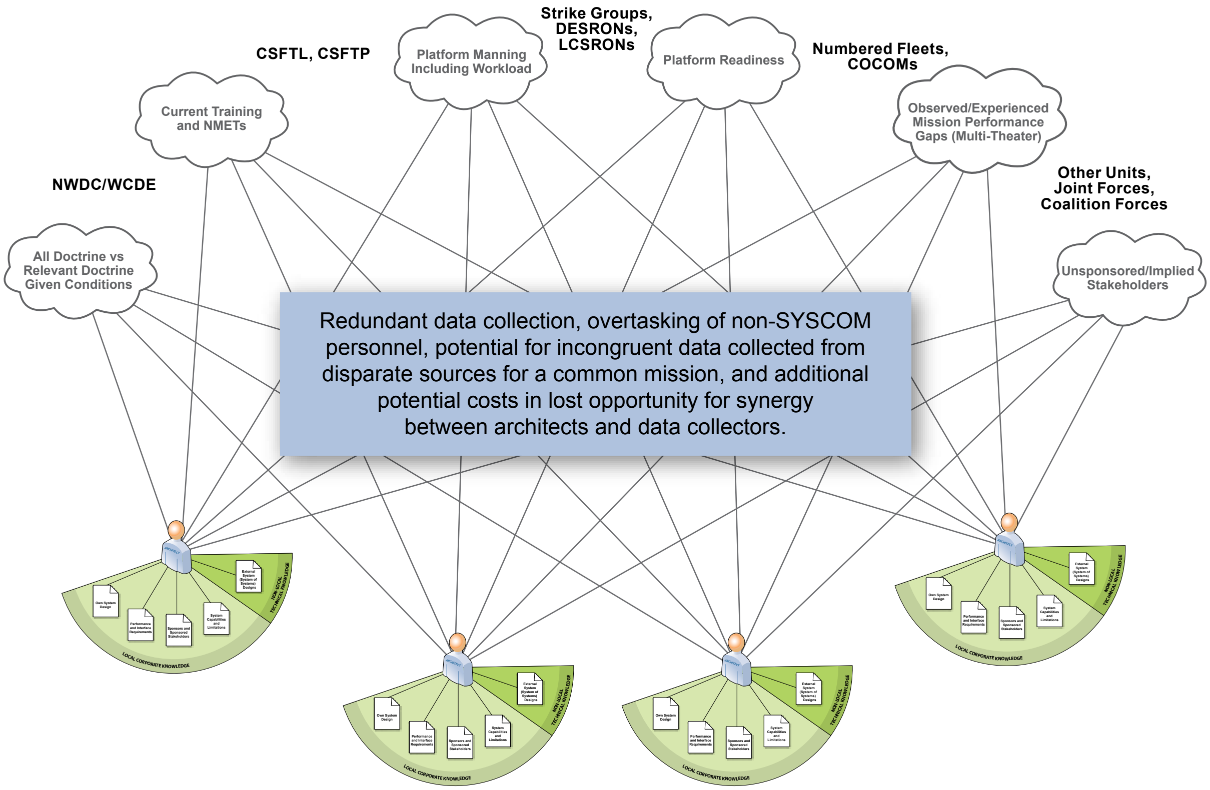


Figure 8. Complexity Caused by Independently Functioning Architecture Efforts

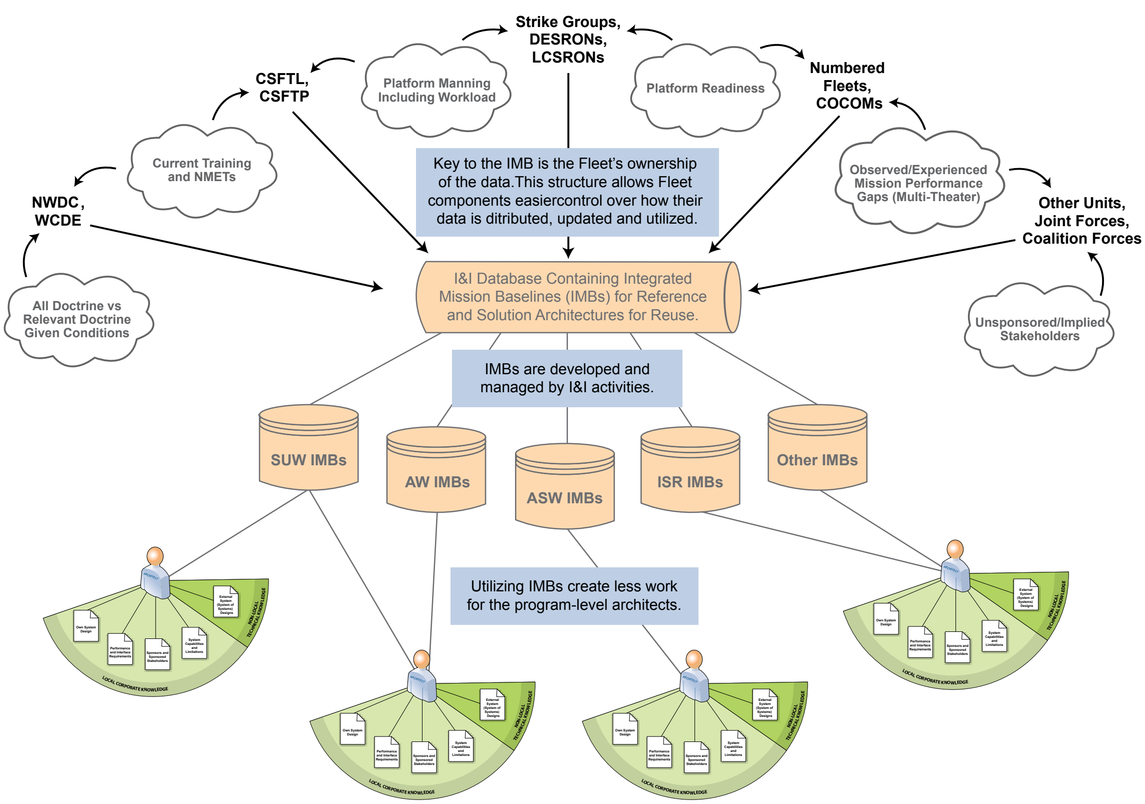


Figure 9. Simplification of Data Collection and Management Using an Integrated Mission Baseline

Implications to Increased Fidelity and Consistency of Modeling and Simulation (M&S)

Following an IMB construct benefits an organization not only through managing data gathering among architects but also in managing and coordinating data gathering among those in the acquisition community who need readily accessible data external to their corporate organization. A prime example of this type of data sharing occurs during investigations and development of M&S strategies as well as each tool's verification and validation process. For a modeling tool to maintain integrity with the mission and to correlate with data produced by other tools, it must access data external to the technical community and owned by the Fleet, such as doctrine, tactics, and physical limitations of the deployed force. To the individual M&S team, it may seem viable to simply contact the Fleet components relevant to a given modeling effort. However, when viewed from the Fleet component perspective, a single engineering or acquisition organization may have multiple M&S teams contacting a single Fleet component office for common sets of data. This not only risks damaging the Fleet's perception of that engineering organization but also reduces the Fleet's willingness to work with the engineering community.

These organizational risks can be alleviated by implementing IMBs into the data sharing and gathering process, which will provide Fleet components a single technical point of contact from which they may publish and subscribe data. This also alleviates the responsibility of each M&S team to contact multiple Fleet components, allowing them instead to simply consult a single IMB reference product that contains vetted and validated Fleet information.

Effort Cost Savings

Typically, as project complexity decreases, so does estimated cost. As previously noted, complexities in organizing architecture and M&S data needs can be greatly simplified through the use of IMBs. This represents significant potential for reductions in labor spent developing, maintaining, and exploiting contacts and releases architectures and M&S developers for more prudent tasking.

Future fiscal year efforts may also experience cost saving by way of architecture reuse, as shown in Figure 10. By leveraging the CBMM architectural methodology, IMB products are inherently compartmentalized by capability. Suppose a mission architecture contains capabilities for conducting intelligence, surveillance, and reconnaissance (ISR) operations and capabilities for conducting small caliber gunfire

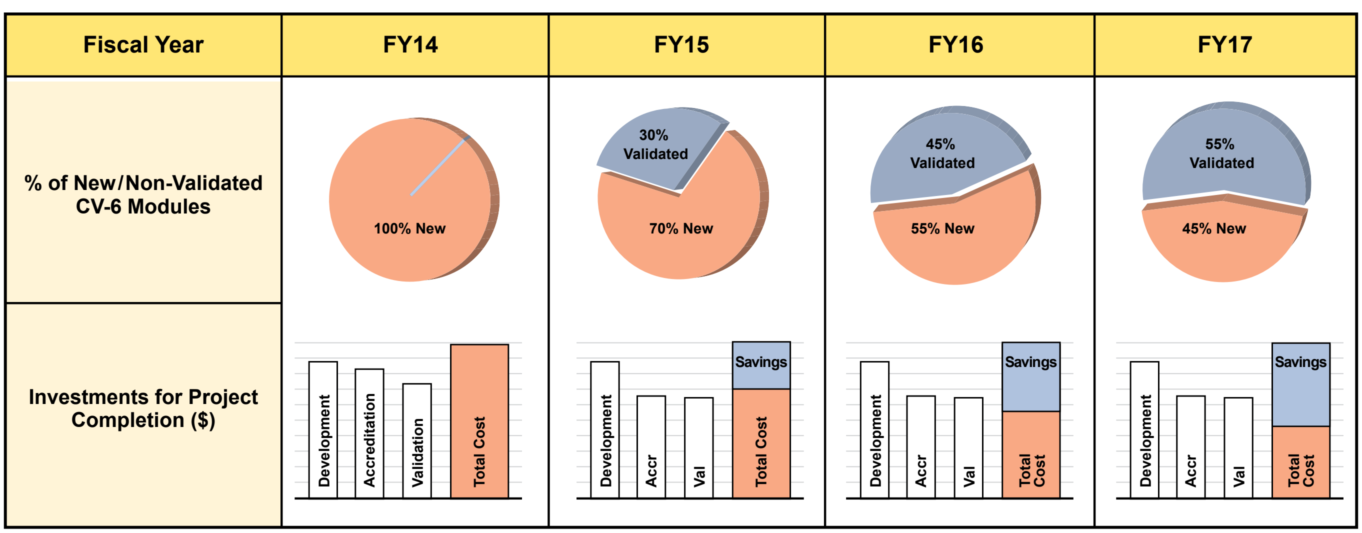


Figure 10. Notional Demonstration of Cost Savings Over Time Using Modularized Rework from Past Architectures

engagements. During the next fiscal year, suppose the same organization wants to produce a similar mission architecture but instead, looks at engagements with directed energy weapons. Both the former and latter architectures would use the same ISR capabilities, thereby preventing the latter architectural effort from investing in redundant capabilities.

Using an activity-based architectural approach would require a revalidation of the activity flow throughout the architecture and an object-based approach would require revalidation of platforms since key engagement systems were changed. However, because the CBMM organizes everything by capability, the architecture contains an inherent modularity. The IMB, composed using the CBMM approach, enjoys the same modularity and, therefore, may experience significant cost savings as more IMBs are produced.

Additional cost savings may be realized through the effective and efficient consolidating of data gathering and consistent use of known information. In a new age of austerity, where funding for data collection during live at-sea events and opportunities for costly tests are diminishing, engineers must maintain clear and open lines of data gathering and sharing to ensure programmatic limitations do not degrade the mission competence used to produce systems for warfighters. Using an IMB to coordinate data across development teams and programs mitigates risks created by inconsistent and insufficient data collection and interpretation, which in turn leads to unexpected expenses associated with data reconciliation.

Conclusion: IMB is Architecture Used Properly

Models are developed for a purpose; an architecture's purpose being the management of data in accordance with a data model. The purpose of an IMB is to coordinate data gathering and sharing and to maintain open data availability across an enterprise. Use of an IMB allows integrated system architectures to connect into the larger federated Navy enterprise, which supports the goals of DODAF and the Global Information Grid Architecture. By integrating system architectures into Fleet-owned and -validated mission architectures, program offices may predict I&I problems before investing heavily in manufacturing and prototyping. The IMB serves as the vehicle that allows program offices to consume that Fleet-owned data necessary for such I&I analysis.

IMBs also serve the important purpose of reducing cross-organizational complexity. The "spirit of I&I" has been one of collaboration and open data exchange. Without some mechanism to act as a catalyst for the tenets I&I endeavors to establish, changing the current means of architectural and system development will be difficult. By building, supporting, and encouraging, if not enforcing, the use of IMB-like architectures, that catalyst exists and enables many of the parallel efforts articulated in the I&I charter.

By integrating efficient data management through use of IMBs, the broader Navy community is better enabled to avoid costly problems with system interoperability and ensure efficient material and non-material solution integration to create a high level of readiness throughout the Fleet. ⚓

Capability Acquisition Management:

Modifying the Acquisition Process to Emphasize I&I

By Joel Washington

Maintaining alignment of the myriad of program acquisition activities spanning multiple program offices, and often across different Program Executive Offices (PEOs), to realize a complete mission thread of warfighting capability, is a daunting endeavor. Success means managing and maintaining alignment of specific interdependent system attributes of the mission thread during system development through what has traditionally been an asynchronous set of technical and programmatic activities. This is one of the four critical core areas the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), Integration and Interoperability (I&I) Mission Engineering team, sponsored by the Deputy Assistant Secretary of the Navy Research, Development, Test and Evaluation has had to address:

1. **Integrated Capability Framework**
   Overarching I&I task structure
2. **Capability Solution Management**
   Finding solutions to gaps
3. **Capability Acquisition Management**
   Managing the production of solutions
4. **Alignment of I&I Processes**
   Identifying stakeholders and best practices

This article describes the Capability Acquisition Management (CAM) Integrated Product Team (IPT) tasks, which are aimed at fusing force-level I&I considerations throughout the system acquisition decision process by modifying Systems Engineering Technical Review (SETR), Gate Review, and Probability of Program Success (PoPS) criteria.

Background

I&I represents synchronization of a series of deliberate steps to provide an end-to-end capability view from an "effects chain" perspective. Where possible, the I&I approach leverages existing Department of Navy processes (e.g., Joint Capabilities Integration Development System, Capability-Based Acquisition, Office of the Chief of Naval Operation's (OPNAV) N81 Warfighting Capability Plan, and the acquisition analysis of alternatives (AoA). I&I also provides a disciplined Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities and Interoperability (DOTMLPF-I) analysis to develop issues based on empirical data, facilitate solution recommendations to achieve effects chain wholeness, and align I&I recommendations to Navy leadership's informed budget and acquisition/investment decisions. The overarching goal is to deliver strategic readiness by ensuring the Fleet is capable of successfully executing the most important effects chains that, together, form the Navy's core contribution to Combatant Commander Operation Plans.

I&I contributors consist of system commands (SYSCOMs), warfare centers, OPNAV, Commander Operational Test and Evaluation Force (COTF), and the Fleet. The Fleet provides mission area advocacy from establishing the I&I demand signal through processing approved solutions. The COTF provides the framework and focal point for expertise to accomplish selected effects chain assessments. SYSCOMs provide the technical rigor to accomplish I&I materiel issue assessments. OPNAV and the Assistant Secretary of the Navy (Research, Development, and Acquisition) [ASN(RDA)] provide the expertise and options to leverage the full range of processing and implementation options for I&I solutions as illustrated in Figure 1.

The CAM IPT was specifically tasked to recommend policy changes to support mission engineering, incorporate rigor into mission engineering aspects of the acquisition process, and to mitigate I&I issues. Candidate policies for change were found in the Technical Review Manual, Naval Sea Systems (NAVSEA) instructions, Naval Systems Engineering Technical Review Handbook, and OPNAV instructions. Emphasis was placed on the criteria required to support mission thread and kill chain execution.

In looking at potential policy changes, the CAM IPT addressed the full end-to-end traceability of mission capability requirements in specific domains by examining:

- Data
- Interfaces
- Decomposition/allocation of end-to-end technical requirements
- Dependencies
- Commonality

Any proposed policy changes would be vetted against and help ensure compliance with overarching I&I acquisition policy statements in SECNAVISNT 5000.2E, "Department of the Navy Implementation and Operation of the Defense Acquisition System and the Joint Capabilities Integration and Development System," 1 September 2011:

> *PMs shall ensure the (I&I) of all operations, functions, system interfaces, data, software based services, distributed decision-making systems, human processing capabilities, situational awareness systems, and other systems to reflect the requirement for all system elements: hardware, software, facilities, sustainment infrastructure, personnel and data. Interoperability shall be addressed by including system of systems (SoS) or federation of systems (FoS) considerations ....(6.1.6 Interoperability and Integration)*

The CAM IPT settled on modifying three interrelated target areas that would then be codified through proposed policy changes: specifically, the SETR process for technical monitoring capability development; the 2-Pass, 6-Gate acquisition management schema for decision control measures; and finally the PoPS dashboard for monitoring program health assessment and reporting. We will explore the CAP IPTs efforts in each of these three areas in this article.

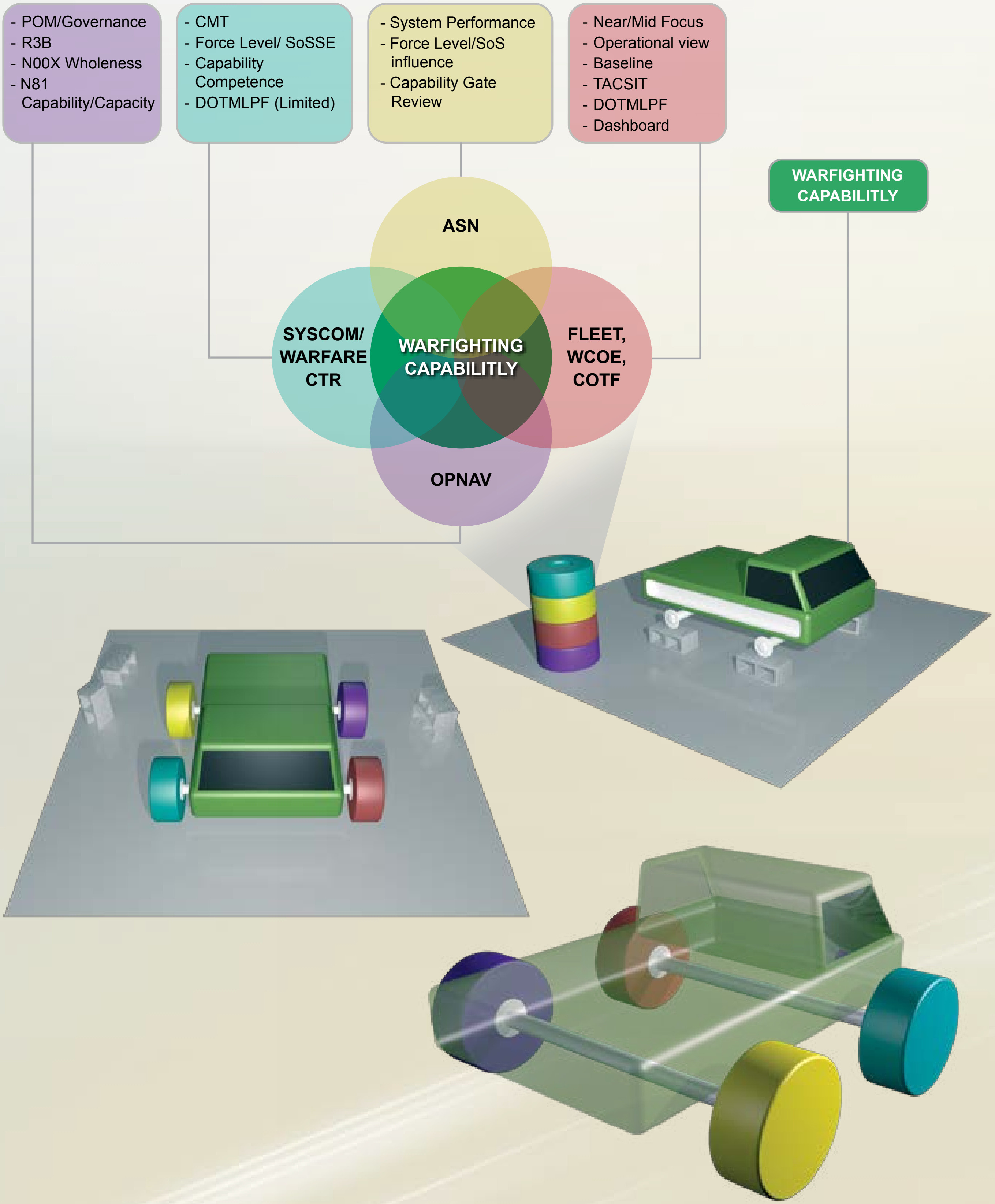


Figure 1. Warfighting Capability

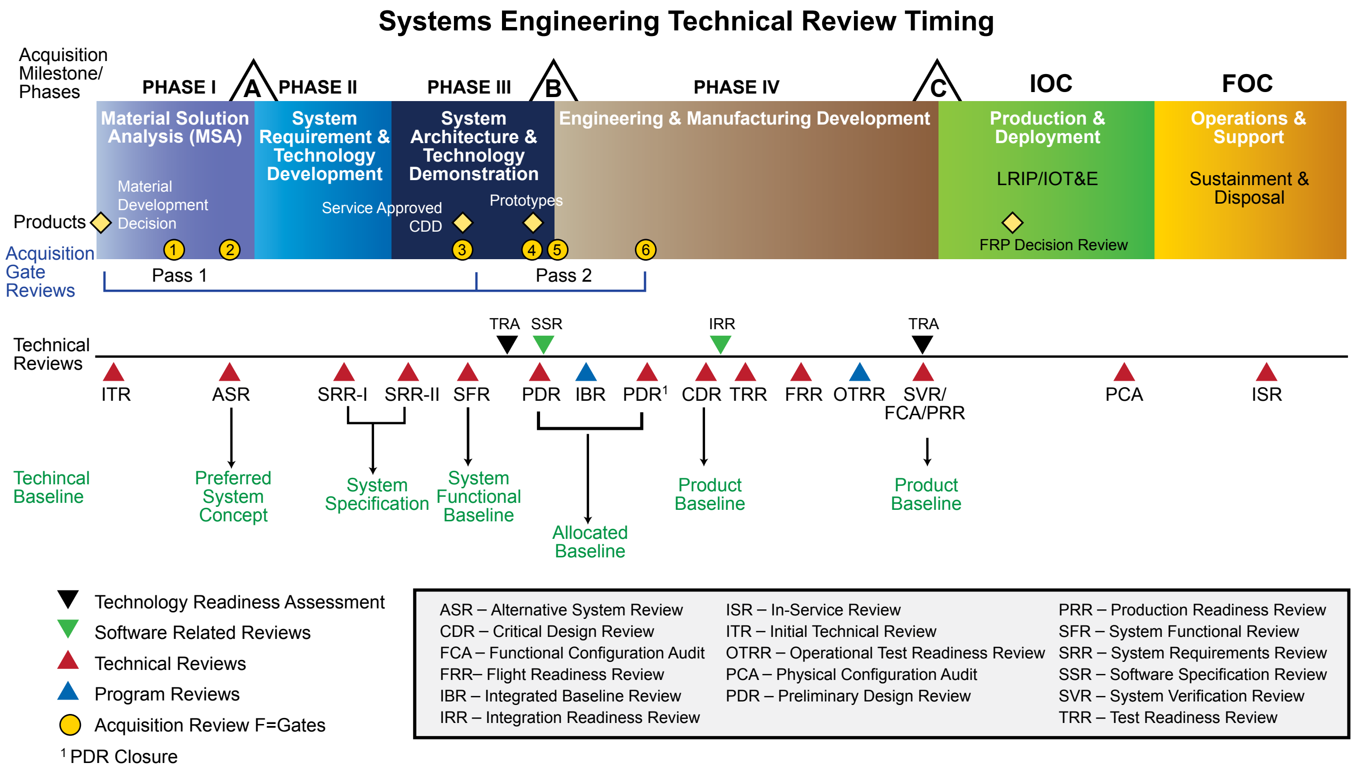


Figure 2. Systems Engineering Technical Review Process

Systems Engineering Technical Review

The first area the CAM IPT focused on was the SETR process. The SETR process is an integral element of the acquisition process and life cycle management, as traditionally depicted in Figure 2. Technical reviews coincide with and support key acquisition milestone decisions and gate reviews in the acquisition process, and provide an independent assessment of emerging designs against plans, processes, standards and specifications, and key knowledge points in the development process. The SETR process is integral to naval systems engineering and is consistent with existing and emerging commercial standards.

Although the SETR process consists of several technical reviews, depicted as red triangles in Figure 2, the CAM IPT assessed I&I-related criteria and targeted three specific reviews: System Requirements Review (SRR); System Functional Review (SFR); and Preliminary Design Review (PDR). Each review is described below.

SRR	The objective of the SRR is to ensure that operational requirements have been successfully represented by system requirements; the system design has the potential of meeting these system requirements when acceptably balanced with cost, schedule, and technical risk; and the plans for moving ahead with system development are reasonable and of acceptable risk.
SFR	The objective of the SFR is to review and approve the system's technical description, including its system requirements and architecture, and to establish the system's functional baseline.
PDR	The primary objective of a system or subsystem PDR is to review and approve the system architecture as defined by the allocation of requirements to the subsystems and configuration items, thereby creating the allocated baseline.

Mission I&I SETR Event Tier Development

The CAM IPT started with a list of criteria that had been previously developed by an earlier SYSCOM I&I team. A tier structure was used to help analyze and determine I&I entry and exit criteria, leading to the traceability and evaluation of the system of systems throughout the life cycle. The SETR evaluation criteria was developed and documented for inclusion into the SETR handbook. The tier structure for organizing SETR criteria consisted of five tiers:

Tier 1	SETR event
Tier 2	Categories: mission engineering, systems engineering, test and evaluation, IA, open architecture
Tier 3	Subcategories of Tier 2, such as capability gaps analysis
Tier 4	Evaluation criteria
Tier 5	Detailed criteria designed to help evaluate Tier 4 criteria

The tier structure numbers are used to identify the categories and the actual I&I evaluation criteria.

2-Pass, 6-Gate Process

The second area the CAM IPT addressed was acquisition milestone management and milestone decision-making policies and processes. The Navy has mandated that all programs use the 2-pass, 6-gate process for program evaluations. The goal is to ensure programs are adequately assessed during the system engineering development process. As depicted in Table 1, the gate review process ensures alignment between service-generated capability requirements and acquisition, and improves senior leadership decision-making through better understanding of risks and costs throughout a program's entire development.

Specifically, the CAM IPT reviewed Gate 3 and Gate 6 templates for inclusion of I&I activities and actions. This included rewriting Gates 3 and 6 entry and exit criteria, based on the understanding of SoS engineering. For Gate 3, the CAM IPT recommended providing test and evaluation strategies for developing end-to-end test plans. Early operational assessments, prior to developmental testing, were also recommended to reduce integration risk and SoS testing. For Gate 6, the CAM IPT recommended the use of mission threads for improving system and platform operational effectiveness, including how mission threads can be used to assess DOTMLPF material solutions.

Incorporating these changes to Gates 3 and 6 will provide the rigor necessary to ensure the program under review is fully reporting I&I characteristics and is capable of transitioning to the next phase with minimal risk.

Probability of Program Success (PoPs)

The Program Health Assessment Guidance, PoPS, assesses the health of an acquisition decision and the likelihood of implementation and associated impacts to capabilities by measuring a program's real ability to accomplish its objectives and effectively illustrate

FIRST PASS		SECOND GATE	
OPNAV Chaired		ASN(RDA) Chaired	
Gate 1	Initial Capabilities Document Approval	Gate 4	System Design Specification Approval
Gate 2	AoA Approval	Gate 5	Request for Proposal Release
Gate 3	Capabilities Development Document/ Concept of Operations Approval	Gate 6	In-Progress Review, Capabilities Production Document Approval

Table 1. 2-Pass, 6-Gate

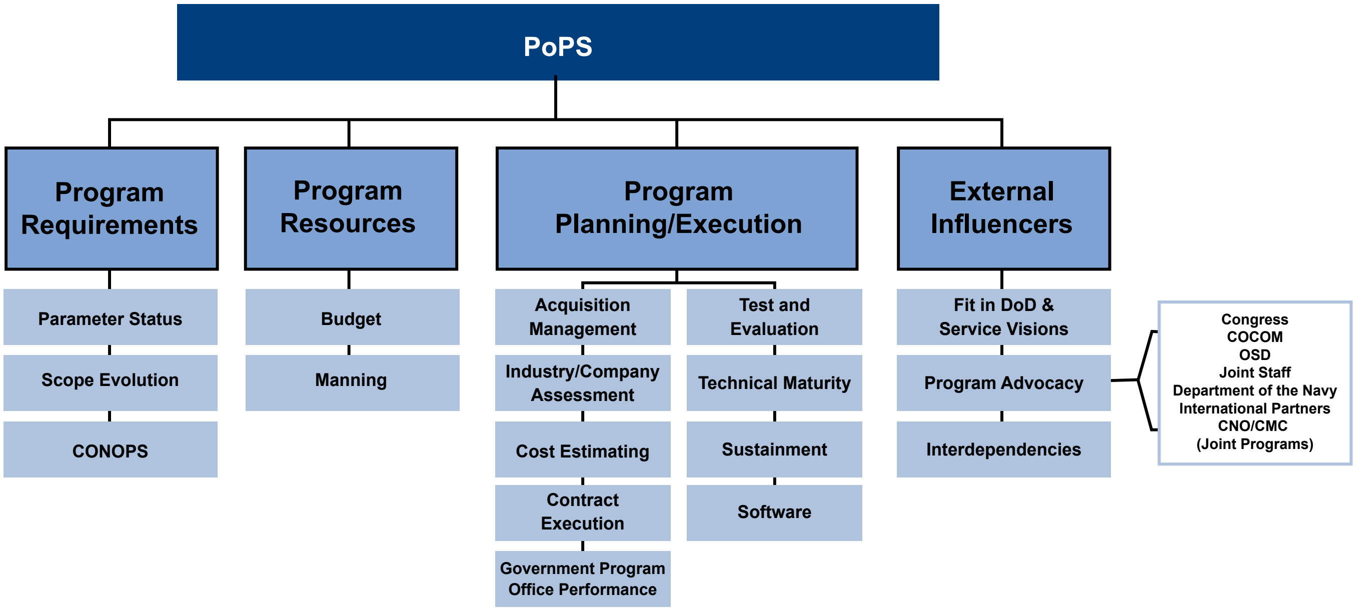


Figure 3. Program Health Assessment Dashboard

that status to decision makers. For Gates 3 and 6, the CAM IPT reviewed the associated PoPS criteria for inclusion of I&I acquisition requirements. When holistically implemented, PoPS produces an interactive dashboard (see Figure 3) that displays a program's current "health status," and enables leadership to identify issues, determine mitigation strategies, and allocate resources accordingly across the program.

The PoPS family tree is intended to provide a holistic look at a program and provide leadership an easily interpreted (red-yellow-green) consistent assessment of current program state. Of particular interest to the CAM IPT was the linkage, shown in Figure 4, among the SETR technical reviews, the acquisition 2-Pass, 6-Gate events, and the continual PoPS measures and program status. The proposed SETR I&I criteria for SRRs, SFRs, and PDRs supports the I&I requirements at acquisition Gates 3 and 6. This information is reported through PoPS, which provides a holistic response to realizing capability acquisition management for mission-level I&I.

If criteria questions reveal issues during any of the targeted reviews, the program manager or senior leader can assess the program's health based on program requirements, resources, program planning and execution, and external influencers.

Recommended Policy Changes to Support I&I

The CAM IPT identified four specific policy-rich documents at various levels of the Navy's acquisition and development organizational structure to achieve coverage of mission-level I&I requirements at organization depth:

- OPNAVINST 9070.2a, "Signature Control Policy for Ships and Crafts of the U.S. Navy"
- CFFCINST/CPFINST 4720.3b, "C5ISR Modernization Policy"
- NAVSEAINST 5000.9/MARCORSYSCOM Order 5400.5/SPAWARINST 5000.1/ NAVAIRINST 5000.24, Naval Systems Engineering Technical Review Handbook
- Technical Review Manual Version 2.0, PEO IWS and NAVSEA 05H

The recommended update to these instructions ensures that integration and interoperability are considered across Navy systems of systems, and provide evaluation criteria for SETRs and design reviews.

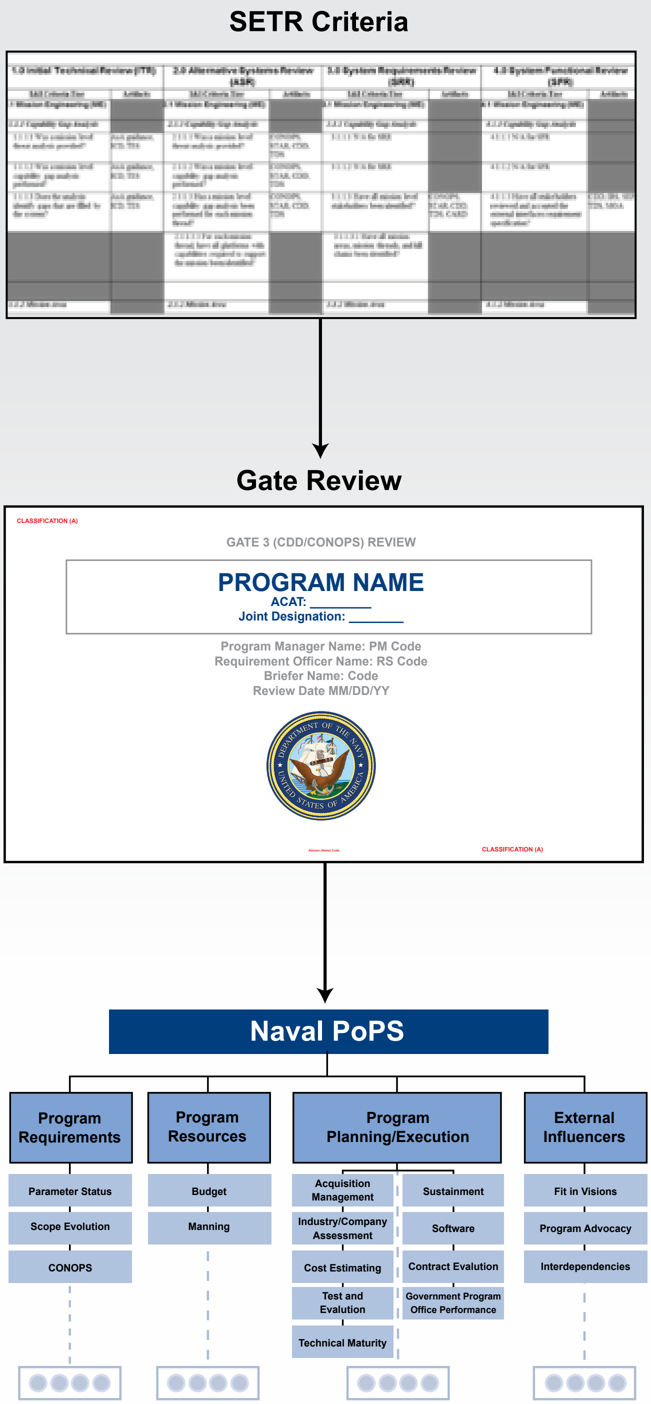


Figure 4. PSETR/Gate Reviews and PoPS Linkage

Summary

The goal of the CAM IPT was to address I&I issues and reduce the programmatic risk to enabling mission-level requirements. To do this, the CAM IPT developed new SETR criteria questions that addressed I&I across mission and platform systems of systems, proposed entry and exit criteria for the 2-Pass, 6-Gate review process, and recognized the value of having I&I issues visible in the PoPS dashboard. Codification of the new SETR criteria was accomplished by providing recommended additions to current policy documents. ⚓

I&I From a Cost Perspective

By Jonathan Brown and Sarah Lloyd

In today's budget climate, how can the Department of Defense (DoD) ensure they are still developing and procuring the equipment that our warfighters need? By focusing on specific mission areas and looking across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) spectrum for solutions to address mission capability gaps, Integration and Interoperability (I&I) is uniquely suited to find the "knee in the curve" and maximize the return on investment. A key component to this optimization concept is the ability to accurately predict costs across a spectrum of mission solutions. An accurate prediction of costs enables decision makers to efficiently utilize their resources to attain the maximum performance for the minimal cost, identify potential trade-offs, and identify areas for cost reduction and/or avoidance. This article discusses the role of cost estimating in the I&I process, including the challenges of mission-level cost estimates. It also provides an evaluation of current cost estimating techniques that may be applicable to mission-level analysis. Finally, it explores promising areas of research that may mitigate some of the current cost estimating challenges, such as the potential for using existing I&I artifacts, technical metrics generated during the I&I process, and Integrated Readiness Level (IRL) as metrics for cost assessments. The integration of cost analysis into the I&I process combines research and development with operational support and readiness in order to provide cutting edge cost support to the warfighter.

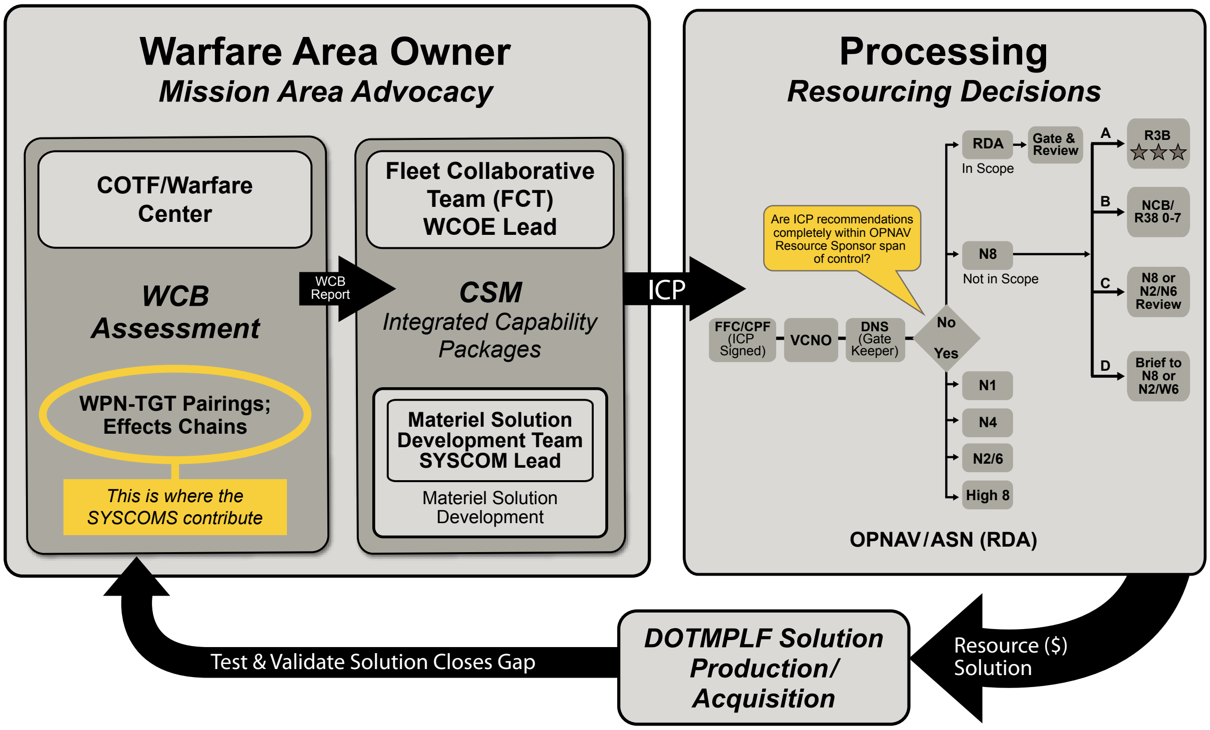


Figure 1. Schematic of the I&I Process[1]

Where is cost involved in I&I?

Figure 1 depicts the current I&I process. As previously discussed in this edition of Leading Edge, the Integrated Capability Package (ICP) prioritizes the set of DOTMLPF solutions proposed to cover the identified capability gap or set of gaps. Cost estimates are required for trades studies and analysis of alternatives as well as for each proposed solution in the set. Having estimates of the required funding for each solution allows decision makers to make more informed decisions. As illustrated in Figure 2, trade-offs between cost, technical, and schedule are required when faced with limited resources.

Challenges of I&I Cost Analysis

Cost Growth

While there are many different ways to measure the extent and nature of cost growth, there are multiple possible explanations and potential solutions for improvement. Often, technology development and acquisition programs are launched with too little focus on system and mission-level requirements needed to develop realistic cost estimates. Program managers may have optimistic schedules and assumptions, such as stable requirements, with corresponding low initial cost estimates that are appealing to funding sources. Realistically, however, significant requirements volatility is common during the early acquisition phase, which in turn causes significant cost growth. When attention isn't given to possible changes and growth in requirements, budget overruns occur and programs

Figure 2. Trade-off between Cost, Technical, and Schedule

risk being canceled. In order to prevent programs from being canceled, one must acknowledge and plan for the likelihood that requirements will grow and change. Canceled programs consume resources with little or no return on investment; moreover, they represent lost opportunities for viable programs that may also fail due to lack of funding. The result is a replicating program failure effect. The longer the program continues before cancellation, the greater the effect.

Requirements and Data

Squeaky wheels get the grease, and dedicated, tenacious program managers are more likely to receive program funding. Cost analysts rely on these system-specific champions to help overcome obstacles to prioritizing the cost team's technical or data requests. Costs cannot be determined for requirements that are not defined in technical terms or do not indicate the level of effort required. Therefore, cost analysts depend upon obtaining data from the engineering and technical teams to ascertain what costs will be affected by the various alternatives. Most important to the I&I efforts is to obtain candid technical assessments of impact to other systems to determine the causal effects on the cost. A strong program manager will set priorities that ensure the engineering and technical teams are thorough and responsive to the needs of the cost analyst's data requests.

Program Focused

Generally, cost estimates, similar to most other systems engineering tasks, are program focused. Cost estimating within the context of the I&I process requires a paradigm shift from program focused estimates to mission focused estimates in order to accurately predict costs across a spectrum of mission solutions. When implemented, this type of analysis is similar to a large-scale Analysis of Alternatives and requires the cost analyst to have breadth vs. depth of analysis. Typically, cost analysis requires some level of specialization. Successful cost analysts often focus on one specific group of systems or platforms or one area of cost analysis. Examples of specializations include combat systems, ships, submarines, rotary wing aircraft, etc. Often, the specific system or platform is large; therefore the cost analyst gains a breadth of experience in a multitude of subsystems that exist within this area of specialization. Similar to the I&I technical subject matter experts, I&I cost analysts need to have not only a broad range of experience but also a large network of experts to leverage when required.

Subject Matter Experts

Expert opinion, or subject matter expert (SME) input, is important to cost estimating by bringing a wealth of experience and knowledge to the estimating process. Many times, experts help to identify analogous systems or provide data on labor hours or testing requirements to build, operate, and maintain a system. At the very least, an expert can provide his or her opinion on cost drivers, functional form of a regression and engineering rules-of-thumb on which the cost analyst can consider in the estimate. When working across multiple platforms, systems, and capabilities, it is not possible to have a dedicated SME for each potential solution on the team as compared to a typical system acquisition cost IPT with dedicated resources. A dedicated team with a robust network of SMEs is needed to have access to the required technical information, similar to a technical warrant holder pyramid as depicted in Figure 3.

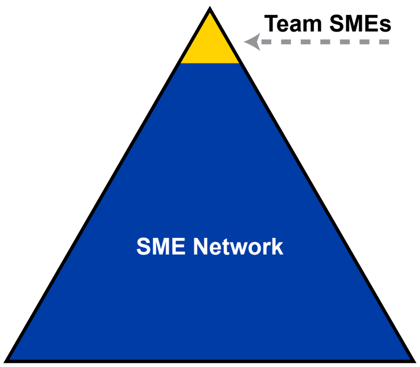


Figure 3. I&I SMEs Require Large SME Network for Support

Opportunities for I&I Cost Analysis

Despite multiple challenges presented by integrating cost analysis into the I&I process, many opportunities exist. I&I related research will set the

conditions for providing more accurate cost estimates early in the acquisition process (pre-Milestone and Milestone A). Mission-level analysis reduces uncertainty, provides better metrics and allows for a more accurate cost model; hence, reducing the overall cost and increasing the probability of program success. Current cost estimating practices include providing cost estimates to program management throughout each phase of the acquisition life cycle. Cost estimates are often required at the earliest stages of a program's development, i.e., Milestone A or earlier, when the acquisition strategy and requirements are loosely defined. This yields rough order of magnitude cost studies, surrounded by a high degree of uncertainty upon which important program decisions are made. Furthermore, sometimes program-specific analysis focuses on a single platform and a single system. This may lead to a product based on a limited sight picture rather than providing the customer with a holistic, system-of-systems life-cycle analysis that is important to providing the decision maker with various program options (both technical and cost). This program-specific analysis increases the risk that problems will arise when the system or capability must interact and interoperate with other systems to accomplish its mission. Interoperability problems are becoming a focus area and are expensive to fix once the system or capability has been developed. An example of this is the recent Accelerated Mid-Term Interoperability Improvement Project (AMIIP) that was created to address Fleet concerns about force-level interoperability; specifically to address consistent correlation between Cooperative Engagement Capability (CEC) and Tactical Data Link (TDL) tracks.[2] Mission-level analysis helps to avoid these interoperability issues and escalating costs by addressing system interactions required to accomplish the mission early, at the concept phase, in an acquisition program, thus reducing potentially expensive interoperability "fixes" in the future.

Another acquisition problem currently facing the Navy is the development of technologies or capabilities with no clear insertion point into the Fleet. These "orphaned" programs have already sunk the cost of development but provide no direct benefit to the warfighter because they are never integrated into a platform. More likely, they are installed onto a platform but not integrated into the combat system. The overall I&I process would reduce orphaned programs by either identifying a specific mission gap each capability will be addressing or, if no mission need or no better solution is identified, the program will not be recommended.

The final opportunity to consider relates to the technical data available for cost estimation. The I&I process puts an emphasis on upfront mission architecture. This architecture process produces metrics that have the potential to be used for cost analysis. The emphasis on upfront mission architecture in the I&I process ensures that the metrics are received early

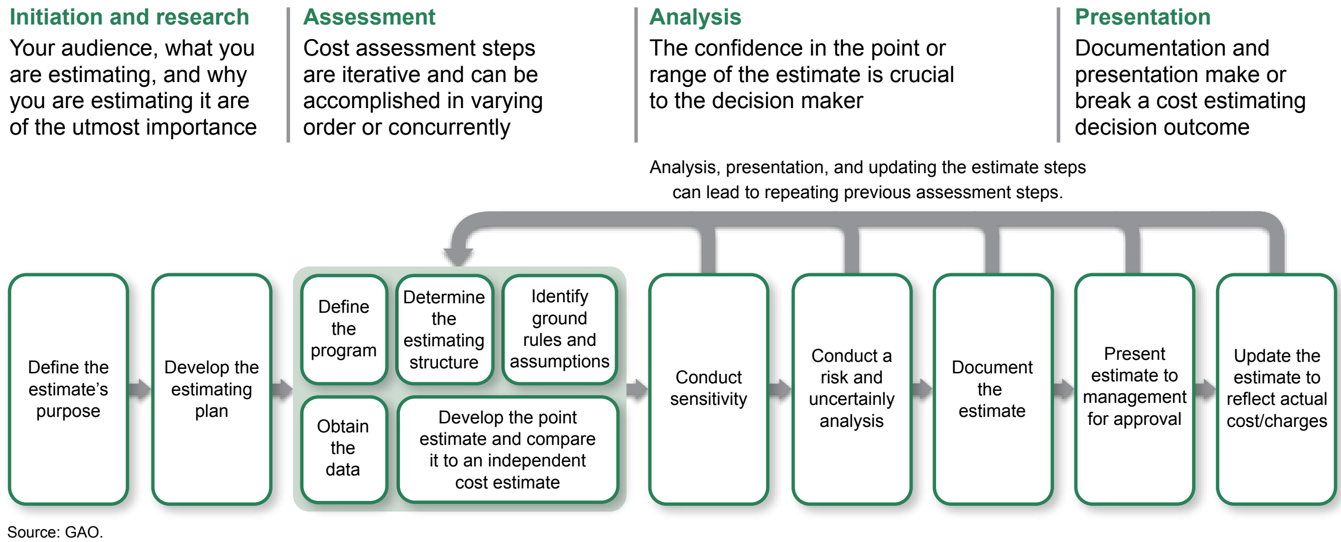


Figure 4. The Cost Estimating Process[3]

and often. This topic will be expanded on later in this article, but some technical metrics that potentially influence cost are information exchange messages and Technology Readiness Levels (TRLs).

Evaluation of Current Cost Process Suitability to I&I Cost Analysis

The following section summarizes the current cost analysis process and identifies the suitability to its applicability to the I&I process. Figure 4 represents the Government Accountability Office's (GAO) cost estimating process. Often, cost analysts apply a tailored version of the GAO's Cost Estimating Process that is most applicable to the program and associated tasks.

Define the Estimate and Develop the Estimating Plan

One of the most critical first steps is to define the scope of the cost estimating effort and to set the due date for the completed cost estimate. Upfront planning will still be required for any cost estimate, I&I or otherwise.

Define the Program

I&I cost estimates will require the analyst to define the program. This will be more difficult for an I&I program because instead of a single program, system or capability, the I&I solutions will likely be a range of options to address the given mission. For traditional acquisition programs, this defining information comes from a Cost Analysis Requirements Description (CARD) or other written documentation from the program office. When the CARD is unavailable or does not include enough information, the cost analyst and technical team must work together to identify constraints and reasonable assumptions that will define the effort. For I&I, similar information is still required; however, there will no longer be a single source document or program office. Furthermore, it is unlikely that the depth of information required in a CARD will be available for each option. Similar to, but broader than an AoA, a prioritized list of information required for an I&I cost estimate must be provided by a network of program offices and SMEs. The list of information required could be far more extensive than other early estimation efforts.

Determine the Estimating Structure

An I&I cost estimate will still require the development of a Work Breakdown Structure and identification of an estimating method for each. This part of the process will likely be similar to other cost estimates.

Identify Ground Rules & Assumptions (GR&A)

While the actual ground Rules and Assumptions (GR&A) developed for an I&I cost estimate may vary from a traditional cost estimate, the process to identify them will be similar.

Obtain The Data

Data gathering is the most difficult task in the cost estimating process. Data collected falls into two basic categories: data from previous programs used as a basis for cost relationships and technical data for the current program used to project future costs from the historical actuals. For a typical cost estimate, the analyst must identify SMEs, analogous systems, previous cost estimates on the topic, relevant databases, Cost Analysis Requirements Description, and pertinent program and engineering data from the program office. As mentioned above, for I&I cost estimates, this process is difficult since there are multiple platforms and systems involved to address a specific mission. However, there are potential new sources of technical data available from the I&I mission architecture to help address this complexity.

Develop the Point Estimate

There are four accepted methods by which cost estimates are generated: analogy, parametric, engineering, and actuals. Table 1 summarizes the four methods.

Analogy

Analogy entails using a single comparison value from a system with similar characteristics. This method is most often used early in the acquisition phase when there is little or no data available on the new system. While it is relatively quick and easy to use compared to with other methods, the results may be generalized and subjective.

Parametrics

The parametric approach uses statistical means to measure trends across multiple programs. This method requires a large amount of data; however, the outcome yields measurable and tractable results.

Engineering Estimate

An engineering estimate is a detailed, bottom-up approach which is usually used later in the acquisition process. Gathering the data required can be a slow process that is labor intensive but costs are estimated at a high level of detail which will provide better insight into cost drivers.

	Estimating by **ANALOGY**	Estimating by **PARAMETRICS**	Estimating by **ENGINEERING**	Estimating by **ACTUAL COSTS**
What is it?	Single value from single data point	Measure of trends across programs	Detailed build-up of Lab, Mtl & OH $	An extrapolation of *current* program cost
When used?	Early in Program Pre-Milestone A & Milestone A	Milestone B	Late in Program Milestone C & LRIP	LRIP Full Rate Production
How is it done?	Adjust analogous system cost ***or*** create cost factor	Apply statistical methods to cost of 2 or more systems (i.e., Develop a CER)	Estimate at lowest cost level & sum costs by WBS	Use trend from your *current* contract to estimate your final system $
PROS	Fast, inexpensive Easy to change	Based on >1 data point =>less risky Can measure error Easy for what-ifs	More details enables better visibility into cost drivers	Most costs are known CAIG prefers over other methods
CONS	Based on single historical data point +> risky! Trends to be more subjective	Constrained by amount & quality of data (GIGO) Statistics can be misleading	Labor Intensive Slow, Expensive Can lose sight of "big picture"	Usually too late to use actual costs to adjust or build budget Not a 1:1 correlation of prototype-to-production costs

Table 1. Cost Estimating Methodologies[4]

Actual Costs

Actual costs or "actuals" are an extrapolation from the current data of the costs that have been incurred. These costs are usually the best and most precise costs; however, often the data becomes available too late in the acquisition cycle to be useful.

While the actual analogies or technical metrics used in a parametric estimate may differ from a traditional cost estimate to an I&I cost estimate, there are no expected variances to the four acceptable methods. Given the information required to use an engineering buildup or actual cost, employing these methods will not likely be frequently used in the I&I process. The fact that the I&I analysis is conducted early in the acquisition life cycle will necessitate a larger use of analogies and parametrics. However, this is not absolute. For example, if an existing technology is proposed as a solution in an ICP, the actual costs of that item would then be used in the I&I cost estimate.

Final Steps in the Estimating Process

The final steps, shown in Figure 4, of uncertainty analysis, presentation to management, and updating the estimate will require no anticipated changes from the traditional process. However, there is a subtlety to be emphasized. A typical cost estimate for a program or system usually resides under a single System Command (SYSCOM) and program office. There may be additional stakeholders, but the SYSCOM and program office are responsible for providing the final review of the cost (SYSCOM Cost Organization) and technical (program office) assumptions and methodologies. By contrast, an I&I cost estimate could include multiple programs or systems that potentially cross multiple SYSCOMs (NAVSEA, NAVAIR, MARCORSYSCOM, etc.). Who would provide the final review and be responsible for the validity of an estimate that crosses multiple SYSCOMs and program offices? Some options for answering this question could include designating a lead SYSCOM for each ICP. The ICP lead SYSCOM would be responsible for approving the entire package. An alternate approach would be to require individual SYSCOM sign off on the respective technical area of a single ICP. The final process is yet to be determined, but responsibility of the I&I cost and technical review will need to be established.

Cutting Edge Research and Promising Topics

Cost estimates for I&I products present several challenges to the cost estimator. These challenges also open up new cost research areas to help mitigate or overcome these challenges. The following topic areas are of particular interest.

Messages, Software Estimating, And Analysis Modeling (SEAM)

A 2009 study conducted at NSWCDD, Software Estimating and Analysis Modeling (SEAM), investigated current software size estimating processes involving Software Lines of Code (SLOC), recommended improvements, and suggested alternatives. One promising alternative technical metric suggested was the measurement of messages. Messages are the packets of information sent from one software component to another. In the research, a preliminary statistical relationship was established between the number of messages and the number of SLOC. While this technical metric for cost measurement requires more research before utilized for cost analysis, it is very promising from an I&I perspective. SLOC is the primary software sizing metric for cost analysis, but as mentioned above, is not likely to be available early on during ICP development. Because of the emphasis on mission architecture, message counts are likely to be available for I&I analysis. If the preliminary results remain stable under further research, this new metric will provide a link between I&I mission architectures, SLOC and cost. To capitalize on this research would require the I&I ICP development process to include sufficient time to conduct the architecture development at a low enough level to be useful to the cost estimate.

Readiness Levels

Previous GAO assessments have correlated low technology maturity with programmatic problems; programs that began development with immature technologies saw a 32% cost growth and 20 month

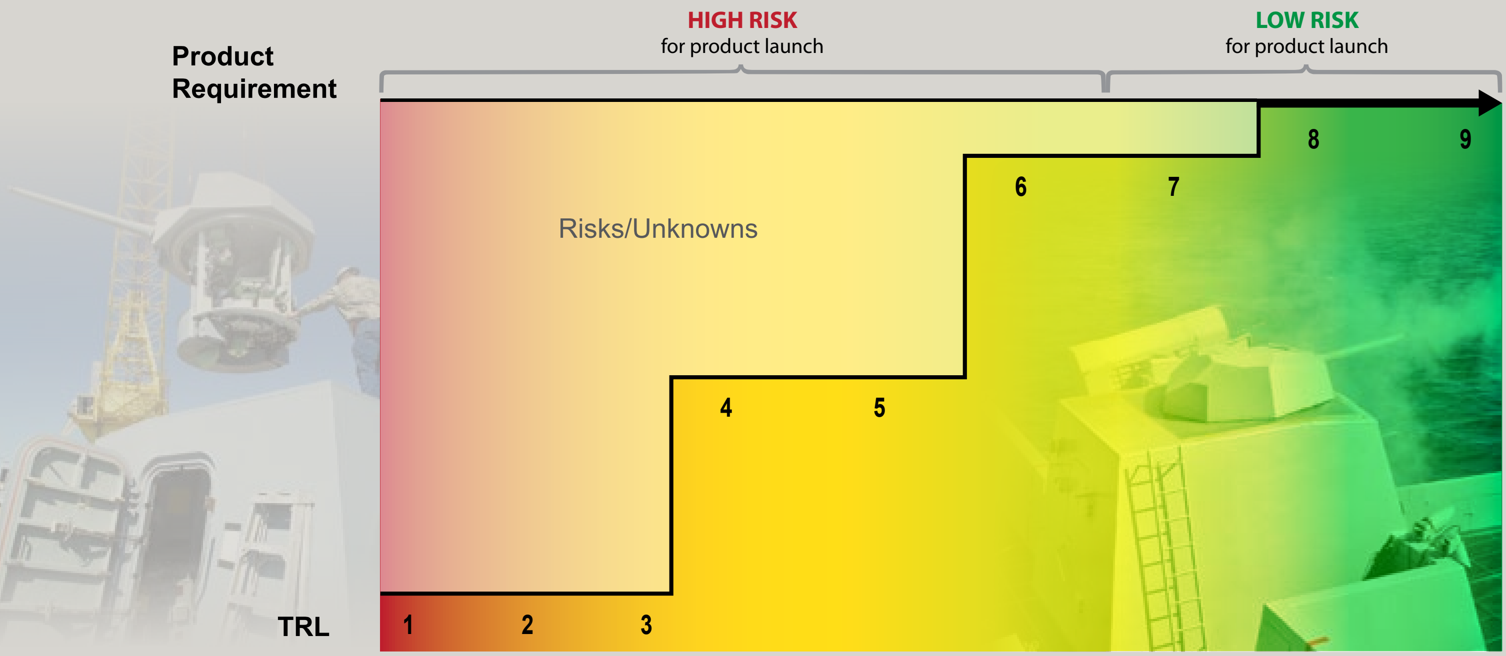


Figure 5. Programmatic Risk as a Function of Technology Readiness Level[7]

schedule growth.[5] There is a growing demand for cost analysis during the early phases of the acquisition cycle when the level of technology maturity is low. Therefore, a promising area of future research, and one that serves to provide significant dividends in the future, includes relating cost to TRL, or any of the various readiness levels, in the face of limited data (see Figure 5).

"Maturing new technology before it is included on a product is perhaps the most important determinant of the success of the eventual product—or weapon system." The GAO (1999) also encouraged the use of "a disciplined and knowledge based approach of assessing technology maturity, such as TRLs, DoD-wide (p. 7)."[6]

Types of Readiness Levels

There are multiple types of readiness levels that may be relatable to cost. Technology Readiness Level (TRL) is probably the most commonly known readiness level because it is used as the DoD standard evaluation system to categorize hardware, software or system concepts.

TRL is simply a measure of an individual technology and it does not account for readiness for use in the system context. The definition of TRL varies across the Department of Defense, Department of Homeland Security, Department of Energy, National Aeronautical Space Administration (NASA), and European Space Agency. Integration Readiness Level (IRL) is the status of the connections between the technologies. System Readiness Level (SRL) is the system-level appraisal of development maturity and is a function of IRL and SRL. Manufacturing readiness levels (MRLs) are quantitative measures used to assess the maturity of a given technology, component or system from a manufacturing perspective. Finally Cost Readiness Levels (CRLs), as used by NASA, are designed to communicate the quality of the cost product and its fitness for use.

Application to Cost

In theory, acquisition program managers generally prefer to seek technologies at TRL 6 or higher; however, in practice, this is not always possible and consequently less mature technologies are selected for development. Cost analysis and support are requested by program managers throughout all phases of the acquisition timeline. Therefore, to increase the accuracy of cost estimates early in the acquisition cycle and reduce the variance of the total cost estimate; further research should be conducted where cost intersects with TRL, IRL, SRL, MRL and/or CRL. Research that statistically describes the relationship between cost and the various readiness levels will enable cost analysts to reduce the variance of the total cost estimate and provide program managers with more precise cost figures upon which to base decisions.

Extension of Current Work

Limited studies, research, and databases exist on relating cost-to-readiness levels.[8] The TRL calculator, developed by the U.S. Air Force, provides a snapshot of maturity at a given point in time. The technology program management model, developed by the U.S. Army, is used to help with technology transition for program managers. In order to characterize readiness levels in terms of cost, further research must be conducted, and the notion that cost is a function of maturity and risk, transition time (duration) and acquisition phase must be tested.

Conclusion

Moving to an I&I based acquisition process has many advantages to the warfighter. The increased focus on missions allows decision makers and resource sponsors to focus limited resources on targeted improvements or acquisitions. Accurate cost estimates are the keys that unlock successful trade offs. Cost analysis from the I&I perspective presents unique challenges and opportunities. Most of the challenges arise from the breadth of platforms, systems or capabilities that may be considered for a particular mission. This necessitates a network of technical SMEs and cost analysts to cover the requisite knowledge and skills. The opportunity related to mission-focused cost analysis is the ability to efficiently characterize alternatives in order to attain the optimal benefit for the least cost. Again, this requires accurate, defendable cost estimates. Overcoming these challenges while producing accurate estimates will require some ingenuity and cost research. Fortunately, there are several promising areas of research, including messages and readiness levels, awaiting interest and resources. ⚓

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Mission Level Assessment and Evaluation:

Driving Fleet Exercises and Experimentation Based on Mission Effectiveness

By Greg McHone

Above:
Valiant Shield 2014
Joint and fleet forces rehearsed during a joint maritime exercise to achieve a desired warfighting capability.

Mission Level Assessment and Evaluation (MLA&E) is a Mission Engineering approach to an iterative fleet/acquisition capabilities-based methodology, by which operational needs are defined through warfighter-validated mission architectures that influence joint and fleet rehearsals, exercises, and experiments. MLA&E's warfighter integration intensive methodology evolves the Chief of Naval Operation's (CNO's) Integration and Interoperability (I&I) coordination with the fleet to one that is centered on warfighting capability and the technical-to-tactical excellence principle. Embedding MLA&E engineers and architects with the warfighter creates conditions for a philosophical change in evaluation, experimentation, and assessment that enables mission engineers to participate in the planning, execution, and analysis of fleet events to provide convincing evidence of warfighting capability through fleet-validated mission architectures. These validated operational-based architectures are then applied to existing programs and evolving technology to improve warfighting readiness. Under MLA&E, mission engineering starts with the desired warfighting capability, then scopes the platforms, systems, and performers necessary to achieve the desired warfighting capability.

Definition

The Vice Chief of Naval Operations (VCNO) established MLA&E activity under the I&I Charter, 19 DEC 2012. Scope, products, and resourcing of MLA&E were not yet defined in the charter, as compared to other prominent I&I activities, i.e., Warfare Capability Baseline (WCB) (weapon to target pairing kill-chain analysis) and Capability Solution Management (proposed solutions to gaps identified in kill-chain analysis). Since the early establishment of the Chief of Naval Operation's I&I initiatives, MLA&E's scope, approach, and deliverables have been vetted and refined through various fleet applications. The current version of the Integrated Capability Framework Operational Concept Document (ICF/OCD), dated 30 SEP 2013, defines MLA&E as understanding and quantifying how well a mission capability is currently achieved, and exploring, across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) spectrum, the concepts for measurable mission improvement; enabling the insertion of I&I stakeholders into Fleet Exercises and Experimentation venues; and applying the ICF/OCD to capture data needed to evolve mission performance.

MLA&E consists of applying two related activities with different applications to fleet rehearsals and exercises. The "assessment" aspect of MLA&E identifies "baseline" warfighting capability through development of "as is" mission architectures derived from fielded systems. "Evaluation" is the application of MLA&E to fleet experiments to capture future

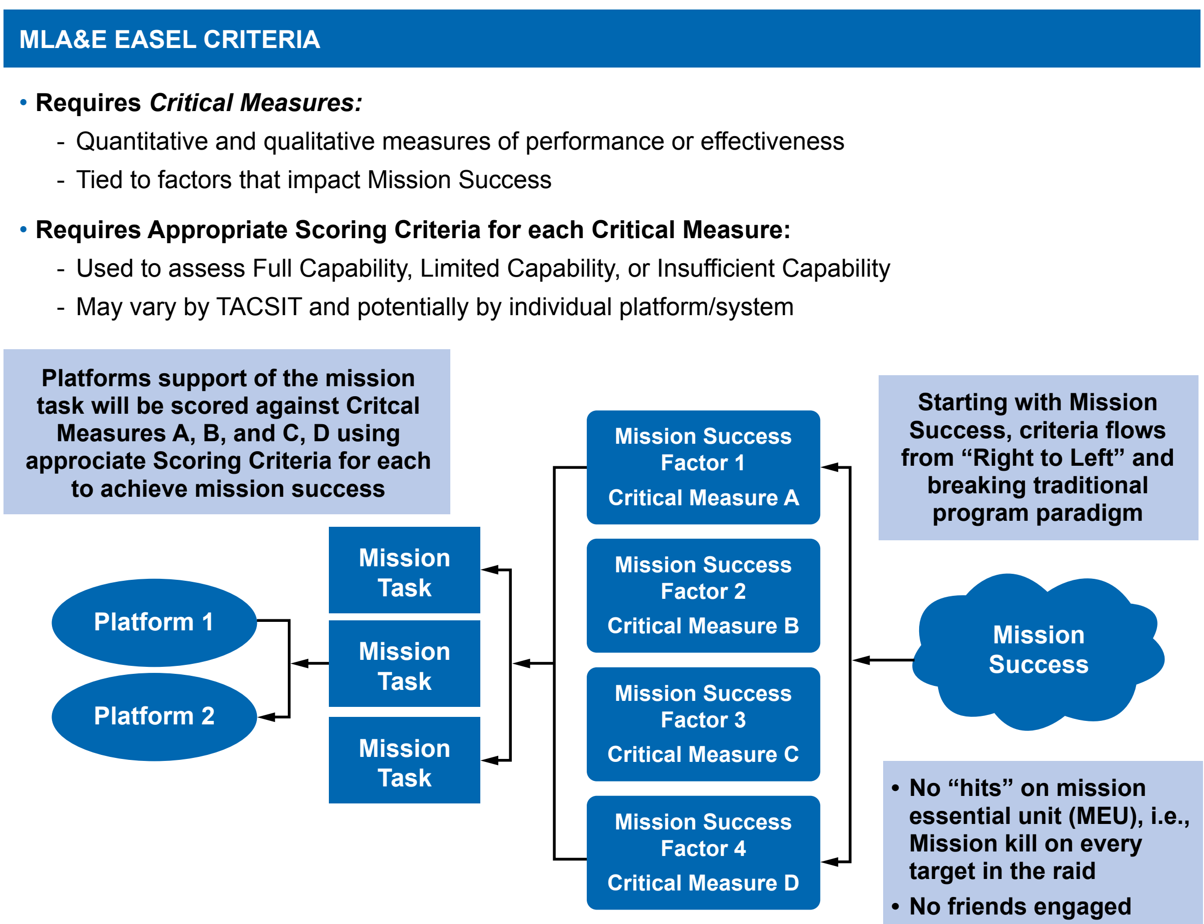


Figure 1. MLA&E Criteria

"to be" mission architectures for non-materiel and materiel modifications. Through collaborative Fleet/Engineering planning and execution processes, both assessment and evaluation applications of MLA&E have direct implications for near- to long-term holistic capability solutions that lead to improved warfighting readiness.

The MLA&E approach considers the larger I&I process, as promulgated in the VCNO's I&I Charter, to embed the ICF/OCD data model application with fleet operations and realize the potential of MLA&E with Warfare Capability Baseline's kill-chain assessments and Capability Solutions Management's Integrated Capability Package development for proposed materiel and non-materiel solutions. MLA&E fleet-endorsed mission architectures represent the Deputy Assistant Secretary of the Navy (DASN) Research, Development, Testing and Evaluation (RDT&E) efforts to understand warfighter requirements for acquisition solutions that are available to the WCB, as well as address gaps identified in Warfighting Capability Assessments (WCA) that focus engineering and architectural resources for proposed integrated materiel and non-materiel solutions. Warfighting capability is represented by "Mission Success" in Figure 1.

The DASN RDT&E resourced the initial MLA&E effort where mission engineers from all Navy Systems Commands (SYSCOMs) were to validate the ICF/OCD by applying the model to a major fleet exercise. The Fleet Experimentation Exercises and training category is one of eighteen uses defined by the ICF/OCD. Once ICF/OCD was applied, MLA&E activity was to provide feedback on the data model's utility for capturing fleet operations. To determine the best fleet operations candidate, MLA&E team reviewed a list of major exercises that provided the necessary mission area opportunities to apply ICF/OCD. Based upon concurrence from Commander, Pacific Fleet (PACFLT) Warfighting Assessment and Readiness (WAR), Valiant Shield 2012 was the major fleet venue selected for initial MLA&E application of the ICF/OCD. The discussion that follows uses Valiant Shield 2012 as a representative use case.

Valiant Shield 2012

Valiant Shield is a recurring blue-red operational and fleet exercise leveraging joint participation of across service assets to counter a notional theater threat to a strategic ally in the Pacific theater of operations. The primary mission area focus of Valiant Shield 2012 revolved around Anti-Subsurface Warfare (ASW). However, from previous Valiant Shield exercises, several capability gaps in the Anti-Surface Warfare (ASuW) domain had been identified. Through coordination with PACFLT WAR staff, the MLA&E team began executing towards modeling ASuW operations. With PACFLT WAR, and given capability gaps identified during previous Valiant Shield exercises, the MLA&E team scoped their modeling effort down to the subject of Surface Action Group (SAG) operations.

Validating the ICF/OCD by applying it to a major fleet exercise was the principal I&I objective of MLA&E for Valiant Shield 2012. To accomplish this objective, the team examined the utility of the ICF data model to support fleet analysis, assessment, and requirements definition of mission performance. Additional objectives of MLA&E for Valiant Shield were to capture mission area architecture by identifying data attributes that establish system performance requirements and constraints, develop compliant architecture for capability integration, and establish fleet user interface views to graphically represent

Valiant Shield 2012 is an integrated joint training exercise that offers the opportunity to integrate Navy, Air Force and Marine Corps forces at sea. (U.S. Navy photo by Mass Communication Specialist 3rd Class William Pittman/Released)

an applied ICF concept. The final objective was to support institutionalization of the CNO's I&I mission assessment processes by establishing MLA&E application to fleet exercises and experiments in order to explore DOTMLPF solutions that meet near- and long-term operational challenges. Embedding I&I mission engineers with fleet users to identify and articulate operational needs for Research, Development, and Acquisition was necessary to capture MLA&E impact—Integrate fleet readiness with system development and performance.

Applying MLA&E during Valiant Shield 2012 provided a full spectrum of data collection activities in compliance with the ICF data model for architecture development. ICF specifies the following data elements and their relationships:

- Authoritative warfighting capability data elements, relationships, and taxonomies
- Canonical viewpoints and models to capture mission and system/platform capability data
- Reference to authoritative guidance, standards, and sources for information
- Configuration management guidance
- Common standards for capturing and sharing framework
- System/Mission Alignment Model (relationships, mappings)

In addition, the MLA&E activities exercised new roles and responsibilities of organizations that collaborate to construct the mission model and system/platform configuration baselines for Valiant Shield. The MLA&E's capabilities-based approaches proved that opposing forces capabilities are essential in determining warfighting capability and were therefore integrated into the Valiant Shield architecture via friendly force's ability to defend and offensively engage. Opposing forces' conceivable capabilities would desire to achieve similar capabilities to those of the U.S. Navy, at least at a high level of abstraction such that tasks from the Universal Navy Task List (UNTL) may apply to both opposing forces and friendly forces. Application of ICF to MLA&E by operational and acquisition stakeholders produced a foundation on which to build and evolve ME disciplines for improving fleet readiness. For example, Valiant Shield forces executed the sinking of a target ship (SINKEX) during 2012 exercise. Under traditional methodologies, the architecture would contain weapon, platform, targeting sensor, and target for the SINKEX. During this event, MLA&E produced architecture that identified the interdependencies of all participating platforms, systems, performers, and authoritative doctrine necessary to achieve the desired effect: sinking of the target ship. Figure 2 is a photograph of weapon impact on target ship.

Figure 2. Sink Exercise (SINKEX)

Capturing fleet user perspective and determining mission area owner guiding principles were necessary to efficiently and effectively translate mission area requirements into acquisition and engineering processes. Under this principle, PACFLT WAR served as the mission area owner and provided governance over the operational data used for architectural development.

Mission Area Owner

Establishment of a "Mission Area Owner" is the keystone to MLA&E's ability to obtain fleet validated and advocated mission threads that drive capability based acquisition:

> *"Fleet ownership of mission from definition, through acquisition, to execution with ability to assess and define mission needs to acquisition community in order to ensure systems will meet full mission needs or understand and agree to limitations."*
>
> (PACFLT WAR: Valiant Shield 2012 Final Planning Conference)

Fundamental to capturing a fleet Mission Model in the ICF is the establishment of the guiding principles for mission area application. This ensures fleet and acquisition objectives and tasks stay true to agreed expectations by following clear and concise guiding principles to performing mission-level assessment processes for the application of the ICF data model to mission areas. The following are representative guiding principles of MLA&E agreed upon with PACFLT WAR in applying I&I activities to capture fleet user requirements:

- Establish continuity of ICF/OCD across near, mid, and long-term to scope acquisition decisions and DOTMLPF solutions.
- Provide convincing evidence to show operational benefit and impact.
- Establish rigorous process to model operational environment that provides consistency and is responsive to change.

- Ensure operational requirements are governed and managed by the fleet and understood by the acquisition community as a user.
- Define interaction with fleet and acquisition stakeholders, consisting of periodic reviews to ensure needs and expectations are understood.
- Allow mission architects to manage the fleet validated operational data and programs of record systems data for development of a common mission area-based architecture.

As the Mission Area Owner for Valiant Shield 2012 MLA&E, PACFLT WAR served as the Fleet Representative to the Mission Technical Baseline Authority. The Fleet Representative is the overall lead for Mission Technical Baseline development and validation, responsible for representing fleet requirements and interests, and to ensure the Mission Technical Baseline accurately reflects or adequately models operational reality (DOTMLPF). Mission Technical Baseline will be discussed in detail later in this article.

With a defined objective to generate a relationship between the fleet's desired effects and the system functions that are necessary to achieve those effects, development of a capability-based model was required to produce mission area architectures.

Capabilities-Based Modeling Methodology

The MLA&E approach to applying the ICF/OCD to produce mission architectures is captured through a capabilities-based modeling methodology. Capabilities Based Modeling Methodology enables the operational, research, and acquisition communities to interpret and decompose the Commander's guidance with consistency using the ICF data model that leads to efficient and effective mission architecture development. The MLA&E team established and followed a Capabilities Based Modeling Methodology to develop architectural products that model fleet operations starting at the fleet's desired effects. Capabilities Based Modeling Methodology focuses on capabilities rather than individual point solutions or specific mission threads; the architecture can be used as a source of mission data and activity relationships for a multitude of different mission threads. Figure 3 graphically demonstrates the roadmap followed to create fleet validated mission threads in a reusable format for engineering and system design.

The objective of Capabilities Based Modeling Methodology is to generate a relationship between the Fleet's desired effects and the system functions performed by material solutions generated by the acquisition community. Through this relationship, the fleet can clearly articulate the current state of deployed material solutions, their current assessment of system performance, and their current and future system needs as compared to particular desired effects and capabilities.

To maximize Fleet relationships and minimize impact to operational staff battle rhythm, Capabilities Based Modeling Methodology processes are integrated with existing fleet planning, assessment and analysis processes. Leveraging the efficiencies of existing fleet processes enables a more effective review of MLA&E products by operational planners. Returning to the Valiant Shield example, to ensure efficiencies optimize I&I impact, the MLA&E team integrated with exercise warfare and assessment syndicates to identify stakeholders, products and attributes. An additional tenant to this approach was to capture the existing PACFLT data collection process and compare it with I&I data, supplementing as needed to complete the architecture.

Establishing a common language between the fleet and mission engineers is essential for operational architecture (data) development. This operational/acquisition taxonomy was realized through significant warfighter integration during Valiant Shield 2012. The data required to develop Department of Defense Architecture Framework (DODAF) Data Model 2 (DM2)-compliant views is comparable to the data needed by fleet readiness planners to perform analysis, complete assessments, and generate requirements. The variation between fleet and acquisition stakeholders is the way the data is organized and viewed based on

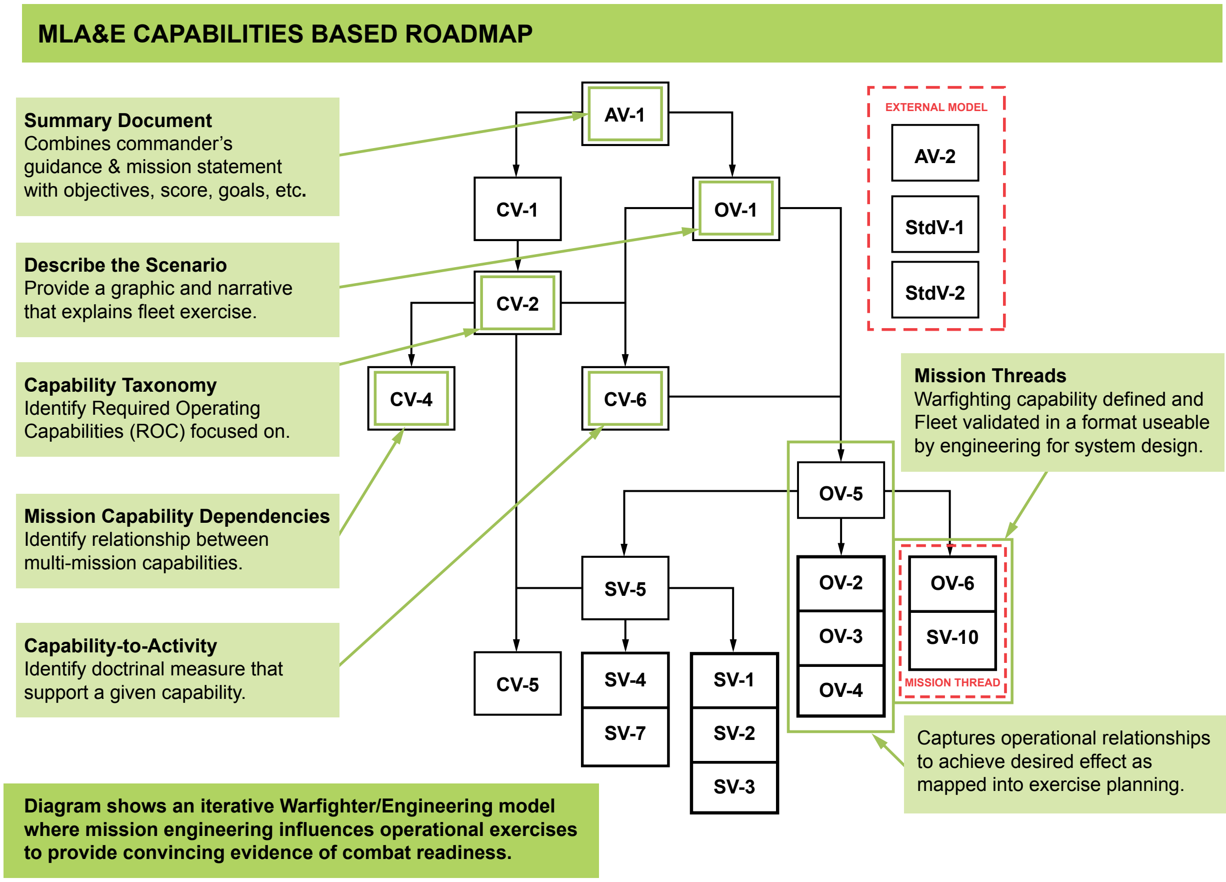


Figure 3. Capabilities Based Roadmap

unique user requirements. For example, Operational Views (OV), such as an OV-6a and OV-6c, would be viewed by fleet users as a "mission thread," that is, a snapshot in time and uniquely tailored to their data requirements. Timelines may include initial conditions that impact how each activity is performed or how well the overall mission thread is able to satisfy the overall desired effect.

Desired effects are inherently linked to a capability. Under capability-based methodology, MLA&E began by identifying the purpose, objectives, scope, hypotheses, and desired effects of the Fleet and then derived from them the capabilities required to achieve mission success. Through a collaborative fleet/mission engineer effort, the AV-1 therefore evolved into Commander's Guidance and Intent for the I&I activities during Valiant Shield. Collaborative AV-1 provided a common reference document to influence the schedule of events planning that supports achievement of overall assessment and acquisition objectives through the development of capabilities-based architecture. As such, the principal product from MLA&E efforts are mission-based architectures created using a capabilities based modeling that reflects overall warfighting readiness against a defined threat.

Mission Technical Baseline Architecture

Mission Technical Baseline (MTB) architecture development of mission threads has evolved to become the principal product for MLA&E related I&I activities. ICF MTB data elements and products capture operational requirements and identify required capabilities at the mission task and interface level that provides a top level Mission Area and Navy Tactical Tasks (NTA)-based task organization that provides a common operational framework for Navy I&I activities. This decomposition provides a mechanism to discover and define needed systems and platforms interfaces and behavior required to support end-to-end mission capability. MLA&E is the foundation for evolving mission engineering disciplines for improving warfighting readiness that provide the vehicle for developing mission architectures that support fleet and acquisition users. There are varying states and uses for an MTB that is determined by multiple stakeholders and their application of the data for specific products. Representative examples of MTB from MLA&E application include:

- Snapshot of a specific instance assessment of deployed warfighting capability
- Reference that baselines applicability to programs and Navy-wide deployed systems
- Excursion derived from experimentation to influence research

Snapshot MTB of deployed mission architecture is developed to support fleet analysis, assessment, and requirements generation of existing warfighting capability. Mission architecture is derived from defined mission objectives and effects, and deployed Joint and Navy assets operating under theater-defined doctrine to rehearse the ability to effectively execute operational and contingency plans. These mission effects are mapped up to authoritative mission capabilities, i.e., Joint Capability Areas (JCA), Required Operational Capabilities (ROC) and Projected Operational Environment (POE), Universal Naval Task List (UNTL), Navy Mission Essential Task List (NMETL), and down to platforms and systems that support achievement of those effects. Valiant Shield 2012 represents a specific instance of Mission Technical Baseline development that supports baseline assessment of deployed warfighting capability. MLA&E mission engineers provided mission threads developed from MTB to PACFLT WAR Data Analysis Working Group (DAWG) to provide convincing evidence of mission effectiveness for ASuW mission area. Theater-specific Mission Technical Baseline that supports assessment of warfighting capability is made available to the development and validation of "reference" architectures. Deployed and reference baseline MTBs are system agnostic as to how missions will be conducted.

Reference MTBs are "top-down" derived from authoritative mission capability requirements, i.e., JCA, ROC, UNTL, and NMETL. This differs from snapshot MTB in that a specific theater operational commander's desired effects are the starting point and core of the mission thread. Reference MTB serves to align authoritative mission capability requirements with fielded systems and systems under development to better inform current acquisition processes and demonstrate applicability to improving warfighting readiness. Reference MTBs are consistent with approved concepts of employment used to provide more informed input to the Joint Capabilities Integrated Development System (JCIDS) and the Planning, Programming, Budgeting and Execution (PPB&E) processes. Offensive Anti-Surface Warfare (OASuW) Alternative of Analysis (AOA) used MTB derived from Valiant Shield snapshot mission threads to better understand fleet Long Range Anti-Ship Cruise Missile (ASCM) employment conditions that impact acquisition decisions.

Excursions from baseline and snapshot MTBs are made to use authoritative "as is" architectures to drive experimentation. Excursion MTB captures experimentation data for "to be," or proposed warfighting capability to influence research, and technology and doctrine maturation. Excursion MTB MLA&E processes are embedded with Fleet Exercise and Experimentation working groups to refine mission level performance metrics and requirements for systems/platforms that are measurable and testable within a mission capability framework before entering a formal acquisition program. In conjunction with Naval Warfare Doctrine Command (NWDC) and PACFLT WAR, MLA&E processes are applied to ongoing fleet exercises to gain further insights and to verify the methodology with the fleet in order to formalize ICF data model application to at-sea experimentation.

The Reference MTB provides the operational conditions and desired warfighting capability to the Integrated Capability Technical Baseline (ICTB). The ICTB compares different architectures by allocating a set of systems (technical) that implement the reference architecture and execute the architecture to generate metrics that quantify the quality of the specific architecture. Sometimes an implementation of an MTB will modify workflows at both the operational activity sequence and functional activity sequence levels. Both snapshot and reference MTBs are useful for the development of an ICTB. Leveraging snapshot and reference mission architectures for Anti-Surface Warfare from Valiant Shield 2012, an ICTB was created to support the Littoral Combat Ship (LCS) Surface Module for Fast In-Shore Attack Craft (FIAC) mission that tied platform activities to fleet-validated mission thread during the Harry S. Truman Strike Group's Sustainment Exercise.

Benefits of MTB expand to both fleet and SYSCOM organizations and work towards improving Navy acquisitions by producing better material solutions, and identifying when non-material solutions are factors to current or future capability gaps. Execution of the MTB allowed the MLA&E team to identify a coherent, fleet-endorsed approach to modeling operations that starts with capabilities and seeks to draw a connection between fleet desired effects and system performance. Participation in fleet events, as with Valiant Shield 2012, allowed the MLA&E's mission engineering team to apply the ICF/OCD to an at-sea naval exercise and gain endorsement by Fleet advocates for the MLA&E process. The coordination between SYSCOMs and fleet organizations ensured that mission architecture products contain the appropriate scope and balance of activities necessary to accurately model end-to-end mission capabilities. Figure 4 depicts how system functions and required operational capabilities are related through an MTB created using a capability based model.

MLA&E is a DASN RDT&E initiative that is complementary to other I&I activities, while using a more

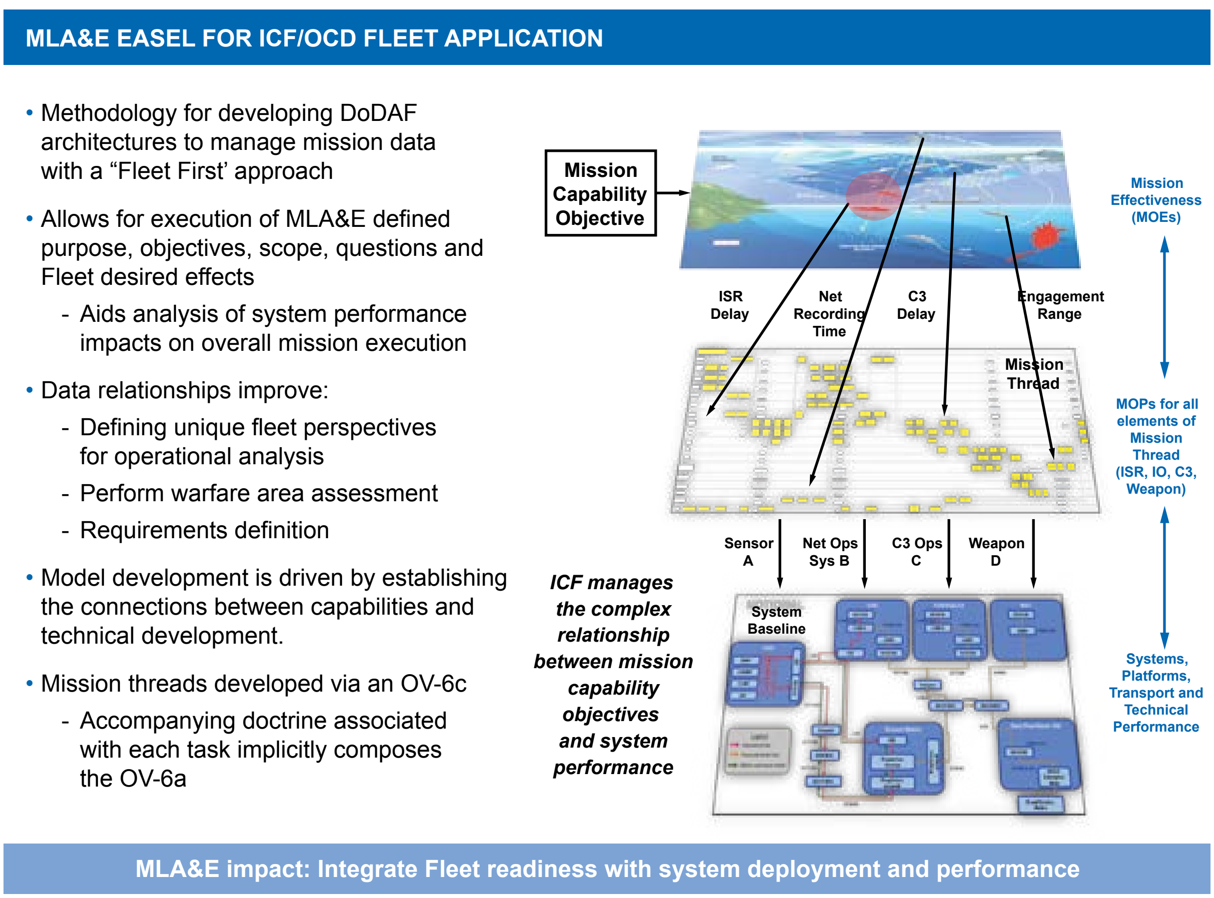


Figure 4. Capabilities Based Mission Model Transition

operational perspective that is more closely tied to fleet activities and understanding of warfighter needs. The DASN RDT&E's objective is to institutionalize and transition MLA&E processes to various fleet and acquisition stakeholders. Using Valiant Shield 2014 as the test bed, RDT&E is partnering with PACFLT WAR and other fleet readiness and experimentation commands, along with acquisition sponsors, Program Executive Offices, and SYSCOMs to assess MLA&E impact on overall warfighting capability. Participating organizations have unique objectives, from applying MLA&E processes to better inform and improve existing processes for improving warfighting readiness through a common data model for analysis, assessment, operational, and sponsored requirements generation, and system design considerations.

PACFLT WAR embedded the MLA&E engineers and architects with Valiant Shield Warfare Assessment Working Groups to assist in the generation of hypotheses, objectives, and assessment criteria to influence planning and execution of fleet events. The objective is to validate that Mission Technical Baseline architectures created during fleet assessment events will better inform analysis and requirements generation that leads to improved near-term warfighting readiness. Additionally, PACFLT WAR has endorsed MLA&E support for experimentation during Valiant Shield to determine how best to apply ICF/OCD data model to long-term assessment of warfighting capability.

The MLA&E team embedded with Valiant Shield Experimentation Working Group to leverage ASuW snapshot and reference Mission Technical Baselines for Long Range SAG Takedown excursion architecture development. This effort evolves MLA&E baseline "assessment" during Valiant Shield 2012 to "evaluation" through excursion architecture. MLA&E, an NWDC sponsored initiative, will serve as the model for linking multiple ASuW experiments during Valiant Shield. MLA&E initiative is the umbrella for separate Find, Fix, Finish, and Engage experiments for an end-to-end kill-chain experiment. NWDC is assessing the viability of MLA&E processes and ICF/OCD data model for improving fleet experimentation.

Leveraging Valiant Shield 2014, a collaborative MLA&E and Naval Ordnance Safety and Security Activity (NOSSA) Weapon System Explosives Safety Review Board (WSESRB) team was established to identify safety and fratricide risks in the effective execution of fleet mission threads. This team, in support of DASN RDT&E will document a process that will integrate weapons safety engineering into Mission Engineering and document gaps in acquisition personnel, policy, and processes. Focus of MLA&E effort is on integrating Mission Engineering, Systems Engineering, and Software Systems Safety Engineering into the VCNO's I&I Activity and system of system reviews utilizing the standing WSESRB processes. Integration effort will discover and document how best to review and assess the I&I characteristics of weaponized systems to understand safety risks, identify hazards and causal factors, assess mitigations, assess test and validation, and issue I&I Safety Findings or Actions to applicable programs under WSESRB review. Focus will be on fleet weapon systems, combat systems, and the respective network interfaces associated with fratricide. The overall objective is to apply MLA&E to further enable the institution of Mission-Level Engineering and I&I efforts in support of ASN RD&A's strategic goals of fleet safety.

Commander, U.S. Fleet Forces N7 (Training) sponsored MLA&E support of Commander, Strike Forces Training Atlantic (CSFTL) assessors to identify improvements in data collection and analysis during fleet certification events, specifically, Composite Unit Training Exercises (COMPTUEX). Fleet Training and Readiness processes employ a NMETL mapped to specific Navy mission areas (capabilities) in a continuous improvement process called the Navy Warfare Training System. The owners of NMETLs use feedback from exercises, operations, and other events to improve how they articulate requirements, measure performance, certify readiness, and implement improvements. Effort to date has focused on FIAC defense during Harry S. Truman and George H.W. Bush Strike Groups' Sustainment Exercises (SUSTEX) and COMPTUEX. It is expected that MLA&E application of the ICF/OCD data model will lead to better defined measures of effectiveness that lead to advanced levels of fleet readiness.

A key acquisition stakeholder from programs of record leveraging MLA&E's Warfighter Integration is Program Executive Office for Integrated Weapon Systems (PEO-IWS). In conjunction with MLA&E, PEO-IWS is sponsoring Mission Technical Baseline development during Valiant Shield to produce an Integrated Capability Technical Baseline for Aegis Capability Baselines Surface Warfare mission area. Other acquisition stakeholders are Naval Sea Systems (NAVSEA) PEO-LCS for Surface and Mine Warfare Modules, Naval Air Systems (NAVAIR) Program Office for OASuW and Tomahawk Weapons Systems, thereby ensuring a broad understanding of operational needs by the acquisition community.

Conclusion

DASN RDT&E resources and MLA&E's warfighter integration efforts to transition technical solutions to tactical capabilities create conditions for a philosophical change in evaluation, experimentation, and assessment that enable mission engineers to participate in the planning, execution, and analysis of fleet events to provide convincing evidence of warfighting capability through fleet-validated Mission Technical Baselines. These validated operational-based architectures are then applied to doctrine, existing programs, and evolving technology to improve warfighting readiness. Validation and transition of MLA&E processes and products with acquisition and fleet stakeholders institutionalizes Integration and Interoperability activities with existing operational readiness improvement processes. ⚓

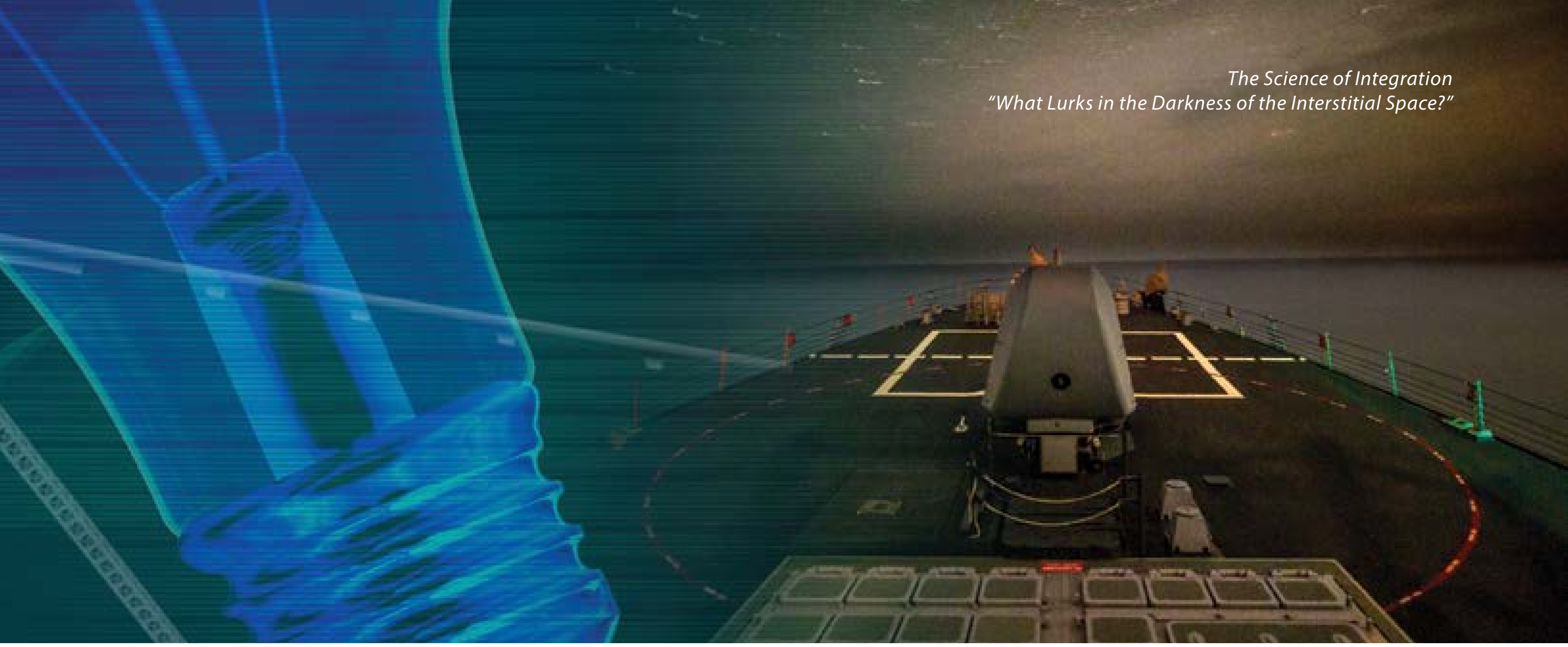
The Science of Integration

"What Lurks in the Darkness of the Interstitial Space?"

By Neil Baron

Neil T. Baron
Distinguished Scientist for Combat Control
Naval Sea Systems Command

Naval warfare and the warship have evolved out of necessity, human intellect, and technology to equitably compare with many other large complex machine developments of humanity, such as vehicles for manned space flight and exploratory devices such as subatomic particle accelerators. Developments demand the highest levels of integration. Investments are large, time scales are long, technical complexity is at an extreme, and constancy of purpose is continually challenged. Although visions are great, success in such large, complex, and highly integrated technical endeavors is rare. It is not enough merely to will it to happen. Success demands a holistic systems focus with the right tools and techniques to allow the best and brightest minds to see into the darkness of the unknown, to envision what could be from what is, to synergize and to maintain dedication from the initial vision until the very different realization of the machine at delivery.



Integration

Navies are unique in that they represent a nation's significant capital investment due to the size and complexity of the machines (ships) utilized for combat. The architecting and engineering of machines of war demand the highest technical scrutiny during development to integrate the known, to invent the unknown, and to hold the public trust during the lengthy acquisition process, thus assuring the warfighter and the taxpayer that the best will be delivered in the end. The design of the naval warship and its role in the highly distributed nature of modern naval surface warfare, like other highly complex modern machines of today, requires striking a delicate balance among the domains of people, process, hardware, and software that when integrated successfully makes the holistic system perform. A primary role of the systems integrator is to bring such diverse domains together successfully, monitor their evolutionary progress, and reach an optimized balance between what is usually conflicting demands. Such domains are not naturally predisposed to interact successfully without a significant amount of engineering due diligence. Hidden flaws and faults, or even over reliance, in any one of the domains can lead to overall system failure.

The Navy laboratory structure, being able to execute the inherently governmental technical tasks, holds the kernel of necessary talent to technically succeed in such large scale complex systems engineering endeavors where flaw and failure lurk around every corner. The British researchers, Prencipe, Davies, and Hobday (2003) of the University of Sussex, address the many facets of successful engineering at the large complex system of systems level in their book, *The Business of Systems Integration*:[1]

> *The early phases of design require the communication of a vision for how the system should operate at the highest level, and then communicating the many visions of the lower level components among those that must ultimately integrate them together. When the visions become artefacts, any communication problems or just simple errors made in the design become obvious once those artefacts are connected to each other. All of the information that the designers used, either implicitly or explicitly, in the creation of the artefact become elements of that artefact. Unlike humans, who might not recognize the implications of lack of information or wrong information, the artefacts interact with each other the moment they are connected and operated together. This is why systems integration is the ultimate point at which social misunderstandings become manifest.*

This article explores a technique for the systems integrator to better define and manage the highly complex nature of system to system dynamics, a critical element of engineering the system of systems that comprise modern naval warfare. This will be critical if the complexity of the overall machine is

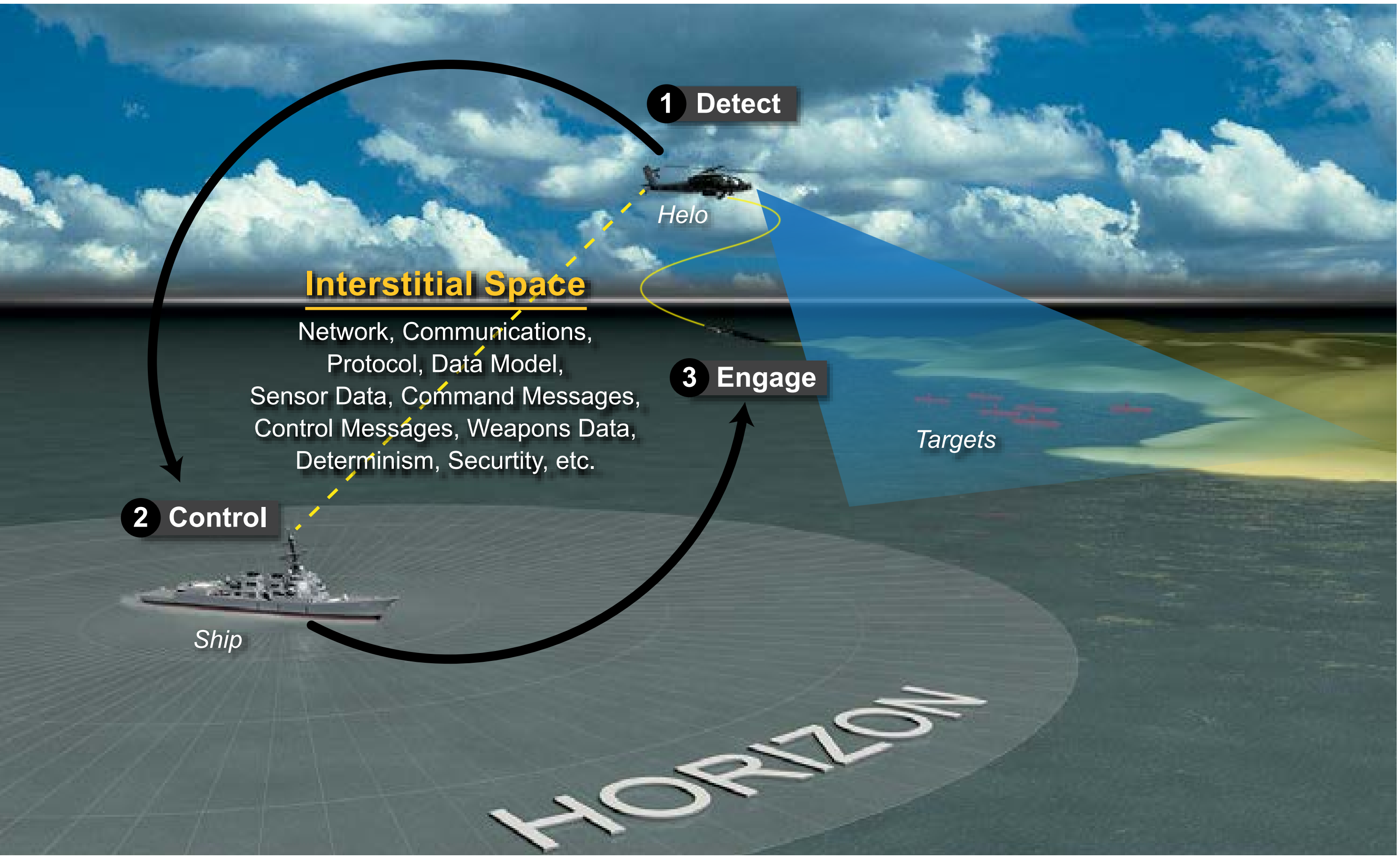


Figure 1. Focusing on the Interstitial Space

to be managed effectively and the desired system behaviors are to be realized and available on demand.

Integration: A Surface Warfare Example

Let's illustrate the concept of integration through a simplified Naval Surface Warfare example. The radar and optical sensors of a surface combatant are challenged to see surface contacts over the horizon resulting in a limited operational picture for combat command and control. Utilizing a helicopter to extend the range of the surface combatant's operational picture over the horizon is one option. The helicopter, if integrated with the surface combatant, could be used to identify, and if necessary, engage hostile targets at greater distances from own ship thus increasing effective battle space. With surface warfare engagement control resident on the ship and an airborne sensor feed and weapon on the helicopter, integrating the two platforms into a new expanded surface warfare capability is conceivable. See Figure 1. Integration would require the filling of the interstitial space between the two platforms to achieve the desired system of systems behavior and control. The two platforms would perform as one integrated system of systems to complete the mission.

Integration: Focusing on the Interstitial Space

Using the term "interstitial" helps differentiate and focus on the dimension between two objects that interact from the more traditional focus on the objects themselves. The subtle but key shift in concentrating on the interstitial from the physical enables the engineer to focus on the dimension of design where the interaction is housed and exercised. Simply put, this is where integration happens. The interstitial space, from classical use, is loosely defined as a gap between spaces full of structure or matter. It is usually thought of with physical properties such as an area, volume or space between two objects. For example, between the wheels and the engine of a car there is a transmission, drive shaft, a differential and an axle. These objects fill the interstitial space between the wheels and the engine to mechanically enable the function of powered mobility.

More generally, and even more interesting to the system of systems integrator, is to envision the interstitial space as simply the domain that enables key elements of behavior between two objects that have the potential to interact for some higher purpose. In this more general definition, the functional and logical interactions between geographically disparate objects can have their interstitial relationships filled with information-based technologies such as computer-based networks (both wired and wireless), protocols, data models, command signals, etc. In our surface warfare example, it is a data link and a set of data protocols with warfighting command functionality between a surface combatant and an off-board helicopter that realizes a ship controlled and helicopter executed surface warfare engagement.

The systems engineering of complex machines has contributed to huge intellectual leaps in understanding the physical interaction of things from the molecular level of atomic particle physics to the celestial level of astrophysics. On a more practical level, systems engineering has lead the technical advancement of machines to ease the human condition. The system of systems integrator must equally master the non-physical interfaces between systems and platforms that serve to establish functional and logical relationships between devices. Synchronizing, monitoring, and managing the behaviors of multiple systems to achieve a larger goal are usually the duties of the control system. The control system seeks to establish the physical, functional, and logical relationships that are realized through the interstitial space between system elements so they can behave as an integrated unit. System engineers need insights into the functional and logical dynamics of the interstitial space just as they currently enjoy today with technical insight into the physical dynamics.

Having a Model

Delving deeper into the interstitial space, some key models are presented below to describe the context around system integration and the interstitial space.

Physical, Functional, and Logical

There are three dimensions one must fully consider when integrating: the physical, the functional, and the logical. The physical dimension of integration is well understood. For thousands of years, it was the only form of integration that took place. With the modern digital age of electronics, communications, and the embedded computer, we are now witness to the significance of the other two dimensions of this model. The functional dimension, an intellectual construct to describe relationships, is characterized through the activity, purpose or task of the system or subsystem and how the system works or operates to perform that purpose. Likewise, the logical dimension is more traditionally defined as the networking topology that defines the architecture of the communications between the subsystems. System of systems integrators interested in focusing on the interstitial space will spend most of their efforts on the functional and logical dimensions of the design. The two examples in Table 1 illustrate this. The first row is a non-military, non-system example of this model applied to the development of a piece of literature. The second example is Navy-specific.

PHYSICAL	FUNCTIONAL	LOGICAL
Book, Chapter, Paragraph	Information, Entertainment, Expansion and Promotion of Thought, Reference, etc.	Theme, Story, Characters, etc
Ship, Combat System, Missile	Mobility, Command & Control, Weapons Control, etc.	Communication Links, Protocols, Signal Timing, etc.

Table 1. Dimensions of System Integration and the Interstitial Space

Warfighting Model

Another key model we rely on to describe the functional relationships of warfare is the warfighting model sequence of Plan, Detect, Control, Engage, and Assess. This terminology varies within and across the service cultures (Army, Navy, Air Force, Marine Corps), but each variation attempts to accomplish the same functional result in a similar sequence of activities.

A kill chain, or more generically, a mission thread, is a specific example of the warfighting model utilizing specific systems to perform the desired functions within the context of an operational scenario. A kill chain can be very local e.g., a Marine with a machine gun engaging an enemy combatant or very global with a multi-service system of systems ballistic missile defense capability defending a nation. Since each of these general functions may be performed by many systems and subsystems, with personnel trained and optimized to perform against threats, the precision of the interplay across the kill chain (through the interstitial space) is critical to a successful warfighting outcome. The role of the integrator is to understand, characterize, and discretely specify the necessary relationships between the systems and people to achieve the desired global behavior for the overall kill chain. Insight into how well the integrator is achieving the goals of system behavior management/control is "hiding" in the interstitial space between the systems.

Next, we will take a look at a tool to help the integrator see into the darkness of the interstitial space and bring to light, through measurement, how well the integration is maturing during system design, development, testing, and delivery.

Integration Readiness Level (IRL)

The establishment and use of "readiness levels" as a tool for the systems engineer to characterize the evolutionary maturity of a specific dimension of system design has been around for decades. Large-scale projects have found utility with the use of readiness levels as a way to simply convey to stakeholders where a specific design dimension of interest is in its evolutionary development. NASA is credited in the 1970's with the creation of the Technology Readiness Level (TRL) as the first of a series of readiness level indicators. The Department of Defense (DoD) has since codified the use and utility of the TRL in acquisition policy and instruction across the services. Technology readiness, as its name implies, tends to focus on the physical instantiation of the system under development. As such, TRL focuses on "the box." This works well for the physical dimension of integration but does little to provide insight into the functional and logical dimensions of the overall system, especially in a system of systems context. Since the integrator is equally as interested in what goes on between the boxes (the interstitial space) to achieve the local and global behaviors of the system, a new readiness level, the Integration Readiness Level (IRL), has been postulated to specifically focus on the interstitial space and work in concert with the TRL.

IRL Definition

The IRL follows the same readiness model structure as the TRL, which makes it easier for the technical and acquisition communities to use and understand. An IRL 1-9 level (1-lowest, 9-highest) numerical designation is assigned to a system at a specific point in time during its development to characterize the state of the integration that is resident in the interstitials of the system (see Figure 2). IRL levels 1-3 are the realization of an interface between two systems, much like the TRL levels 1-3 are the initial discovery and analysis levels for a technology. IRL levels 4-6 are higher levels of integration and control between two systems, much like the TRL levels 4-6 are the physical realization of the technology in a laboratory environment. Finally, IRL and TRL levels 7-9 are the demonstration and validation stages in ever more representative operational environments.

IRL Use and Utility

The vast majority of modern system developments rarely get past IRL level 3. For stand-alone or self-contained systems, this may be adequate. But in an increasingly interconnected world, where "The Internet of Everything" is a term bantered about and

READINESS LEVELS

TECHNOLOGY READINESS LEVELS — TECHNOLOGY — ELEMENT | INTEGRATION — INTERFACE — INTEGRATION READINESS LEVELS

TRL	Definition	Technology	Integration	IRL	Definition
9	Actual system "flight proven" through successful mission operations.	Demonstrate	Demonstrate	9	Integrated is **Mission Proven** through successful mission operations.
8	Actual system completed and "flight qualified" through test and demonstration.	Demonstrate	Demonstrate	8	Actual integration completed and **Mission Qualified** through test and demonstration in the system environment.
7	System prototype demonstration in	Demonstrate	Demonstrate	7	The integration of technologies has been **Verified and Validated** with sufficient details to be actionable.
6	System/subsystem model or prototype demonstration in a relevant environment.	Build	Integrate	6	The integrating technologies can **Accept, Translate, and Structure Information** for its intended application.
5	Component and/or breadboard validation in relevant environment.	Build	Integrate	5	There is sufficient **Control** between technologies necessary to establish, manage, and terminate the integration.
4	Component and/or breadboard validation in laboratory environment.	Build	Integrate	4	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Discover	Interface	3	There is **Compatibility** (i.e., common language) between technologies to orderly and efficiently integrate and interact.
2	Technology concept and/or application formulated.	Discover	Interface	2	There is some level of specificity to characterize the **Interaction** (i.e., ability to influence) between technologies through their interface.
1	Basic principles observed and reported.	Discover	Interface	1	An **Interface** between technologies has been identified with sufficient detail to allow characterization of the relationship.

Figure 2. Technology and Integration Readiness Levels

individual weapons may have their own Internet Protocol (IP) addresses, systems with a TRL 7 and an IRL 3 will no longer integrate well with other systems. This disconnect between the physical, functional, and logical maturity of system development has led to dissatisfied stakeholders and end users. It is seen as a failure of system integration that has manifested itself as interoperability problems in the fleet.

The upsurge of the Interoperability and Integration (I&I) pandemic we are experiencing in the fleet today has largely come about due to increased warfighting demands, and from envisioning how very expensive and individually competent weapon systems could and should operate more easily together and in new ways. The aim is to provide a force multiplier (the synergy that comes with successful system of systems realization) with little additional effort/cost by drawing out latent capabilities from our current force structure by integrating existing systems in new ways. The frustration lies in not being able to easily realize the holistic kill chain across the system of systems due to I&I problems. Today's I&I problems are recognizable through the lens of the low IRLs of the individual weapon system components we are attempting to integrate. Having an IRL designator for the interstitial space and actively analyzing and managing the IRL during system development is a first critical step to improving functional and logical integration and designing the mission rather than just delivering the boxes.

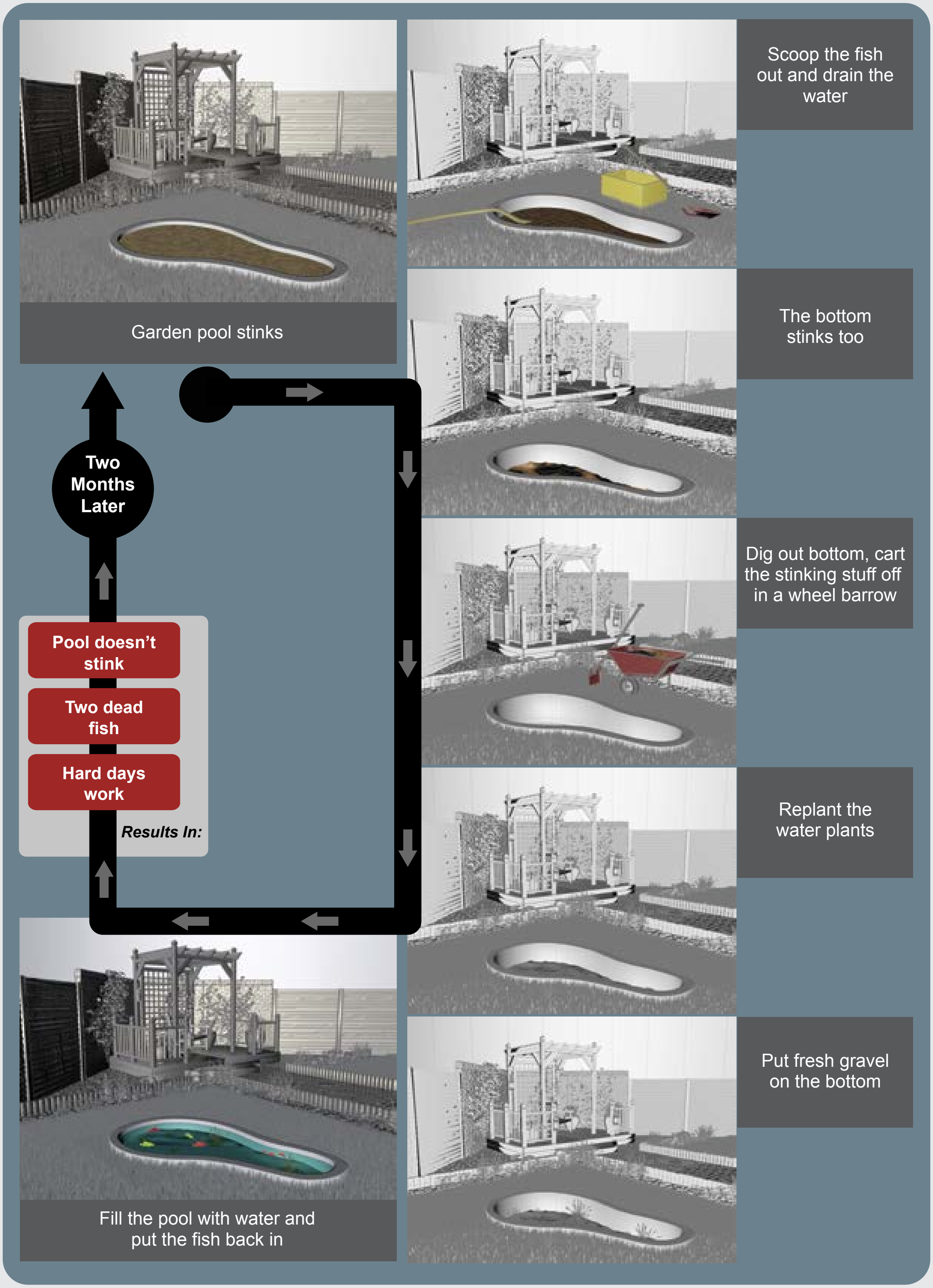


Figure 3. Stinky Garden Pool Analogy

Complexity

As we presently experience the ubiquitous nature of information technology all around us, caution is warranted regarding the understanding of and the dealing with system complexity. Large complex system of systems development does not lend itself to oversimplified serial problem solving employed by more traditional engineering and program management techniques. The interrelationships among components and subsystems are never completely known for all conditions, although they can and must be characterized for a very specific desired response, based on discrete input and controlled conditions. The richness of response that comes from interdependency and integration leads to complexity and uncertainty.

A system development program that is preoccupied with immediate goals tends to see bundles of many independent mini-systems instead of one overarching system. With a desire for simplification of understanding, the program decomposes design problems (symptoms) and the potential solutions into a discrete cause-and-effect modulus. Information overload is also a contributor. With a desire to "solve" the problem expeditiously, a minimum set of data is gathered and analyzed that can logically support a proposed plan of action. If the problems are oversimplified in a complex interdependent system and a serial symptom-solution/symptom-solution model is in place, unforeseen causal relationships can eventually undo the solution. This scheme becomes readily apparent in a simple analogy presented in Dietrich Dorner's, *The Logic of Failure* (1996),[2] where oversimplification of complex phenomena can lead to unintended consequences (see Figure 3).

Oversimplification tends to result in selecting and focusing on one variable as central (the problem), while ignoring the complex interrelationships among the multitude of interdependent variables in the system. In the above example, the contributing factors — pool depth, oxygen content and stratification, water circulation, bacteria type and metabolism — all contributed to the undesired symptom, a stinky garden pool. A simple, permanent, and much less laborious (costly) solution was available in installing a small recirculation pump to prevent the anaerobic foul smelling bacteria from forming on the bottom of the pool. Unfortunately, this option was never considered due to a serial symptom-solution mindset. It is obvious why simplification is a desired strategy for a quick solution, which appears to be much more efficient, avoids apparent unnecessary data gathering and analytical efforts, and streamlines planning. Schedule pressures and an overzealous desire to please, temporarily, are also contributing factors. The lead systems integrator of a complex system must avoid the strong tendency toward oversimplification when schedule pressures are great and technical problems are not well understood; he must seek out the often hidden root cause (stagnant water) and bring to light simple and much more effective (and permanent) solutions.

Conclusions

Mastering the discipline of integration requires taking a much harder look at the interstitial space, that gap between spaces full of structure and matter. The highly networked system of systems construct for modern naval warfare demands that the system integrator bring new light and technical discipline into the interstitial space to combat I&I deficiencies and better manage the global system behavior. One mechanism to gain vision into the darkness of the interstitial space is the use of an IRL designator to continually monitor the maturation of the system design as it relates to the key integration dimensions of functional and logical response within a kill chain or mission context. This is yet another step toward harnessing the complexity of large-scale systems design and shedding light on the potential design deficiencies that lurk in the darkness of the interstitial space. ⚓

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Capability Evolution Documents:
Managing R&D and S&T Investments to Improve Warfighting Capabilities

By Anthony Zilic

Acquisition decisions are made in the context of a complex system of systems. These decisions are driven by many different factors; threats, capability gaps, requirements, legacy architectures, measures of effectiveness and performance, business process changes, and strategic choices.

Developers currently synthesize their plans and milestones through an iterated manual process until reaching stakeholder consensus that capability, cost, performance and schedule are appropriately balanced. Articulating the vision and resulting plan to senior leadership to explain how capability matures over time is more art than craft. Imagine if your car's dashboard changed every time you turned the key, or worse, every time you looked down to check your speed. Providing a common holistic view of how drivers influence technology and how technology matures into capability is the challenge to managers, designers, scientists and engineers.

This article proposes the use of "Capabilities Evolution Documents" (CEDs) as a "common dashboard." The CED is a data-driven, high-level depiction of a mission framework, enabling capabilities, warfighting systems and supporting technologies. By exploring the foundational CED elements and the relationships across capability, technology and threshold, the reader will better understand how these documents foster improved management of the Navy's research and development and science and technology investments. Before exploring the elements of the CED, it helps to review a basic approach to Systems Engineering illustrated in the process known as the Systems Engineering "V."

The Systems Engineering "V"

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete Systems Engineering domain, including:

- Cost & Schedule
- Performance
- Manufacturing
- Test
- Training & Support
- Operations
- Disposal

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all stakeholders with the goal of providing a quality product that meets the user needs. The International Council on Systems Engineering provides resources explaining this process (http://www.incose.org/practice/whatissystemseng.aspx).

Processes have matured since the Systems Engineering discipline was recognized in the 1950's. Figure 1 depicts the modern process as applied to design and acquisition of military systems, commonly known as the System Engineering "V."

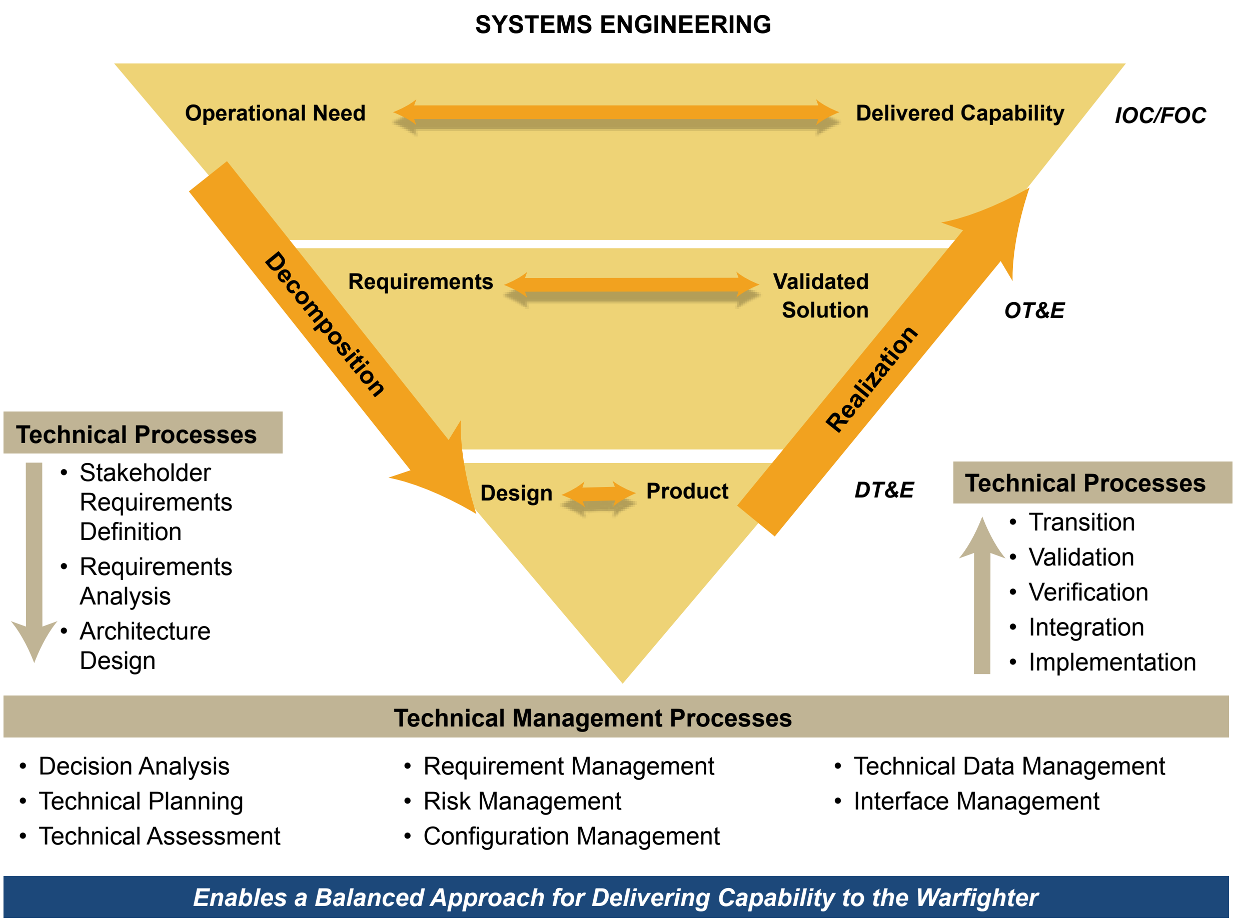

Figure 1. Systems Engineering "V"[1]

Inputs and Processes

Processes and inputs that flow down the left side of the diagram represent increasingly granular and specific statements of the user's needs. The technical processes are iteratively applied until it is possible to develop a detailed production design, test plans, and employment concepts. This activity is undertaken using well defined "Technical Processes" listed on the left side of the diagram.

Outputs and Processes

After selecting a design that best meets the requirements, tasks flow up the right side of the diagram until capability has been delivered to the warfighter. The activity progresses using well defined "Technical Processes" listed on the left side of the diagram. Both the top-down requirements flow and bottom-up capability development are governed by Technical Management Processes which, when properly applied, ensure requirements "creep" i.e., uncontrolled changes or continuous growth in a project's scope, is minimized within the context of the system design.

Introduction to the Capability Evolution Document Concept

It is easy to imagine the complexity of developing the acquisition documentation package. There is often very little detail regarding enabling science and technology (S&T). A new artifact depicting the relationship of S&T to a warfighting need is required. This artifact will articulate the total system of warfighting need to research, acquisition and fielding. The Capabilities Evolution Document (CED) is proposed as a solution to this need.

The CED in Figure 2, is a depiction of technology flowing through development and integration to meet a warfighting need over time. It is a top-down mission architecture enriched by the bottom-up, data-driven summaries of research, technology, systems, platforms, missions, and drivers. Drivers can be strategy, capability gaps, requirements, technical gaps, policy — all of which correspond to the upper left side of the System Engineering "V."

As the focus flows through Mission(s) to Capability to Systems/Components to Technology Advancements, the impact of today's research is shown to be increasing in the far term. Reversing this flow corresponds to the right side of the System Engineering "V." The relationship of solid research and/or technology development today is aligned to operational needs of the near, mid and far term, thus reinforcing research investments (Budget Activity 2 and Budget Activity 3 S&T projects) as part of the Systems Engineering processes.

Common taxonomy is a key factor of practical and usable CED's. Properly developed, sets of CED's underpinned by shared taxonomy can be analyzed across missions. This helps identify cases where technologies can contribute to multiple capabilities. For example, improved information technology has application to many DoD systems from weapons development to business office operations. Such analysis is possible if CED developers not only use the same vocabulary but also the same definitions. In later paragraphs, we explore techniques to enforce shared taxonomy across communities.

Figure 2 is an idealized CED model. In practice, the model is adaptable to incorporate only the layers needed to help "tell the story" of how user's needs guide technology advancements and system development. Other themes available in the CED are the identification of missing projects or programs from the critical path to capability development and how newly available technologies can inform system design.

"New capabilities desired by national leadership may involve modifications to kill chains, Command and Control (C2) constructs, improved coordination, and performance. These capabilities must be realized through modifications to programs of record and integration across elements of the system that have their own independent programmatic momentum. A challenge of Systems of Systems Engineering is to objectively evaluate competing solutions and assess the technical viability of trade off options." [2] Figure 3 depicts how CED's both are informed by the system engineering process and inform leadership of key relationships between capabilities and end items.

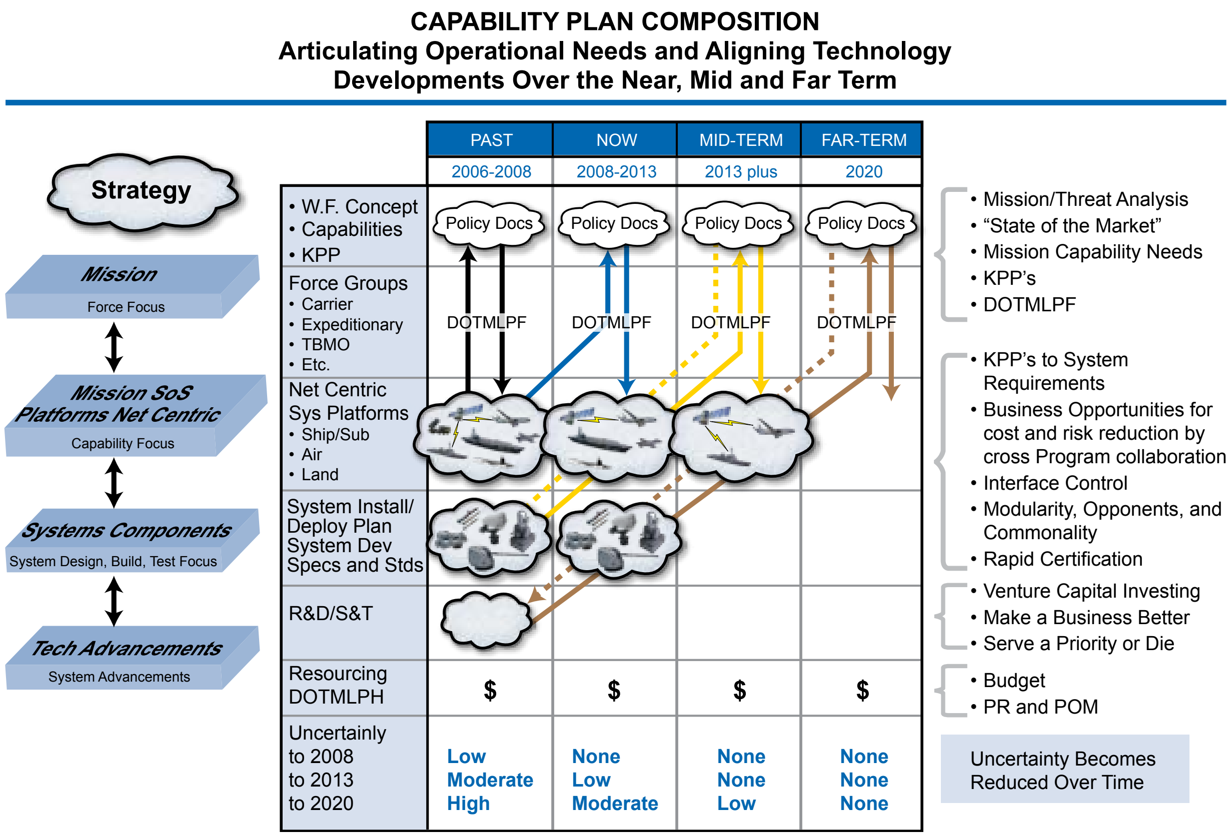

Figure 2. Conceptual CED Model

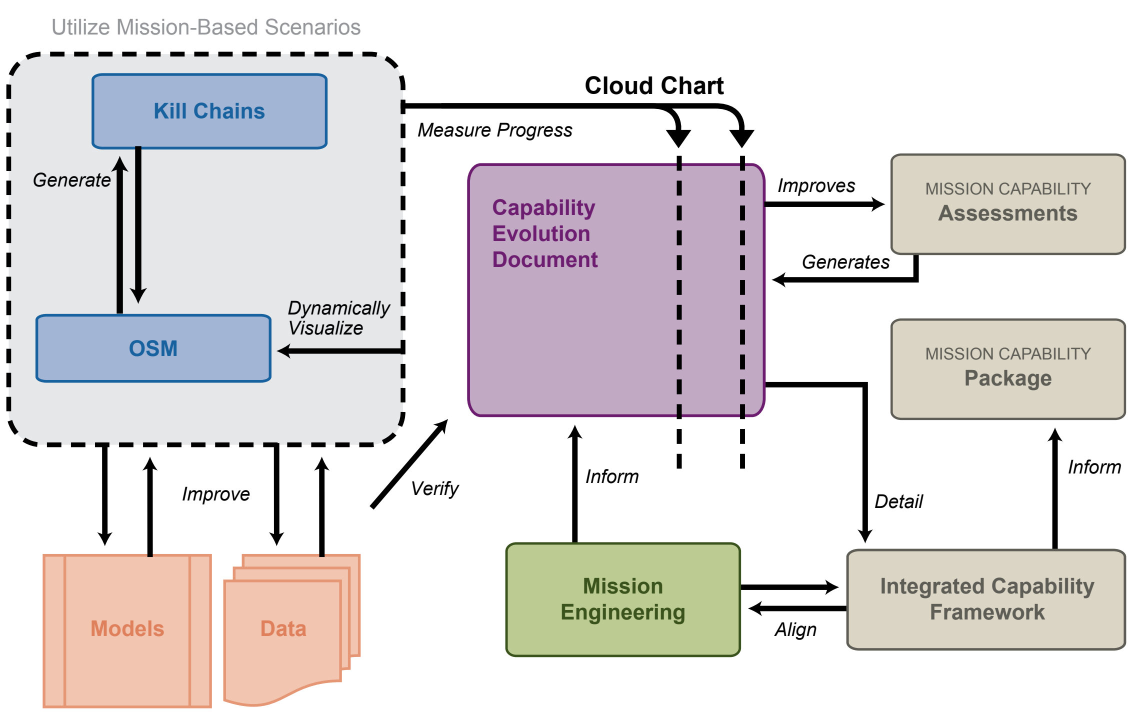

Figure 3. How Capability Evolution Documents Fit in System Engineering Process

Automation Requirements

CED generation is a multi-disciplinary participatory activity. Critical discussion among program managers, system engineers, and both technical and operational subject matter experts contributes to the CED. Figure 4 depicts the results of a work session where the interrelationships (strings) of specific developments (note cards) are worked out and understood by a set of participants. While effective, employment of this approach is not an efficient use of time in the long-term due to the maintenance demands of manually placing note cards and string on a war room wall. Also, the product is not easily reproduced or copied to other media types.

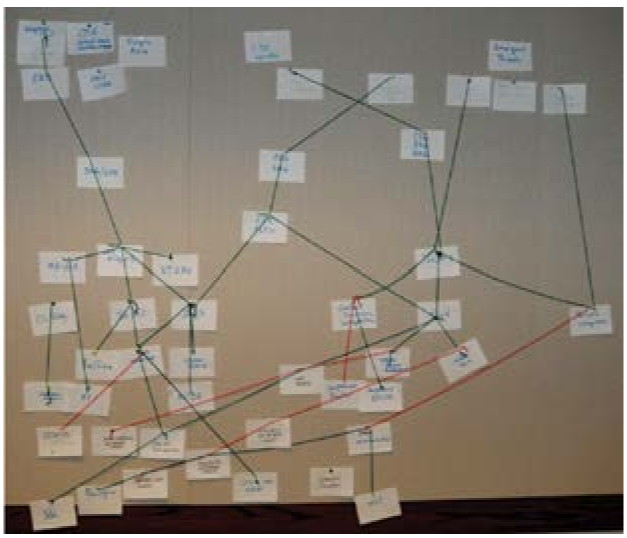

Figure 4. Manually Constructed CED

At a minimum, the tool must be able to track relationships and changes, and graphically display an entire plan for achieving an Operational Capability such that the relationship of maturity of capability and time are clearly shown. All database variables listed below must be included.

Functionally, such a tool needs to:

- Track capabilities, programs, and activities
- Manage linkage across programs and fielding process
- Provide multiple views (e.g., roll-up, timeline, functional, relational, etc.)
- Provide a flexible and extensible database
- Provide menu driven data entry capability and connection to the Integrated Digital Environment
- Track risk and dependencies
- Handle varying levels of classification
- Provide network based access

Summary

The primary goal of the CED is to develop processes and tools to manage, track, and visualize the dependencies across time from desired warfighting capability, through system development, down to foundational S&T while considering the links between the following:

- Strategy
- Mission
- Systems of Systems to perform missions
- System components
- Technological advancements and how they impact system performance
- Warfare concepts and capabilities
- Key performance parameters
- Force Structure such as Carrier Strike Groups, Expeditionary Warfare Groups and/or Tactical Ballistic Missile Defenses Groups
- Network enabled systems and platforms and how the they relate
- Systems installation and deployment plans
- Full range of RDT&E (Research, Development, Test, and Evaluation)
- Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) modifications and/or alternatives to achieving capability

The taxonomies, relationships, and tracking analysis shown in Figure 5 must be included.

Achieving this goal will ensure the application of System of Systems and Mission Engineering methodologies results in a better alignment of future RDT&E with warfighting needs. ⚓

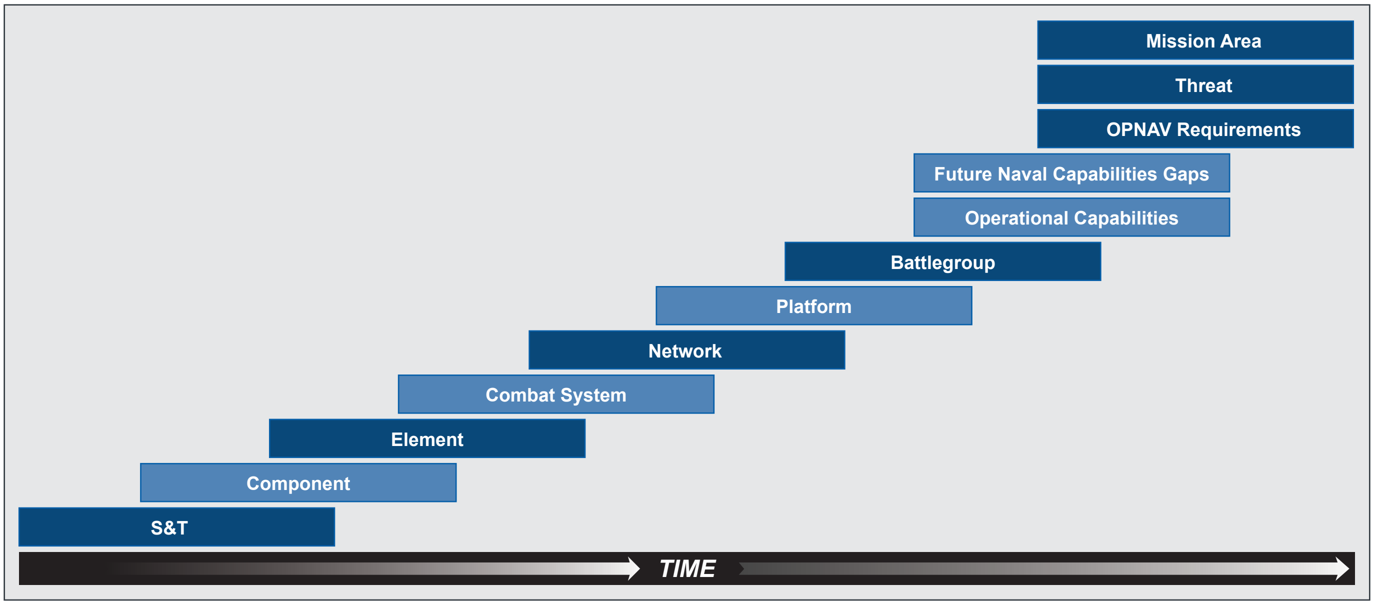

Figure 5. Taxonomies, Relationships, and Tracking Analysis Needed for CED

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Integration and Interoperability Fratricide Safety

By Peggy L. Rogers and Michael G. Zemore

When most people hear the word safety, they often consider a variety of conditions that may affect public and working class sectors. For example, safety to some would mean product safety (e.g., using products obtained as consumers), occupational safety and health (e.g., workplace hazards and health factors), personal safety (e.g., avoiding accident through precautionary actions), or safety due to environmental conditions (e.g., extreme weather). Although these are all valid considerations for the term safety, this article will address safety as an engineering discipline falling within the systems engineering arena as applied to military systems. The definition of System Safety Engineering (SSE) is *"an engineering discipline that employs specialized knowledge and skills in applying scientific and engineering principles, criteria, and techniques to identify hazards and then to eliminate the hazards or reduce the associated risks when the hazards cannot be eliminated."*[1] In other words, an SSE expert actively studies requirements and design proposals to recommend alternatives that will lower the risk of accidents for the life of the system. That would include accidents associated with designing, producing, handling, installing, testing, maintaining, operating or disposing of the system. Applying that engineering philosophy to military systems ensures our highly sophisticated combat systems, information infrastructures, and weapons remain safe pre, during, and post mission. This article will discuss the history of SSE and its transformation from single system or component focus to the collection of systems as a complex yet highly functional System of Systems (SoS). It will then consider the challenges of applying SSE to an even wider view of the mission engineering and warfighting environments deemed Integration and Interoperability (I&I). The Naval Ordnance Safety and Security Activity (NOSSA) is leading the charge in defining system safety engineering's application to I&I, terming the resulting application I&I Fratricide Safety. NOSSA has obtained the engineering support of the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), in this quest to define and apply I&I fratricide safety analysis techniques. There is a recognized critical need for an expansion in the application of SSE to widen the view of analytical assessment for systems in the real-world environments in which our military operate. The goal is to lower the risk to the warfighter and preserve valuable assets for the Department of Defense (DoD).

Background/History

The formal application of SSE principles using military standards began in the 1960's, charged by an alarming number of accidents. One such accident occurred on the carrier USS Forrestal (CVA 59), a defining example of the need for SSE and its application to weapon systems. On 29 July, 1967, USS Forrestal had several aircraft on deck preparing for flight during combat operations. Aircraft, once taxied to the runway, underwent manual procedures to electrically connect wing mounted rockets for pending missions. The procedures were performed on the runway as a safeguard to ensure any potential mishap with a rocket ignition would fire down the runway and off the bow of the ship without hitting critical ship systems or other aircraft on the flight deck. There were two independent steps for electrical connectivity—one to connect the electrical umbilical to the rocket and a second to remove the arming pin. Once completed, the pilot had control of the rockets using the fire button in the cockpit. In the case of USS Forrestal, the electrical umbilical was being connected while the aircraft was parked and before it was positioned for takeoff. This decreased the preparation time for takeoff once the plane was on the runway. It seemed acceptable at the time since any rocket activation still required the arming pin to be removed (safety barrier) and a firing signal. Unfortunately, on this particular day during pre-flight preparations, a parked aircraft with the electrical umbilical connected to a Zuni rocket fired a rocket unintentionally as the aircraft transitioned from external to internal power. Since the aircraft was parked at the time, the rocket pointed towards other aircraft on the deck. Once the rocket fired and crossed the deck, it exploded into parked aircraft causing tremendous fire and explosion. As depicted in Figure 1, the crew of USS Forrestal worked to extinguish the raging fire; 134 Sailors were lost that day.

Figure 1. Crew Members Fighting Fires Aboard USS Forrestal, 29 July 1967

The obvious question was, how did the rocket fire given the arming pin was inserted and the firing button was not engaged by the pilot? In the investigation that followed, it was determined the single act of connecting the umbilical to the rocket while parked did not cause the accident. As a matter of fact, no single action caused the accident. With the umbilical connected, the arming pin maintained electrical isolation of the rocket from the fire switch in the cockpit. The arming pin had a long tail attached to it for ease in identification and removal on the flight line. Unfortunately, it was determined the arming pin tail could catch wind and become dislodged from the socket without human intervention. On that day in July 1967, it was windy on the flight deck and that arming pin dislodged inadvertently. With the umbilical connected and the arming pin dislodged, only the fire button in the cockpit prevented inadvertent firing. There was no pilot error that caused the rocket to release. The rocket actually received an electrical signal to release as a result of final aircraft power changeover. Once the pilot appropriately transitioned the plane from external to internal power, a power spike infiltrated the circuit sending the inadvertent signal to fire the rocket. The resulting mishap was infamous, the loss of life devastating, and the need for system safety engineering evident.

System Safety Engineering

After the incident aboard USS Forrestal and other shipboard safety events, safety practitioners were embedded within design teams to bring a unique perspective to the systems engineering process, providing alternative views on the consequences of design decisions that could prove to be hazardous to the warfighter. These practitioners implemented system safety analysis techniques, many of which are used for individual systems today. The safety practitioner would concentrate on the weapon or energetic components as the designs were typically single function intent with stand-alone modes of operation. Safety techniques such as fault tree analysis, event tree analysis, sneak circuit analysis, failure modes and effects analysis, and common cause failure analysis are examples of safety analysis techniques implemented.

If one of these techniques, such as fault tree analysis, had been applied to USS Forrestal and the Zuni rocket-firing event prior to the accident, it would have identified the conditions required for rocket ignition. This would have allowed engineers to assign probability numbers to each condition to characterize and understand the potential for mishap. This, in turn, would have allowed a focused effort on mitigations to prevent probabilistic conditions that could lead to mishap. In other words, this analysis technique would likely have discovered the potential for arming pin dislodgement and power surge, increasing the potential for inadvertent rocket ignition. The analysis results would have motivated the implementation of mitigating measures to avoid the accident. The knowledge gained from the USS Forrestal accident helped institutionalize SSE and its application to individual systems. That concentrated SSE effort and the associated requirements for safety engineering evolved as numerous analysis types and techniques were developed, culminating in safer weapon systems and a series of updates to MIL-STD-882, DoD Standard Practice for System Safety.

Combat System Safety Engineering

Within the last 20 years, the portability of technology and the introduction of software, firmware, and programmable logic for major weapon system functionality have significantly influenced shipboard designs. Modern systems are now developed as multi-functional and multi-mission Combat Systems (CSs), as an arrangement of interdependent systems that are associated or connected to provide warfighting capability. It was the complex multi-functional combat system approach that posed new questions concerning safety. Given each individual system was analyzed for safety, did that truly characterize the risks of all systems interacting as a collective combat system? The answer was no, and the system safety engineering discipline was challenged to define and execute safety programs that encompassed the SoS

Figure 2. USS Milius (DDG 69) with Aegis Combat System Illustration

philosophy for Navy acquisition. The system safety community stepped up to the challenge by developing analytical methods and safety risk assessment techniques for collective combat systems, with NSWCDD on the leading edge. The primary objective was, and continues to be, identifying unique hazards that exist within the CS context and mitigating those hazards to prevent death, injury, and damage. The difficulty in executing CS safety programs is that systems that make up the SoS often have individual and independent Program Managers, Principals for Safety, safety analyses, engineering processes, schedule drivers, and program urgencies. Thus, understanding and characterizing all systems collectively as a CS and performing the CS safety analyses within a constructive and collaborative engineering environment is a challenge. Meeting this challenge requires employment of a safety engineering approach that was developed to include special methods, techniques, and processes while leveraging support from Navy leadership and individual programs.

The combat system level safety analysis techniques extend beyond individual system level analyses and focus heavily on shipboard operations, operational training, interfacing systems, contextual data threads, situational awareness, and complex casualty configurations. The scope of the analysis covers all systems involved in situational awareness, command, and control of the weapons on the platform. The SSE analysis techniques applied to these scalable, dynamic, SoS configurations are not necessarily different in name from single system safety efforts, but are very different in context and execution. The safety engineer must understand the workings of any given system and its contribution to the collective combat system for consideration of hazards and mishap scenarios. Therefore, the safety engineer for combat systems must be a trained expert with contextual intellect, chartered to understand and identify hazards associated with the collection of systems. Figure 2 represents the SoS context, a complex combat system aboard an Aegis destroyer, delivering Anti-Submarine Warfare,

Figure 3. Four U.S. Ships with Unique Combat Systems Within a Battle Group Interacting

Anti-Air Warfare, Surface Warfare, Strike, and Ballistic Missile Defense capabilities. In the figure, the combat system diagram illustrates the number of individual systems installed on the ship that interrelate to make up the combat system configuration.

Battle Group System Safety Engineering

Performing safety analyses and mitigating risks for a collective combat system has been an evolutionary step for the safe training and use of shipboard weapons. However, the fleet does not operate a collection of ships, often called a battle group, as isolated platforms steaming in close proximity with a hope of defending against the adversary. On the contrary, our fleet is comprised of numerous ships mixed and matched in combination and configuration to best maximize the capabilities for a given circumstance. For a battle group, situational awareness, track databases, and even weapon system engagements can be shared across multiple platforms to manage all mission objectives. In this case, the safety engineer would not focus on hard-wire interfaces between systems within a combat system configuration, but the distributive functions of situational awareness, command, and control across the battle group as illustrated in Figure 3. Much like CS safety, this introduces new challenges for the system safety engineering discipline in defining and executing safety analyses. Studies must focus on identifying and mitigating particular mishap risk scenarios that span across multiple platforms. In this case, the safety practitioner must be an expert in battle group configurations, operations, communications, and tactics. This safety expert must utilize safety artifacts and engineering analyses performed by the combat system safety teams as the functional and foundational basis for assessment, while combining that with unique skill and knowledge to understand how multiple configurations, communications and combat system operations could create hazards beyond what an individual ship would experience.

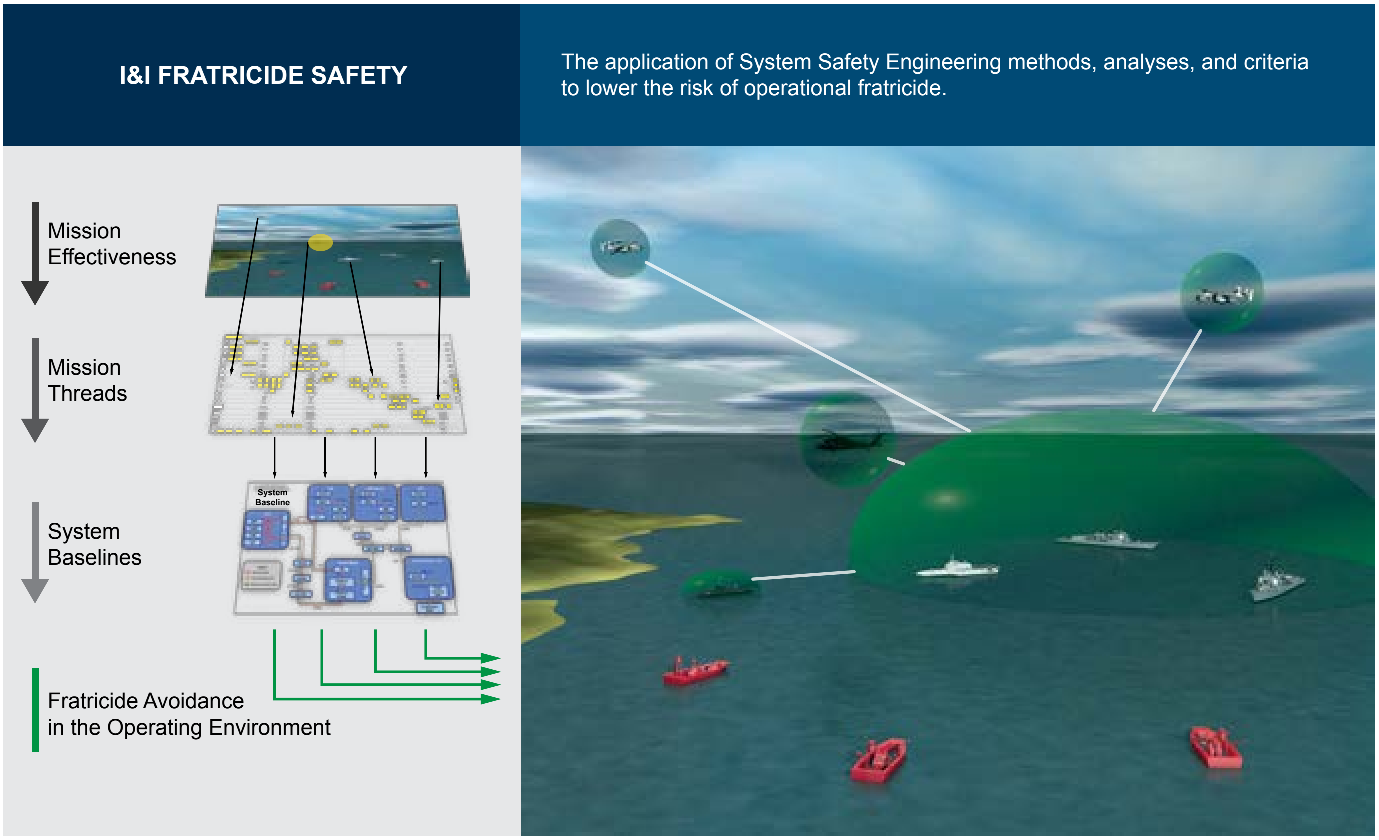

Figure 4. I&I Fratricide Safety within the Mission Engineering Construct

Integration and Interoperability Fratricide

As the evolution of naval warfighting capability continues, we are now seeing an increased focus on I&I. This includes the philosophical approach to engineering as it relates to SoS and battle groups, but extends beyond the battle group to adopt a focused approach to mission accomplishment and mission success. Utilizing this approach, every system engaged within the construct of the operational Navy can be evaluated for function, availability, operation, reliability, communication, command, and effectiveness towards the success of a mission. This approach ensures a continued focus on mission success, as opposed to early and individualized system definition that may or may not support mission success when deployed within the variety of combat system configurations. Clearly, the focus on I&I and mission success must include system safety. For any engineering effort associated with energy and the potential for injury and damage, safety and the system life cycle must be considered during the engineering phases. In this case, the safety engineering scope is centered on fratricide, described as the unintentional impact of dangerous energy to a friendly force or object.

One focus of I&I activity is to fully characterize mission effects by viewing individual systems and system performance within a defined kill chain. The focus ensures end-to-end execution for any and all of the kill chains defined. To support this activity, a structured approach has been developed to define mission models matched to supporting systems, platforms, and baselines. The alignment provides the kill chain assessment matched to warfare capability, mission threads, functional requirements, and product baselines. Although the methods, techniques, and instruments for I&I fratricide safety are not yet defined, the framework presented with the I&I activities provides an opportunity for system safety to engage in the mission engineering approach to add functional requirements to support I&I fratricide avoidance. Figure 4 provides an illustration of operational views-flowed to effects/kill chains and the technical baselines with an added objective of fratricide avoidance.

As the Navy moves forward with I&I and the inclusion of safety in the I&I fratricide avoidance initiative, the intent is for NOSSA, in collaboration with Deputy Assistant Secretary of the Navy (Research, Development, Test, and Evaluation (DASN (RDT&E)), to focus on integrating Mission Engineering, Systems Engineering, and Software Systems Safety Engineering into the I&I activity and SoS reviews utilizing the standing Weapon System Explosives Safety Review Board (WSESRB) and its current processes. The team will discover and document how best to review and assess the I&I characteristics of weaponized systems to understand safety risks, identify hazards and causal factors, assess mitigations, assess test and validations, and issue I&I Safety Findings or Actions to applicable programs under WSESRB review. Focus will be on fleet weapon systems, combat systems, and the respective network interfaces associated with fratricide. The team will characterize the materials and tools necessary to perform these tasks while providing recommended taxonomy, processes, tools, and objective quality evidence requirements for incorporation into Navy policies and guidance, Systems Engineering Technical Review (SETR) criteria, and Probability of Program Success (PoPS)/Gate Reviews. The overall objective is to apply Mission-Level Systems Engineering to further enable the institution of Mission-Level Engineering and I&I efforts in support of the Assistant Secretary of the Navy (Research, Development, and Acquisition) (ASN (RDA)) strategic goals surrounding safety within the fleet.

Conclusion

The I&I fratricide safety engineering initiative will provide valuable insight into the identification of safety risks that have not been characterized in the past. Knowledge is power, and the knowledge that is gained from this engineering initiative will provide the DoD the power to save lives, as well as provide for a more effective contributor to the mission of the warfighter. ⚓

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Admiral Bill Gortney
Commander
United States Fleet Forces Command

Introduction

The Navy must identify, correct, and work to prevent gaps between platforms, sensors, systems, and weapons that form kill chains. Integration and Interoperability (I&I) improves warfighting capability by assessing gaps between systems and platforms, and by providing gap closure recommendations across the range of Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities solutions. I&I activity also identifies barriers – breaks in the kill chain – and aligns responsible stakeholders across the naval enterprise to effectively resolve those barriers and ensure Fleet readiness. The ability to assess and obtain feedback from the warfighter through a tight technical-to-tactical linkage with scientists and engineers is foundational for this ongoing effort.

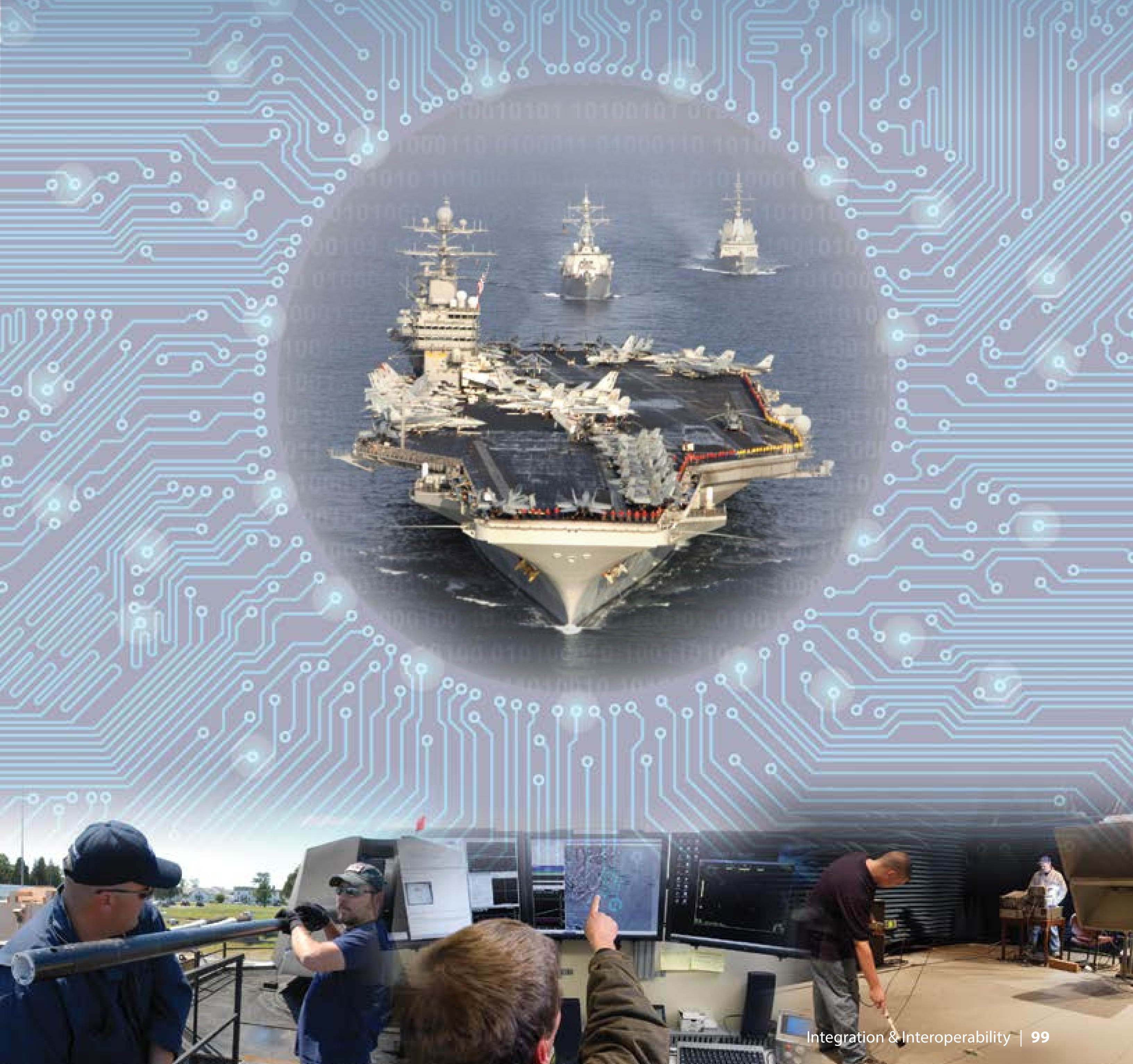
United States Fleet Forces Command contributes to the prioritization for the I&I assessment agenda to ensure the focus remains on the warfighter and commanders. The resulting I&I assessment agenda focuses on capability gaps in operational and contingency plans. This integrated approach connects input from Fleet operators to the technical community. It supports our responsibilities as the chief advocate for warfighter readiness production in the Fleet. I&I ensures that our policies, resources, and products are aligned and prioritized to deliver ready forces to the naval component and combatant commanders.

I encourage you to read and learn more about I&I in this edition of Leading Edge. Investing time and effort in I&I pays great dividends; it will contribute to a whole and ready Fleet that is capable of meeting the operational challenges of the future. ⚓

OPERATIONAL

INTEGRATION & INTEROPERABILITY

Strengthening the Technical-to-Tactical Link to Ensure Fleet Readiness



Warfare Capability Baseline:
Assessing Operational Gaps

By David A. Clawson, Sara E. Wallace, Gregory D. Little, and Keith Wheeler

Mission engineering, including the desire to predict and assess the warfighting capability of the Navy, is nothing new. Analysts in the private and public sectors have supported warfighting capability assessment for years. Most studies have relied on subject-matter experts and the use of modeling and simulation (M&S) to assess system performance. While this approach has proven to be invaluable to the acquisition and engineering communities, experience has shown it does not necessarily capture integration and interoperability (I&I) issues that could impact the performance of complex systems. Manually assessing performance using technical expertise alone is not feasible for most cases and, although M&S allows analysts to model very complex system behavior, models may be wrong, may not accurately represent interfaces or important (possibly unknown) interactions between systems, and may not accurately reflect how the systems are used once deployed. Clearly, the identification of gaps in our warfighting capabilities requires that these and other issues to be considered in the system assessment process. This article provides an overview of the Warfare Capability Baseline (WCB) assessment process, which identifies current capability gaps using an approach primarily based on operational test data.

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Figure 1. Warfare Capability Baseline Organization

Background

Investigation into a possible fleet issue necessitated the assessment of current fleet capabilities grounded with data collected from fleet exercises and system operational and developmental tests. WCB began as a pilot study led by Commander, Operational Test and Evaluation Force (COMOPTEVFOR). Its mission is to provide senior Navy decision makers with rigorous, fact-based reports of current baseline systems-of-systems warfighting capabilities "that are not available anywhere else in the Navy."[1]

Since the pilot study, the WCB assessment process has been executed three times (referred to as "increments"). Each successive increment has expanded the scope of the assessment to include more threats and more warfare areas. As of this writing, approximately 150 assessments have been performed across six warfare areas: Ballistic Missile Defense (BMD), Air Warfare (AW), Surface Warfare (SUW), Anti-Submarine Warfare (ASW), Mine Warfare (MIW) and Electronic Warfare (EW).

The WCB assessment process is derived from the Naval Air Systems Command (NAVAIR)'s Horizontal Integration and Capability Assessment Process (HICAP). Some modification of the HICAP scoring criteria was necessary to address the expanded scope of the WCB assessment. Specifically, Threat Evaluation and Weapon Assignment is a critical, complex activity not explicitly identified in the HICAP functions.

Assessment Team

The WCB team comprises a diverse set of naval agencies including COMOPTEVFOR; NAVAIR; Naval Surface Warfare Center, Dahlgren Division (NSWCDD); Naval Surface Warfare Center, Panama City Division (NSWCPCD); Naval Undersea Warfare Center (NUWC); Naval Air Weapons Center (NAWS) China Lake; and the Space and Naval Warfare Command (SPAWAR). An organizational chart depicting the team hierarchy of the WCB assessment team is displayed in Figure 1.

COMOPTEVFOR leads the overall WCB assessment. The assessment team is divided into five groups: surface; mine; undersea; air; and command, control, and communication (C3), each led by a different warfare center.

The lead at each warfare center is referred to as a "Mission Engineer" (ME) and is responsible for working with MEs from other warfare centers to develop and review scoring criteria, provide the rationale behind the assessment, and provide support for the integrated assessment of all kill chains, including the creation of the final report. Each ME also forms a working group of "Principal Investigators" (PIs), who are responsible for scoring systems in their particular area of expertise. (e.g., the surface sensor PI will score the performance of surface-based sensors such as the SPY-1B). PIs also work with warfare center subject-matter experts and keep program offices informed as the assessment proceeds.

Each group is assigned a "Mission Integrator" (MI), who is an active military COMOPTEVFOR representative. MIs serve as liaisons between WCB technical personnel and the warfighter community. MIs' roles include working with the fleet to develop tactical situations (TACSITs) used in the assessment, working with warfare centers to ensure current Navy doctrine and tactics are represented, and supporting the integrated assessment of kill chains.

Several other agencies played a role in the WCB. These agencies include Program Executive Offices that provided access to platform, sensor, weapon, and network test data; and Commander U.S. Fleet Forces Command (CFFC), who provided prioritized weapon target pairs for assessment as well as the mission context and criteria for each kill chain. The Warfare Centers of Excellence also provided inputs into developing TACSITs and provided feedback on WCB findings.

Assessment Process

The WCB assessment process consists of several steps:

- Defining and prioritizing weapon-target pairs of interest
- Developing kill chains and TACSITs
- Developing scoring criteria
- Scoring kill chains
- Performing an integrated kill-chain assessment
- Reporting assessment findings

A brief overview of each step is provided.

Defining and Prioritizing Weapon-Target Pairs

The WCB assessment process begins with a fleet-prioritized list of weapon-target pairs (WTPs) that identify a specific weapon for use against a specific target. CFFC requests each fleet to provide a prioritized list of WTPs that are of interest to them. The CFFC and COMOPTEVFOR use these submissions to determine the WTPs to examine in the next WCB increment. For each WTP, the WCB team attempts to answer the question: "Can this weapon be effectively employed to achieve the desired effect against this target under the circumstances described in this TACSIT?"

Developing Kill Chains and TACSITs

Scored kill chains are the basic tool of WCB assessments, are used to answer the above question, and are the foundation for WCB products. A kill chain consists of mission tasks or functions required to successfully employ a specific weapon against a specific threat and the platforms that could provide the required functionality (e.g., target detection could be done by an aircraft or a surface ship). In addition, the kill chain includes the major decision nodes (e.g., the decision to commit an aircraft to visually identify a tracked object) as well as the communication links required to transmit information between and within units. The specific mission tasks and C3 nodes represented in a kill chain are dependent on the mission area being examined and are subject to change from one increment to the next. In increment 3, the AW kill chains consisted of eight mission tasks plus three subtasks and six C3 nodes, as illustrated in Figure 2.

Given the number of combinations of mission tasks and platforms and/or performers that could carry out those tasks, there could be many "paths" through a kill chain. Many of these paths will have "broken" links, some will have "weak" but not broken links, and (hopefully) some will be comprised of all "strong" links. Since assessing all possible paths through a kill chain is not generally possible, WCB focuses on assessing the primary path, which represents the Navy's preferred path, based on current doctrine, training, etc., and possibly one alternative

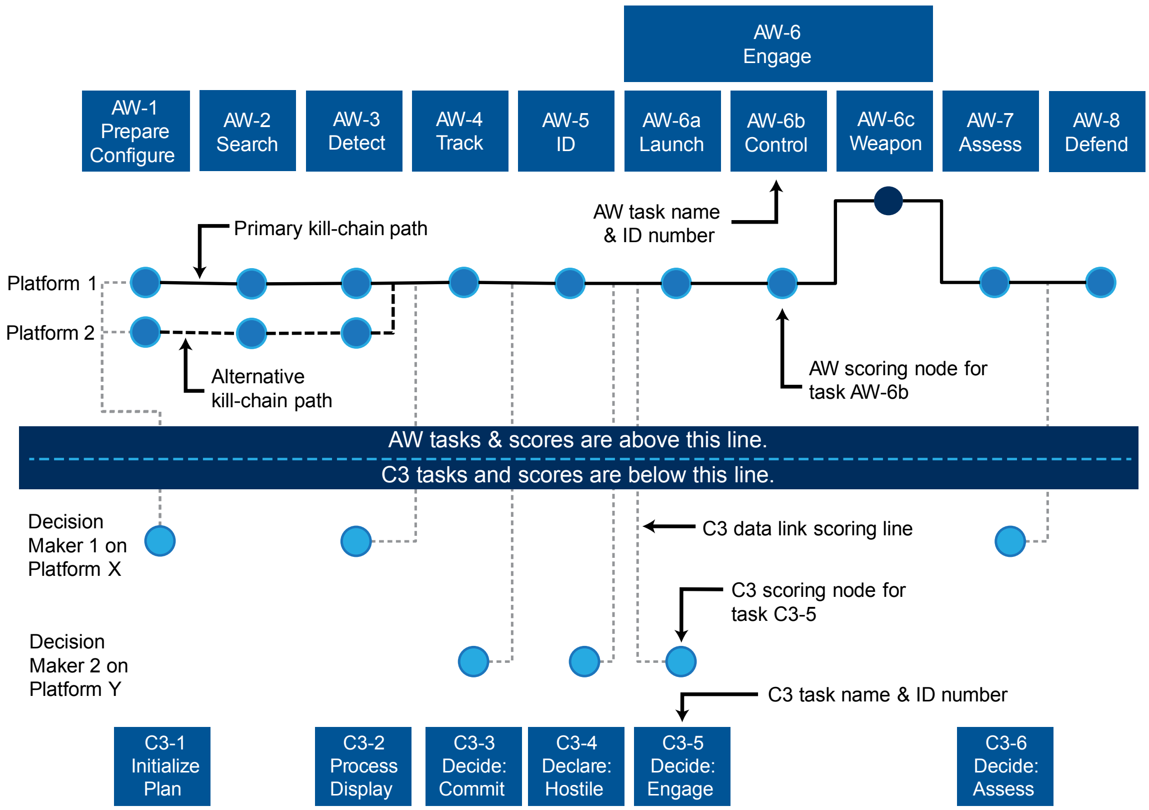

Figure 2. Notional Unscored Kill Chain

path that may circumvent weak or broken links in the preferred path. In Figure 2, the primary path is indicated by the solid black line connecting the scoring nodes for Platform 1, and an alternative sensor path is indicated by the dashed black lines connecting the scoring nodes for Platform 2.

Kill chains are inherently tied to TACSITs, which are vetted through an annual TACSIT development effort with participation from fleet warfighters. These TACSITs set the baseline year and provide warfighting scenarios for kill chain assessments. The TACSIT contains several important factors that must be considered in the assessment, including the threat, the participating platforms, the operational environments, and expected methods of employment showing associated geometries and timelines throughout mission execution. In short, TACSITs provide the context within which kill chains will be scored.

Developing Scoring Criteria

Each kill chain function must be scored in the context of and constraints defined by its TACSIT. Scoring criteria define what the systems must do. In general, Green, Yellow, Red or White scores, as shown in Table 1, are applied for each scored platform as follows:

- ***Green:*** The platform provides the full level of performance required by the TACSIT.
- ***Yellow:*** The platform provides a partial or degraded level of performance in the constraints defined by the TACSIT. For instance, a Yellow score would be applied to performance that occurred between a desired and a minimum threshold, if both were defined. In some circumstances, the desired and minimum threshold are the same, and a Yellow score does not exist, i.e., performance is either Green or Red.
- ***Red:*** The platform fails to provide the minimum level of performance required by the TACSIT.
- ***White:*** Test data does not exist or is insufficient to accurately score system performance. The PI responsible for scoring a given system or function makes the

Critical Measures	Notional Scoring Criteria	Notional Score and Rationale	Overall Task Score
Launch_1	Is the correct weapon selected?	**GREEN:** No issues observed in testing	YELLOW
Launch_2	Is all prelaunch data provided to the weapon?	**YELLOW:** Hardware interface issues prevented launch in x of y attempts	
Launch_3	Is the launcher able to fire all requested rounds for the engagement?	**GREEN:** No issues observed in testing	

Table 1. Notional Critical Measures, Scores, and Justifications for the Launch Subtask

decision as to whether there is sufficient data to score system performance. In some cases, accredited M&S is used to supplement test results. If the M&S supports the trend observed in the test data, then the function will be scored; otherwise, the White score remains in effect.

Although, as explained above, the decision to apply a White score is left to the discretion of the responsible PI, the Green, Yellow and Red scores must be justified and traceable to specific scoring criteria developed for each mission area. For the AW mission area, each mission task is broken down into a set of critical measures. These critical measures are tied to factors impacting mission success in a given TACSIT. The ME and PIs develop the scoring criteria used to score each of a task's critical measures. Table 1 provides a notional set of critical measures and scoring criteria for the Launch subtask.

Scoring the Kill Chain

After receiving access to the test data, PIs must sift through the data to determine which tests are applicable to the mission task they are scoring, given the conditions specified in the TACSIT. For example, a PI may reject a test because the target drone is not sufficiently representative of the threat. The PI then uses the applicable test data and the appropriate scoring criteria to score each of a task's critical measures. The lowest score assigned to any of a task's critical measures determines the task's overall score for a given platform. Notional scores and rationale are provided in column 3 of Table 1.

Note: This data is for illustrative purposes only and is not consistent with the actual WCB assessment. The overall task scores (e.g., Green, Yellow, Red or White) are applied to the scoring nodes and data links shown in Figure 2 to provide a top-level summary of the kill chain's health.

It is important to understand that each mission task in a kill chain is scored independently of the tasks that precede it. For example, the Launch task will be scored as if all tasks "upstream" were scored Green, so it is possible to have a Green Launch task even though the Track task is scored Red. This is done to avoid masking the overall strength or weakness of a "downstream" link, so that multiple issues affecting the successful completion of a kill chain can be identified.

Performing an Integrated Kill Chain Assessment

In this step of the assessment process, all of the individual platform and system scores and scoring rationale are discussed in a working group consisting of the entire WCB team. The national team critiques the scores and justifications for every critical measure in every kill chain to ensure they properly reflect the scenario laid out in the TACSIT and accurately reflect current capability in the TACSIT context. The week-long national team meeting allows the WCB team to work through issues in real time and finalize all scoring with the full consensus of the team across all mission areas.

Reporting Assessment Findings

The primary purpose of a single scored kill chain is to highlight broken and weak links or failed interoperability and integration that would prevent success in delivering a particular weapon against a particular target with a specific mission employment in a given environment. WCB findings are the delivered product for highlighting such capability gaps in individual kill chains. As the number of scored kill chains grows in a particular mission area, including functional, degraded, and broken kill chains, a broader picture of warfighting capability becomes clear, and major warfighting capability gaps identified.

In WCB Increments 1 and 2, a formal report documented the major assumptions, scores, justifications and findings for every assessed kill chain. In Increment 3, annotated electronic presentations served as the final report. In all three increments, scoring and justifications were placed into the WCB database maintained by COMOPTEVFOR.

Interpreting Results

The current WCB assessment process is not perfect, and care must be taken when interpreting the results. In particular:

- Because overall platform scores are based on a rollup of subsystem performance as well as tactics, doctrine, etc., a score of RED does not necessarily indicate the platform vice the doctrine or tactic is at fault. PIs will document the cause of the failure.
- Each AW kill chain to be assessed considers only one weapon and one shooter. The cumulative effect of multiple shooters or additional weapons is not included in the assessment. One implication of this decision is that a "broken/failed" kill chain does not necessarily imply that the targeted platform is at risk.
- Similarly, since the kill chain is assessed against a single-target raid, GREEN scores do not necessarily indicate the kill chain will perform well against a multi-target raid.
- Finally, in order to score a complete kill chain, it is likely that data will be pieced together from separate test events that occurred under different conditions. Consequently, the availability, applicability, and consistency of test data must be considered during the scoring process, when interpreting the results, and when drawing any conclusions.

Conclusion

The WCB process provides a valid method to assess current warfare capability based on actual system performance data from live-fire tests. The integration of warfighters' experience with analysts' technical expertise ensures that tactical needs will be addressed at the technical level. Findings from previous increments have established areas of focus for the acquisition and science and technology communities that align with the fleet's highest priorities and concerns. ⚓

Acknowledgements

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Endnotes

a. It is important to note the weapons and threats identified in the WTPs are currently deployed systems. WCB does not attempt to assess capability of non-deployed weapon systems or of current weapon systems against future threats.

b. "Platform" is used generically to refer to the entity performing the kill chain function. This entity may be an aircraft, ship, vehicle, person or weapon, and includes all of the sensors, systems, equipment, and software used by that entity to carry out the given kill chain function.

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Closing the Gaps... Capability Solutions Management

By Linda Learn

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With ever-changing political climates and rapidly evolving threats, our military is faced with the constant need to evaluate capabilities to ensure that they meet or outpace those of our adversaries. So how should the Navy's leaders go about identifying and closing gaps in capability? This has been a long-standing question with far reaching strategic, budgetary, and organizational implications.

On 9 December 2010, the Chief of Naval Operations (CNO) hosted a summit on Integration and Interoperability (I&I) that tackled this question. At the summit, the Naval Air Warfare Center (NAVAIR) proposed a sequential, proactive approach to identify shortfalls in current capabilities, develop comprehensive solution recommendations to identify shortfalls and process the results within the Department of the Navy (DON) for approval, execution, and implementation in the Fleet. The objective of the process was to begin with input from the Fleet and look across systems to identify capability gaps and solutions in effects/kill chains associated with specific weapon-target pairs. A generic example of such a kill chain would be a scenario in which a United States Carrier Strike Group (CSG) is located in one of the world's "hot spots" and the adversary in that region launches "Red Missile X" at the carrier; the CSG responds by engaging that threat with "Blue Weapon Y" (i.e., Blue Weapon Y vs. Red Missile X). The question becomes *"How well does that weapon perform against that threat?"* It's a question that assesses the System of Systems (SoS) in a kill chain that spans search, detect, track, identify, engage, assess, etc.

When it comes to fixing problems or inserting new technologies into the Fleet, funding lines have historically dictated that maturation and deployment of new capabilities focus on *individual systems* rather than *SoSs*. As voiced by NAVAIR's Vice Admiral David Dunaway in a recent issue of Proceedings Magazine,

> *"That important alignment is necessary and must continue to be executed vigorously. However, we must also implement a new process that includes a horizontally integrated view of how that system will work in the System of Systems (SoS)."*

Figure 1. WCB Effects/Kill Chain Assessment Example

Since the summit, representatives from NAVAIR; the Naval Surface Warfare Center, Dahlgren Division (NSWCDD); the Naval Undersea Warfare Center, Newport (NUWC Newport); Space and Naval Warfare Systems Command (SPAWAR); Chief of Naval Operations (OPNAV); Commander, Operational Test and Evaluation Forces (COTF); Fleet Forces Command (FFC); the Naval Air and Missile Defense Command (NAMDC); the Naval Mine and Anti-Submarine Warfare Command (NMAWC); and the Naval Strike and Air Warfare Center (NSAWC) have worked together to refine and implement the process initially proposed at the 2010 I&I Summit. In December of 2012, these efforts culminated in the signing of the I&I Charter by the Vice Chief of Naval Operations, ADM Mark Ferguson. From that time, the process has been through several iterations.

The first step in the I&I process is the Warfare Capability Baseline (WCB) assessment. The WCB team takes specific weapon-target pairs designated by the Fleet as high priority and develops the mission threads and Tactical Situations (TACSITS) that provide context. They develop scoring criteria for such areas as search, detect, track, identify, engage, and assess (and others as necessary); then they score each task in technical detail. The findings are housed in a master database at COTF. A mock example of possible results is depicted graphically in Figure 1.

The next step in the process is to look for potential solutions across the entire spectrum that includes Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF). That's where the Capability Solutions Management (CSM) Team comes in. Led by the Warfare Development Command (WDC) for the mission area under consideration (i.e., NAMDC is the WDC for the Integrated Air and Missile Defense (IAMD)), the team also includes experts from across the DOTMLFP spectrum. Their goal is to find solutions that can be acquired within the five years spanning the Fiscal Year Development Plan (FYDP).

As a leader in RDT&E, NSWCDD's primary role on the CSM Team has been to assemble and lead the Materiel Solutions Development Team (MSDT). A subset of the larger CSM team, the MSDT delves into potential materiel solutions and applies a rigorous analytical assessment. The team is comprised of experts from each of the following disciplines: Systems Engineering, Warfighter Integration, Architecture, and Warfare Analysis.

This task is a challenge in communications as much as technical ability. It requires reaching across the internal NSWCDD departments as well as to other System Commands (SYSCOMs), WDCs, program offices, research facilities and others with expertise that can aid in the analysis and evaluation task.

Each potential solution is considered in the context of the kill chain and TACSIT in which the WCB team evaluated it. The final output is presented in the Integrated Capability Package (ICP), a document written in a prescribed format that provides DOTMLPF recommendations to close gaps identified by the WCB. The final recommendations are grouped into three categories:

Immediate: *Solutions that are currently available*

Near-term: *Solutions that can be delivered in 1-2 years*

Mid-term: *Solutions that can be delivered in 3-5 years*

NAMDC presents the final document to FFC, who reviews it and makes any necessary changes. It is then delivered to OPNAV for consideration in the Program Objective Memorandum (POM) budgeting cycle.

The I&I process is not alone in the Navy's efforts to identify and close gaps. NAMDC follows a Warfare Improvement Program (WIP) process. The Program Executive Office Integrated Warfare Systems (PEO IWS) employs a Capability Phasing Plan (CPP) process. SPAWAR makes evaluations and recommendations based on a Portfolio Health Assessment (PHA). Although seemingly disparate processes, the object of all of them is to identify gaps and submit proposed solutions to the POM cycle. Recent efforts have been driving toward a more cohesive approach that capitalizes on the "best of all worlds." The I&I process is now merging with existing processes to feed the POM cycles at OPNAV.

To return to the original question… "How should our leaders go about identifying and closing capability gaps?" The answer will never be easy. We live in a world of growing complexity with increasingly complicated problems that require increasingly innovative solutions. The I&I process is a step in the right direction to ensure that the systems delivered have been evaluated across the DOTMLPF spectrum in the relevant mission contexts to ensure that the Navy brings the best possible solutions to the problems that are the highest priority to the Fleet. ⚓

Technical-to-Tactical Interfaces:

Importance of Consistent Interface between Warfighters and Scientists/Engineers

By Greg McHone and Dr. James D. Moreland, Jr.

A carrier strike group sustainment exercise illustrates the complexity existing from multiple platforms and systems that are necessary for defense of a high value unit.

Extensive Fleet interaction establishes the necessary stakeholder relationships to understand operations, capture capability needs, and consider the art of the possible in scientific/engineering solutions through architectures, derived from mission area requirements, which are the vehicle for technical-to-tactical mission engineering principles. In July 2013, scientists and engineers from the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), participated in an operational experiment and exercise known as Trident Warrior. The exercise teamed systems and software scientists/engineers with warfighters aboard a destroyer as well as in the Combat Direction Systems Activity (CDSA) laboratory to study surface warfare functionality and evaluate effects/kill chains to determine warfare effectiveness and technical execution of a specific operational mission thread. These subject matter experts witnessed and evaluated a Concept of Employment (CONEMP) for Surface Warfare (SuW); SuW Tactics, Doctrine, and Rules of Engagement (RoE); SuW effects/kill chain for target dissemination using tactical sensors; a prototype Common Weapons Control System (CWCS) that introduced SuW functionality; and technology for in-flight weapons communication. The CWCS was manned by operational warfighters to gain feedback on the systems' design, functionality, and Human Computer Interface (HCI). Shipboard scientists/engineers provided expertise on the SuW CONEMP, in-flight weapon communications technology, and existing combat system capabilities and functions that were applied to the experiment. From this information, SuW operational requirements, system designs, system architectures, and other related technologies were then developed. Unquestionably, the technical-to-tactical insights gained from collaborating with warfighting operators provided an accurate view of capability gaps that would lead to better system designs and system architectures.

Definition

The Vice Chief of Naval Operation's Integration and Interoperability (I&I) Activity has evolved NSWCDD's coordination with the Fleet/Joint warfighters, other Systems Commands (SYSCOM) and Warfare Centers to one that is centered on mission engineering and the technical-to-tactical excellence principle. This principle is centered on the warfighter's desired mission effects. The tactical capabilities required to achieve those effects are understood by the acquisition community and included in technical system designs by tight coordination and interaction between warfighters and the warfare centers' scientists/engineers. The collaborative Fleet and scientific/engineering team create mission architectures based on a snapshot of Fleet exercises and experiments to serve as technical reference documents, Mission Technical Baseline (MTB), to inform the naval community on the validated means of executing particular mission threads. Mission architectures of deployed force operations are developed to support Fleet analysis, assessment, and requirements generation of existing warfighting capabilities. MTB architectures are derived from defined mission objectives and effects, and deployed Joint and Navy assets operating under theater-defined doctrine to rehearse our blue force ability to effectively execute operational and contingency plans. Theater-specific MTB architectures that support the assessment of integrated warfighting capabilities are made available to the development and validation of system and system-of-systems specific architectures. The extensive Fleet interaction required to transition technical developments to tactical capabilities has been termed "warfighter integration."

Benefits of the technical-to-tactical principle are still being realized, as the interaction of warfighting and acquisition communities continues to mature. Across the naval enterprise, however, warfighting capability has lacked clear definition between the various acquisition and operational stakeholders. Efforts to standardize processes and employ consistent procedures to improve warfighting readiness continue to evolve.

Strategic Implementation

NSWCDD began to formalize the technical-to-tactical relationships by establishing Mission Focused Capabilities (MFC). Mission Focused Capabilities are represented by mission thrust areas in the context of the Joint Capability Areas (JCA) to solve warfighter challenges of today and tomorrow through an iterative operational and engineering process. Heavy emphasis continues to be focused on relationship building with key warfighter and sponsor stakeholders. The culmination of this effort is to understand the stakeholders' operational needs and to develop a comprehensive understanding of the stimuli that drive them (e.g., threats, challenges, and opportunities) for current-, near-, mid-, and far-term capabilities. These operational needs and stimuli are used to drive the future direction of research and development activities to focus the naval enterprise on the right requirements and investments with the objective of increasing the transition of capabilities to the Fleet.

I&I activities institutionalize the processes and products across the naval enterprise that are necessary

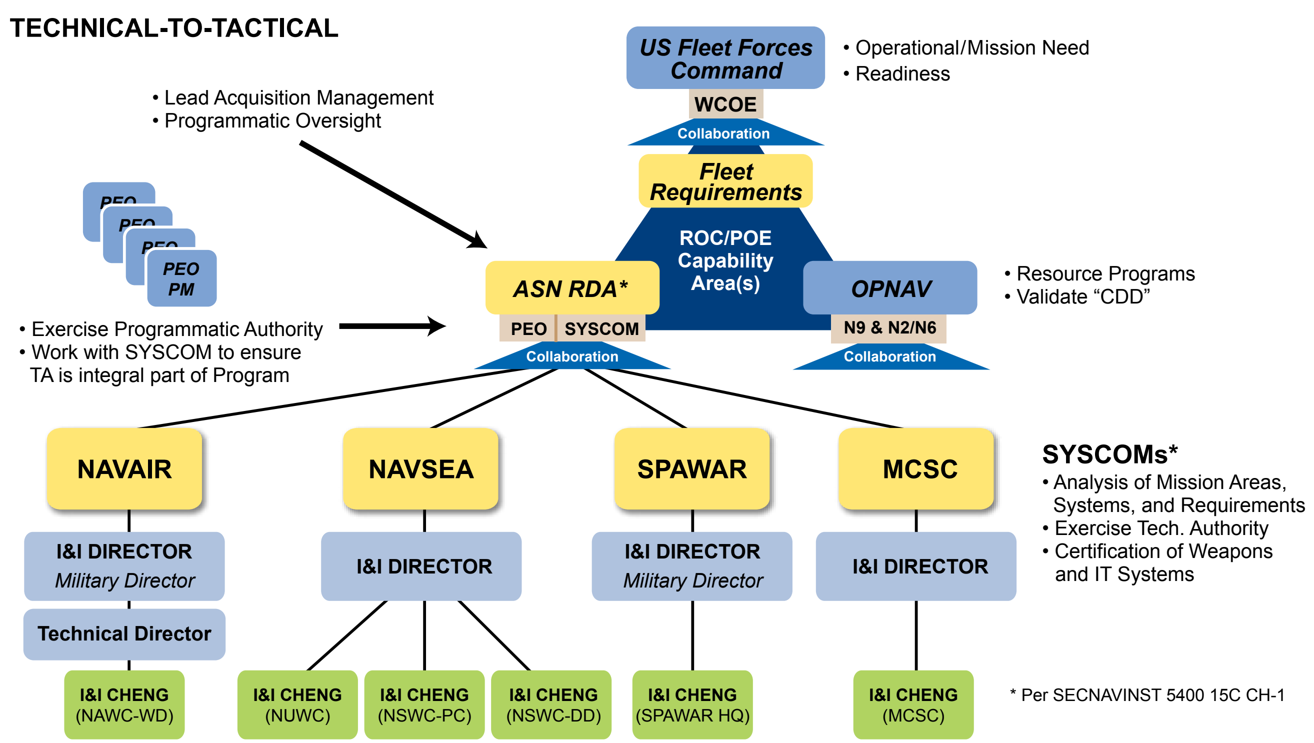


Figure 1. Naval Enterprise Governance Structure

to effectively and efficiently improve warfighting readiness. The governance structure across the naval enterprise is illustrated in Figure 1 demonstrating a tight linkage between Fleet operational needs and readiness, OPNAV requirements and resourcing, and Assistant Secretary of the Navy for Research, Development, and Acquisition (ASN RD&A) programmatic oversight and acquisition direction.

Technical-to-tactical efforts provide a better understanding of mission-level gaps and deficiencies across the entire acquisition cycle and facilitate a decomposition of requirements from technology to the warfare level.

To align with Vice Chief of Naval Operation's I&I Activity and achieve organizational strategic goals for technical-to-tactical relationships, NSWCDD created an organization that serves as the unifying focal point for mission engineering initiatives, known as the Mission Engineering Cell, to enforce the development of integrated warfighting capabilities. This organization, working in conjunction with the Fleet and similar organizations at other Warfare Centers and SYSCOMs, draws on the technical depth of the scientific/engineering community and tight Fleet relationships to produce affordable and integrated capabilities for the Fleet. These solutions consider the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) spectrum to make sure any technical inputs are tactically aligned to provide realistic recommendations for acquisition investment decisions and modifications to existing programs of record. By working with the Fleet components, Operational Test and Evaluation Force (COTF), Warfare Centers of Excellence (WCOE), and the Navy Warfare Development Command (NWDC), better Fleet experiments and data collection efforts are occurring to result in better requirements generation based on proven warfighting operational needs. The team also works with technology efforts to determine the future impact on mission capability with proper technology integration plans thus promoting the successful transition of promising new technologies. Figure 2 represents NSWCDD's strategic organization alignment for mission engineering.

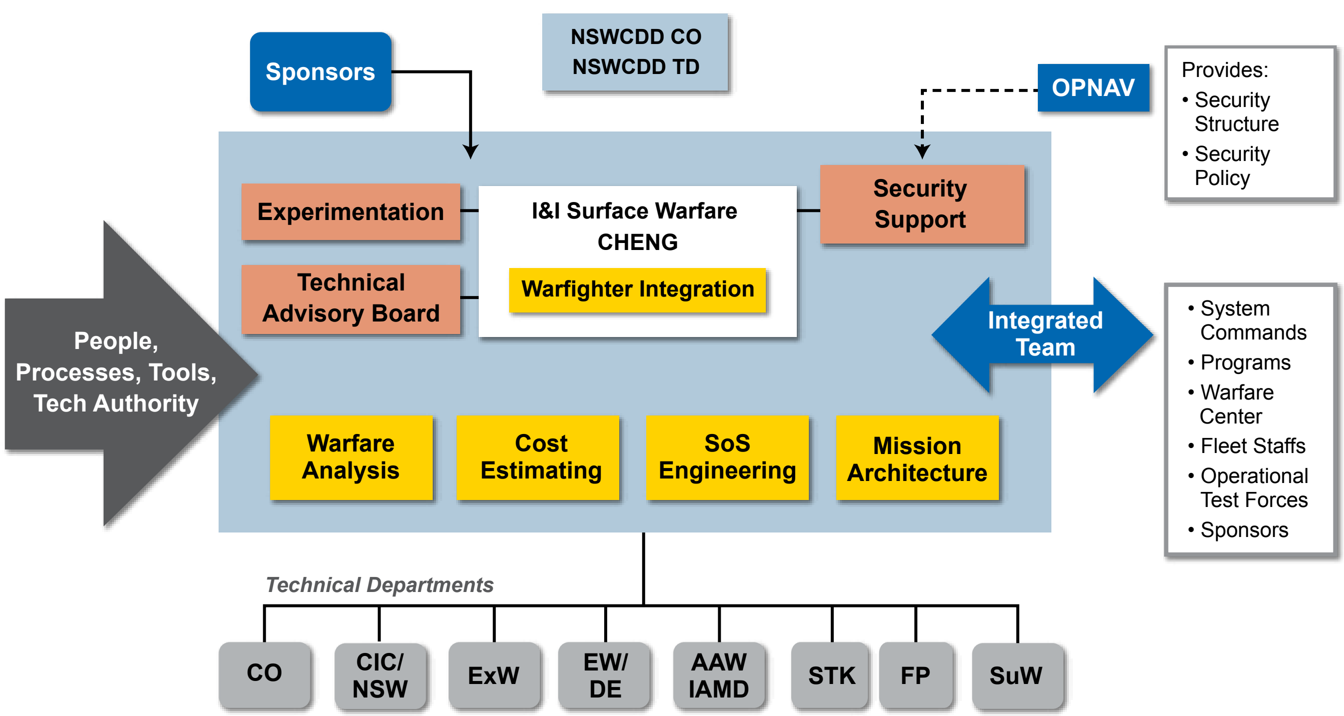


Figure 2. Naval Surface Warfare Center Dahlgren Mission Engineering Alignment

The Deputy Assistant Secretary of the Navy (DASN) Research, Development, Testing and Evaluation (RDT&E) provides resources for I&I initiatives to support the future development of tools, processes, and workforce development for the new mission engineering discipline. Mission Level Assessment and Evaluation (MLA&E) is one of those initiatives that embeds mission engineering principles with Joint/ Naval exercises and experiments to capture desired warfighting capabilities. This initiative serves as the primary mechanism to institutionalize the technical-to-tactical principles. The MLA&E methodology closely aligns Fleet assessment processes by building stakeholder relationships and requirements identification through intensive warfighter integration efforts.

Finding Solutions to Warfighter Needs

Past technical-to-tactical relationships and developments have suffered from lack of collaboration between the major stakeholders leading to tactical implementation and weapon system introductions with inaccurate warfighter requirements, integration and interoperability problems, and uninformed user community. Fleet-produced Tactics, Techniques, and Procedures (TTPs) development driven by identified system shortfalls or responding to emerging threats have not always been specifically identified to the technical or acquisition community. Technical developments and acquisition programs have not routinely benefitted from direct observations and objective analysis obtained during Fleet exercises or been informed by TTP developments. Technical engineering and tactical solutions are different in their nature, but these efforts impact each other and must be informed by the other to achieve holistic, cost effective solutions.

To address past technical-to-tactical deficiencies, NSWCDD and the Navy's Surface Tactical Development Group (STDG) are developing a template for long-term collaboration and alignment between the WCOEs and the Naval Sea Systems Command's Warfare Centers under the Surface Warfare Enterprise (SWE). The objective is to align the surface domain operational and engineering forces to ensure coordination of both technical and tactical developmental efforts; provide timely, pertinent information to both parties; establish recurring reporting procedures; ensure analyses are consistent; and address critical performance issues.

During recent Fleet engagements, NSWCDD aligned technical experts with Fleet tacticians in a collaborative Surface Warfare Improvement Program (SuWIP) tactical analysis process with the STDG and other operational and tactical Fleet organizations. The SuWIP produces an Integrated Prioritized Capabilities List (IPCL) for the Surface Warfare community to drive the investment areas within the Program of Memorandum (POM). This is accomplished by conducting in-depth analysis on operational and systems test data to define technical improvements that are aligned with Fleet priorities to determine possible improvement areas for warfare effectiveness through performance characteristics for combat/ weapon systems. The SuWIP Working Group consists of Anti-Surface Warfare (ASuW) tactical and technical subject matter experts and stakeholders

Figure 3. Griffin Missile Firing from Coastal Patrol Craft

with an overall objective to assess current tactical procedures and identify operational gaps in multi-platform combat/weapon systems and their employment against adversary threats. NSWCDD has incorporated I&I activities with SuWIP to ensure tactical/technical alignment of warfighting gap analysis, requirements generation, and proposed holistic solutions to accomplish mission wholeness. This technical-to-tactical collaboration supported implementation of new warfighting capabilities demonstrated in a forward deployed test firing as shown in Figure 3.

Fleet Exercise Thrust

National policy for realignment of forces to the Pacific Fleet area of operations provides strategic guidance for technical-to-tactical alignment resourcing requirements to achieve warfighting capabilities. To align technical community with key operational stakeholders and increased collaborative efforts with Pacific Theater combatant, component and tactical commanders are necessary to understand operational needs that drive technical and tactical solutions.

Through DASN RDT&E-sponsored MLA&E initiatives, the mission engineering team embedded with key Pacific Theater Commanders (Pacific Command (PACOM), Pacific Fleet (PACFLT), Commander, Seventh Fleet (C7F)) and other theater component and tactical commanders to assess full warfighting capabilities. Using the Trident Warrior and Valiant Shield Fleet exercise venues and processes as a test bed, the team conducted engineering analysis of deployed combat system operational and test data to define performance characteristics and deficiencies in combat and weapon systems to enable full effects/kill chain capabilities. By articulating Fleet requirements, expectations were better managed across technical and operational stakeholders. Figure 4 shows the Fleet forces rehearsal during Valiant Shield exercise with NSWCDD scientists/engineers aboard to achieve a desired warfighting capability.

MLA&E warfighter integration application during Joint/Fleet exercise Valiant Shield surface warfare events demonstrated the utility of mission engineering principles as the underpinning for assessing existing mission performance and proposed solutions. This collaborative operational and technical community approach to major Fleet exercises laid the foundation of utilizing a Fleet user perspective to establish the guiding principles necessary to capture mission area requirements through capabilities-based architectures. The outcome has driven the development of combat system design specifications that enable full combat employment of weapon systems capabilities. A better understanding of the gaps and deficiencies is now achieved at the mission level across the entire acquisition cycle, which facilitates a decomposition of requirements from the development of technology to the execution of mission threads as an integrated warfighting capability.

Figure 4. Valiant Shield Exercise Carrier Strike Group Operations

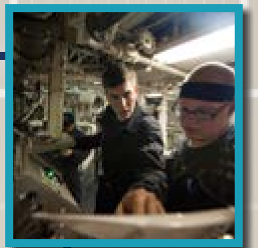
Commander, U.S. Fleet Forces (Training) sponsored mission engineering support of Commander, Strike Forces Training Atlantic (CSFTL) assessors to align technical experts with tactical experts in order to identify improvements in data collection and analysis during fleet certification events, specifically Composite Unit Training Exercises

Figure 5. Gun Engagement of High Speed Maneuvering Targets During Sustainment Exercise

(COMPTUEX). Fleet Training and Readiness processes employ a Navy Mission Essential Task List (NMETL) mapped to specific Navy mission areas (capabilities) in a continuous improvement process called the Navy Warfare Training System. The owners of Navy Mission Essential Tasks use feedback from exercises, operations, and other events to improve how the Fleet articulates requirements, measures performance, certifies readiness, and implements improvements. Efforts to date have focused on Fast In-Shore Attack Craft (FIAC) defense during Harry S. Truman and George H.W. Bush Strike Groups' Sustainment Exercises (SUSTEX) and Composite Unit Training Exercises. It is expected that the MLA&E application of the ICF/OCD data model will lead to better defined measures of effectiveness that lead to advanced levels of Fleet readiness. Figure 5 shows a 5-inch gun engagement of High Speed Maneuvering Targets representing Fast In-Shore Attack Craft during Harry S. Truman Strike Group's Sustainment Exercise.

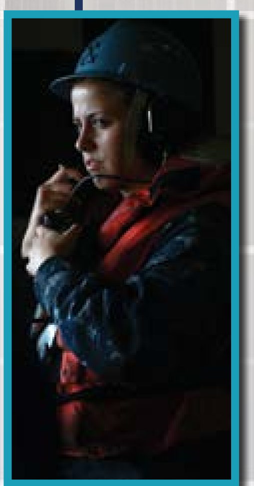
Summary

Intensive warfighter integration technical-to-tactical alignment enables achievement of surface domain excellence through I&I by reducing costs, preventing disjointed efforts, ensuring a linear approach, and reducing time required to develop and implement effective materiel and non-materiel solutions for the surface warfare community. Warfighter integration efforts to transition technical solutions to tactical capabilities through MLA&E create conditions for a philosophical change in evaluation, experimentation and assessment that enable mission engineers to participate in the planning, execution and analysis of Fleet events. This tight technical-to-tactical linkage results in higher confidence of producing integrated warfighting capabilities for our warfighters through validated MTB architectures from the Fleet. ⚓



Exploring Solutions Across Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities (DOTMLPF) Using Orchestrated Simulation through Modeling (OSM)

By Sara Wallace and Mary Ann Cummings



Historically, the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) has solved many systems engineering challenges using deterministic, physics based Models and Simulations (M&S) of the systems. For example, NSWCDD has developed high fidelity M&S such as radar propagation models, six degrees of freedom models for missile trajectories and blast fragmentation lethality models to support various projects and sponsors. However, in order to perform analysis at the mission level, it is necessary to model the multiple systems involved in achieving the mission objective, especially the interactions between systems. New programs, such as the Integration and Interoperability (I&I) efforts, require NSWCDD to begin to analyze the interactions between the weapons, sensors, and weapon control systems.

Many of the current models used by the naval community analyze the interactions by adding the other systems to their own system model, especially for common systems such as threats, communications, etc. This introduces error and redundancy by having each modeling entity create its own models, which are neither shared nor reviewed between organizations. This dilemma can be solved by having a government-owned, modular, and scalable software framework capable of allowing the models to interact in a common environment. NSWCDD has invented and submitted a patent request for a software framework called Orchestrated Simulation through Modeling (OSM), which is truly a model agnostic and capable of modeling the interactions between systems by "plugging in" system models from government, industry or academia. Plug-in is a term for a software extension that adds capability or new features. Adding system models via plug-ins allows software customization for each project without making changes to the framework. In addition, OSM enables a mission-level, fast-running, qualitative assessment of the system's interactions. This assessment permits more focused follow-on analytical deep dives with specialized tools currently used for systems engineering. This article describes the OSM framework; provides an example of how OSM was used to support the Commander, Operational Test and Evaluation Force (COMOPTEVFOR) (Navy); and discusses the future of M&S to support mission engineering.

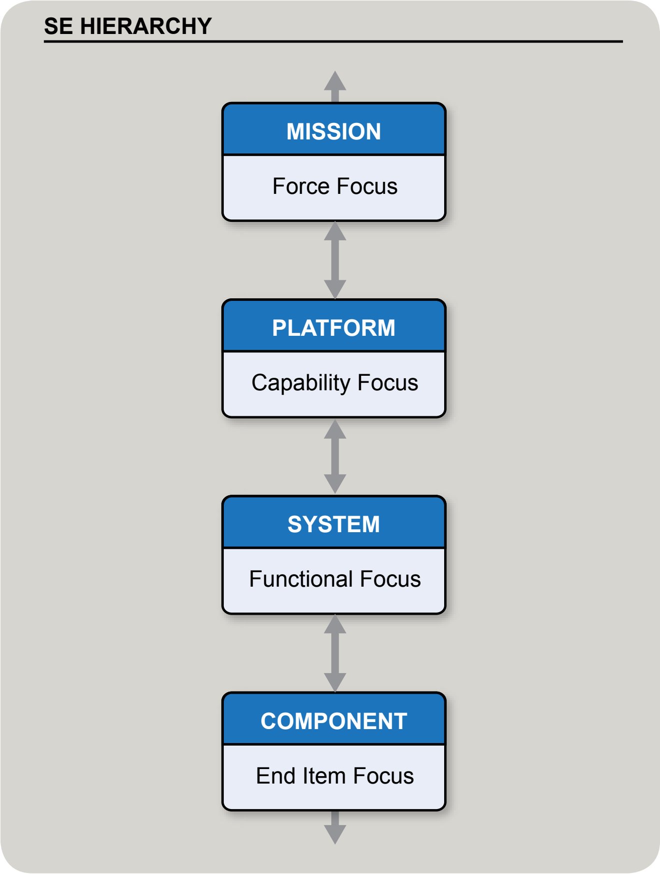


Figure 1. The Systems Engineering Hierarchy

Background—The Need for OSM and Mission Level M&S

Across NSWCDD programs, M&S is typically developed to support systems engineering for acquisition. Currently, the system commands are typically organized to develop and acquire systems (i.e., weapons, sensors, weapon control systems, etc.) and platforms (i.e., submarines, ships, etc.). Mission engineering accounts for the interactions and performance of the components, systems, and platforms that support the mission(s) being performed. This relationship is depicted in Figure 1.

As a rule, mission engineering studies aggregate the performance of systems in order to perform studies in a reasonable amount of time and effort. If the detailed performance M&S for each platform, system and component were used and each design parameter analyzed, the time required to perform the study would be astronomical and would not support timely acquisition decisions. The approach detailed in this article proposes use of behavioral models to represent the systems. Behavioral models represent the systems as independent entities that follow a defined state diagram where the system moves from state to state by stimulus from other systems or the environment. This approach allows for emergent behavior, for example, system performance, to be observed as systems interact throughout a scenario. The behavior is not predetermined or scripted. Each system's behavior can be unique for each run since it is dependent on its interaction with other entities within the model. One interaction may lead to another interaction and so on. For example, a simple gun state machine could have two states: fire and stand-by. To move between the states, the gun could be stimulated by another system, for example, a human, who has a state of pulling the trigger. By using behavioral models, the mission analysis can focus on the performance effects of interactions of the systems.

Traditional modeling uses a set of equations to dictate how the system operates and interacts, both independently and with other systems. This equation-based approach is used with many of the current System of Systems (SoS) M&S tools used in the Navy. SoS M&S tools often rely on the systems being described by varying degrees of complexity. Further, enormous energy is spent modeling system behaviors down to the minutest detail and attempting to fully exploit all possible outcomes of SoS behavior. While the high fidelity M&S approach is quite feasible, as stated earlier, it requires an abundance of time and funding. This approach does not eliminate the need for M&S at the lower levels since independent, detailed characterization of system performance is still required, especially when an issue is revealed at the mission level. However, using behavioral models allows program managers to be aware of a larger set of solutions across the DOTMLPF spectrum, vice the current paradigm of primarily looking at system materiel solutions. This approach will be extremely useful to explore "what-if" scenarios for mission engineering, which is focused on how changes to tactics and doctrine may close gaps in kill chains.

Analysis Definition—Integration & Interoperability (I&I) Process

As discussed throughout this edition of Leading Edge, the I&I process is different from most existing acquisition processes in the Navy. First, the fleet defines warfighting threads from operational plans and/or needs. Second, COMOPTEVFOR and the warfare centers characterize technical descriptions of the warfighting thread. Third, the Integrated Capability Framework (ICF) is used to identify possible solutions to gaps. These mission thread assessments are performed using M&S tools as well as operational test data. Finally, the warfare analysis products (results) become the basis for materiel and non-materiel solution decision making in support of Office of the Chief of Naval Operation's (OPNAV's) Capability Phasing Plan (CPP).

OSM Overview

OSM is an evolutionary SoS framework that was developed under NSWCDD in-house research funding to investigate and solve computer science challenges facing SoS modeling and mission engineering. OSM follows the Discrete Event System (DEVS) specification formalism which is a modular and hierarchical formalism for modeling and analyzing timed event systems. The OSM framework allows output visualizations and DEVS M&S frames to be developed separately as plug-ins and combined to form a mission level model of many systems. OSM was designed to use behavioral or agent-based models of the systems, since this allows the analysts to interrogate the interactions between the systems. There are five goals for the OSM development effort as listed below.

1. Create a government-owned, DEVS based M&S framework using Object Oriented Design (OOD), Agent Oriented Programming (AOP), and plug-in computer science design techniques to provide a model agnostic, scalable tool that enables integration and execution of multiple, independently developed models that can be used by government, industry, and academia.
2. Provide mission analysts with another (but not the only) M&S tool in their tool-box that supports M&S-based system analysis and validation from the component level up through the system, system-of-systems, and mission-level.
3. Minimize the effort required to integrate independently developed models and simulations.
4. Facilitate the development of a rich set of re-usable plug-ins.
5. Facilitate the use and reuse of M&S components to advance the discipline of M&S based analysis.

OSM Framework Description

First and foremost, the OSM framework was designed to be as simple as feasible. OSM provides the minimum core set of services and functions that will enable multiple plug-ins (models or simulations) to exchange data and perform as an integrated program. The OSM framework includes only the core functionality and a common set of basic plug-ins that users can select when creating a specific instantiation. The OSM framework does not include user-specific (system) plug-ins. Figure 2 depicts the framework using several plug-in types.

The OSM framework is a core structure, or skeleton, onto which users attach software and/or hardware configuration items that are required to communicate with each other. The core structure is a well-defined set of classes, libraries, application program interfaces (APIs), and development rules that provides a large amount of reusable code and a systematic development and integration approach. To investigate an issue or solve analysis questions, users must formulate their analytic approach and either build new or re-use system models and output models on top of the framework. Four main types of plug-ins are used with the prototype OSM framework. They are the system, experimental, simulator, and output plug-ins.

The first type of plug-in used in the OSM framework, is the model plug-in. The model plug-ins depicted in Figure 2 are: sensor, threat, ship, and weapon. OSM uses behavior-based system models called agents to observe and analyze the interactions between the systems modeled. Prior to agent-based modeling techniques, many system of systems simulations relied upon systems dynamics modeling, which is based on ordinary differential equations (ODEs) to represent the interactions between systems. Using agents allows the models to interact so the analysts can explore the interrelationships and interdependencies between the systems.

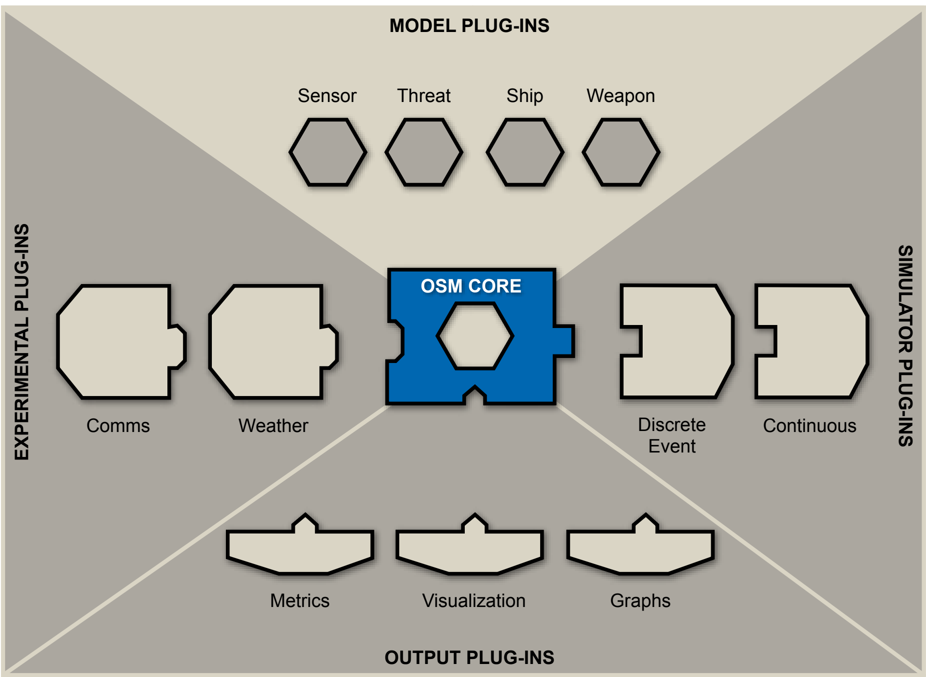


Figure 2. Depiction of Prototype OSM Framework with Plug-ins

The second type of plug-in used is an experimental plug-in, which follows the DEVS formalism. Experimental plug-ins define pieces of the scenario being modeled that are not part of the system behaviors. For example, experimental plug-ins could include weather and communications models. While weather is not part of a system model, changes in weather will affect the system, thus the interactions between the weather plug-in and system plug-in are important to model.

The third type of plug-in is the simulator plug-in, which also follows the DEVS formalism. The kill chain analysis prototypes have typically used a discrete event plug-in, although other simulator plug-in types, including continuous and real-time simulator plug-ins, have been demonstrated in OSM. The real-time simulation plug-in allows the user to interact with the model to dictate its behavior. To describe the difference between the simulator plug-ins, an example could be a model which defines how a ship travels from point A to point B. For the discrete event plug-in, the ship transits by its defined behaviors in the model. These behaviors could include making the transit in the shortest distance, escorting another ship, and/or following a pre-defined pathway of points. For the real-time simulation, an analyst can override the behavior by manual input of directions for the ship. This shows potential to reduce model development time to evaluate the effects of changes in behavior. Instead of rewriting the model, the analyst can input new directions for the ship while the simulation is running.

The last type of plug-in is the output plug-in. Output plug-ins are tools to aid in analysis. Many of the output plug-ins are developed to visualize the simulation. With so many systems interacting with each other, visualization tools aid the analyst in identifying issues. The prototype OSM development efforts have used NASA's Worldwind (a 3-D geospatial tool), and OpenMap (2-D open source mapping tool) extensively for visualization. Using externally developed, open source tools allow analysts a plethora of benefits, including the ability to leverage existing tools within the open source community, to customize desired outputs, and use other familiar software. Other common output plug-ins include a metrics plug-in and a graph plug-in. The metrics plug-in is populated by the analyst with measures of performance, measures of effectiveness, and/or other numerical measures that are important to the specific analysis. The graph plug-in displays these metrics in charts for easy viewing. Since each analysis is unique, many output plug-ins have been customized to support specific projects. In addition, the OSM team developed an output plug-in that extracts all data into a generic text file, allowing the file to be imported and used to perform analysis in external analysis tools.

Behavioral Models using Agents

This section provides a high level description of agents. Agent-based modeling is important to the OSM framework, since agents were used to create the behavioral models for OSM. Agents, as used here, are defined as autonomous decision-making entities with diverse characteristics. In OSM, the rules for each agent are defined through state diagrams and vary by agent. The decision rules define models specific for the agent of the external world, and carry a level of sophistication. The rules employ memory of the agent's experiences, and are limited by the cognitive ability or load of each agent. Each agent varies by its specific attributes and available accumulated resources. This is of particular significance because multiple, identically coded agents can exist even if their behaviors during the simulation are not identical.

The simulation is based on the interactions among agents and each agent will have its own, unique set of interaction experience. For example, for two, identically coded, unmanned aerial vehicle (UAV) agents, each may fly on a different flight path based on the rule to hold a stand-off distance from other UAVs. In another instance, the UAVs may have the same flight path, but when launched at different times, the view of the world will be different. Each UAV agent detects moving threats at different points in time and makes the decision to engage at a different time perhaps based on being fired at or receiving a command to fire. When faced with a decision, each agent makes an independent decision that may or may not be the same decision similar agents make. The decisions are based on each agent's interactions with the world and other agents. The interactions can be simple or complex depending on what questions the analyst is trying to answer. Agents are beneficial to model interactions since, unlike traditional equation-based models, there is not a central authority or controller dictating how the system operates, how the system is modeled, or how the system moves from state to state in the state diagrams. Using agents and behavioral models has allowed interrogation into mission engineering challenges, especially with system interactions that were difficult to model with other M&S approaches.

OSM Instantiation

An instantiation of OSM is defined as a mission scenario that is run to answer specific analysis questions based on a defined analytical process for a given mission thread. An OSM instantiation includes the user-specific plug-ins (for systems, experimental, and output) plus selected common and shared plug-ins (output, experimental, and simulator) built on the OSM framework. The plug-ins are selected based on the analysis to be performed. During an instantiation, the OSM framework provides the core services that

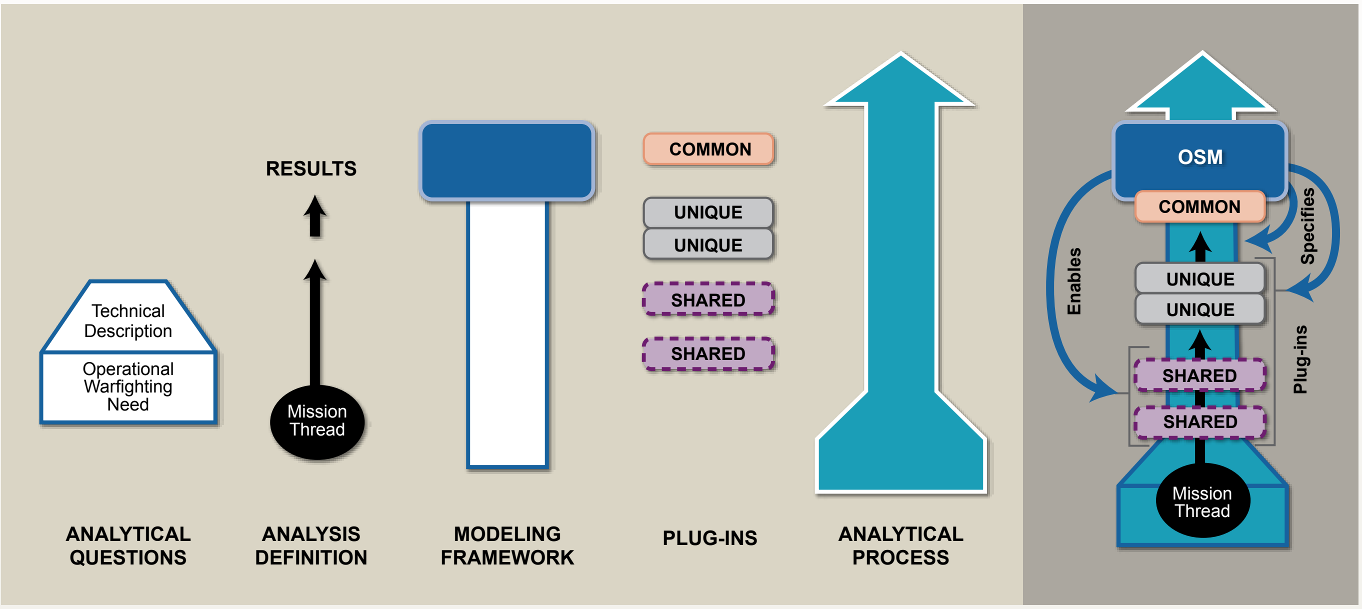


Figure 3. OSM Breakdown Structure

enable multiple user-provided plug-ins to run as an integrated product. This is depicted in Figure 3.

An OSM instantiation, as depicted in Figure 3, consists of five main parts. The technical description of the problem to be assessed and the operational warfighting need are used to form the analytical questions. The analysis definition is created by the mission thread along with a description of the results to be collected. The OSM modeling framework allows the plug-ins to execute together and is populated with a combination of common, unique, and shared plug-ins. Common plug-ins include output plug-ins, such as visualization tools, which are useful to most applications and generic enough to be suitable for a variety of programs. A shared plug-in could be a missile model created for one program, but the model is shared with another program. A unique plug-in is a model developed and used by only one program. Finally, the analytical process is how the user chooses to execute the instantiation. The analytical process may include analysis assumptions, plans for technical reviews, and other tasks deemed important by the user.

An example instantiation of OSM is a fleet exercise planning and assessment model developed for COMOPTEVFOR. COMOPTEVFOR's vision was for the model to be used before a test event for planning, and after a test event for analyzing the event outcome. Agents were created for naval systems playing a critical role during the test event. This included guns (i.e., Phalanx Close-In Weapons System (CIWS), 5-inch, etc.), sensors, ship movement, helicopter movement, small boat threats, and ship tactics. The agents were based on the system behaviors including system interaction and reaction to other systems. The system behaviors were created by ship commanders and helicopter pilots from COMOPTEVFOR and by NSWCDD's weapon experts and warfare analysts. The team documented the system behaviors and relationships in Systems Modeling Language, which was used to code the system plug-ins in OSM. The behavioral models also used data from high-fidelity, physics-based lethality models, including probability of kill and time-of-flight tables. Coupling high-fidelity algorithms and look up tables to the OSM instantiation adds the benefit of the high fidelity, lower system models, without significant increases in run time. In addition, COMOPTEVFOR wanted the interactions displayed on a map and metrics captured. Both types of output plug-ins were already created for other instantiations of OSM and were available for reuse. Plug-ins that can be shared across programs are called "common services" plug-ins. Typically, these include methods

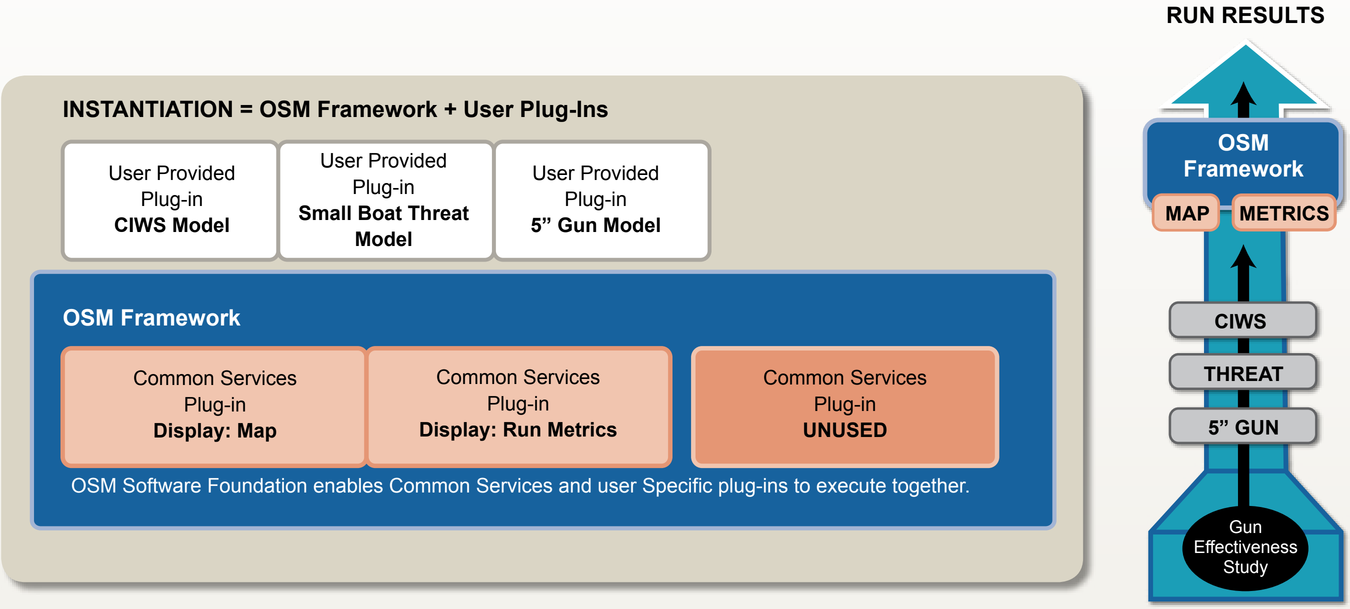


Figure 4. COMOPTEVFOR Instantiation of OSM

for displaying the data output from the model. The COMOPTEVFOR instantiation of OSM is depicted in Figure 4.

The OSM framework allowed COMOPTEVFOR to build behavioral (agent-based) models of the systems of interest and use common services plug-ins from prior instantiations of OSM. In addition, COMOPTEVFOR wanted a way to display output metrics on the map plug-in. This included metrics measuring which weapons were engaging a particular threat, how many rounds had been fired, and which weapon killed the threat.

Collaboration with NAVAIR Warfare Center China Lake

During the creation of the OSM instantiation for COMOPTEVFOR, the OSM team began a formal collaboration with the Naval Air Systems Command (NAVAIR) Warfare Center (NAWC) at China Lake as a research effort between two systems commands and warfare centers. The goal was to determine if an outside organization could effectively use and develop plug-ins, also called models, for OSM. The joint team selected a common threat and kill chain with Navy surface and air assets. NSWCDD built the surface agents (ships, ship sensors, ship weapons, etc.) while NAVAIR built the air agents (unmanned air vehicles, air sensors, air weapons, etc.). NAVAIR was given the OSM software specification and several examples of prior OSM instantiations. The team held weekly phone conferences, but, for the most part, NAVAIR developed their behavioral models independently. Since all the models were developed and complied with the specification, each had a common interface. At the end of the project, the two software development teams met face to face and were able to bring the models together in the OSM framework within a matter of hours. After integration, the software developers ran multiple scenarios to test how the models reacted to various conditions to ensure the integration was successful. A screen shot of the effort is shown in Figure 5.

Figure 5 depicts the scenario containing models from both NSWC Dahlgren and NAWC China Lake. The round, colored icons represent various agents depicting notional assets such as ships, unmanned vehicles, and threats. The wedges represent notional engagement areas for the weapons or coverage areas for the sensors. This effort proved that software developers external to the OSM were able to use the specification and create behavioral models that would work in the OSM framework with the models developed by

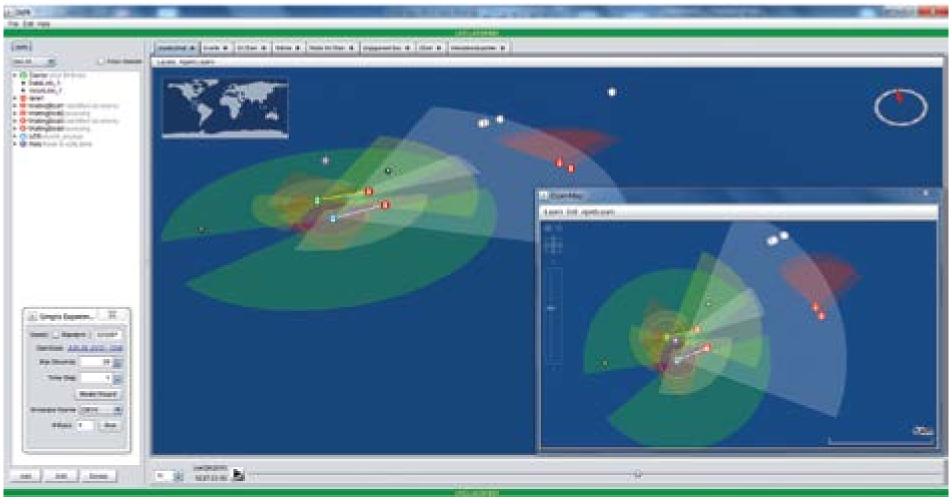


Figure 5. Screen Shot of OSM Collaboration with NAWC China Lake

the OSM team. The effort also fostered collaboration between the two warfare centers and provided the OSM team with feedback on the performance of the framework.

OSM to Support Future Mission Engineering Projects

OSM enables the simulation of integrated warfighting capabilities to assess multiple weapon/target pairs and tactics. The current assessment is a static assessment (on paper) of a single weapon, single target pair. The future of mission engineering will continue to include the assessment of gaps in warfare ability (currently performed during the Warfare Capability Baseline (WCB) studies), and an assessment of possible solutions as part of the Integrated Capability Plan (ICP). One concept for increasing the capability of mission engineering is to augment the WCB and ICP studies with cloud charting, the Integrated Capability Framework (ICF) and OSM. This futuristic, conceptual mission engineering process is depicted in Figure 6.

The first step in the proposed I&I process is identical to the existing I&I process. First, warfare gaps in kill chains will be identified during the WCB studies. Next, the kill chains assessed by the WCB will be "brought to life" by developing system behavioral models within the OSM framework by using data from test events, models, as well as from system architectures and other products from the naval community and the ICF. Technology insertions, as identified in the cloud charts, will be injected into the OSM simulation to determine the mission effect of the technology insertion on the kill chain. This capability will be a valuable new tool, allowing acquisition managers to assess which technologies produce the most significant impact to the mission. Further, the ICF of the future will contain test data, system models, architectures and acquisition data, all of which could be used to answer a diverse set of analysis questions using OSM. In addition, system and mission architectures could be used as a basis for the behavioral-based models. Architectures define the relationships and interactions between systems. The future assessments and analysis using OSM will allow for a more thorough assessment of the design space for solution sets to support the ICP.

Another promising solution for future work is for OSM to tie into other Department of Defense (DoD) frameworks. OSM is designed for the analysis of SoS using behavioral-based models. While legacy models can be wrapped into OSM, many high-fidelity, physics-based models were not designed to work with other models. OSM has used look-up tables from high-fidelity models in lieu of wrapping the model, but other DoD frameworks may be able to offer additional functionality by quickly wrapping legacy, standalone models and hardware-in-the-loop test articles. One DoD framework that shows promise for linking legacy software is NAVAIR's Architecture Management Integration Environment (AMIE). Funded by the Office of the Secretary of Defense (OSD), AMIE is a proven framework to wrap existing models and simulations of all types, including test articles. The OSM team is currently collaborating with the NAVAIR AMIE team. The OSM team proposes to use AMIE to wrap legacy software into OSM and

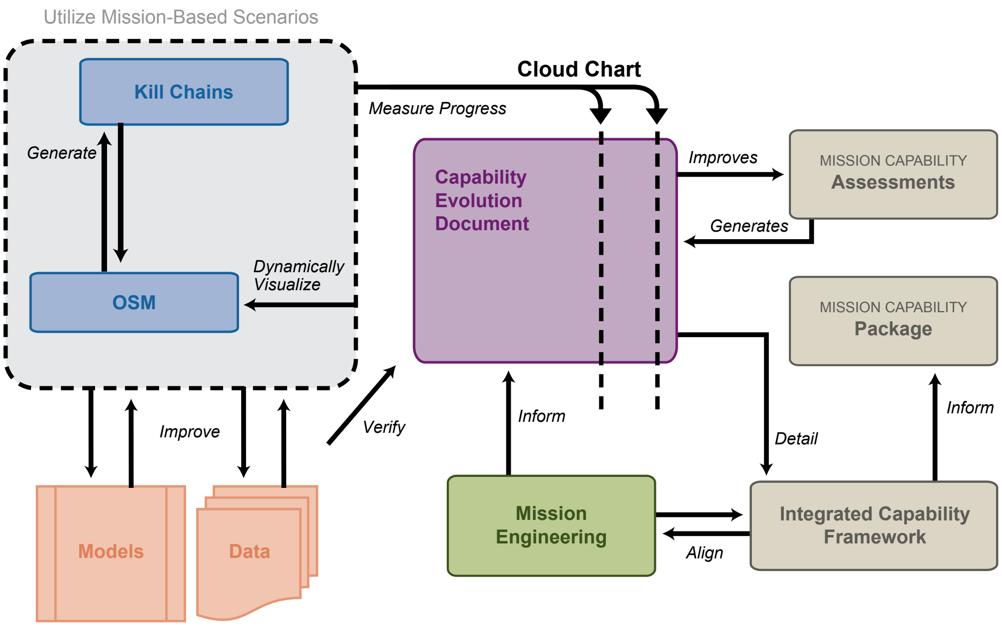


Figure 6. OSM's Use in the Future I&I Process

is developing an OSM to AMIE interface. This would allow other models and simulations to interact with OSM through AMIE instead of being converted to a behavioral-based model and wrapped into OSM. Pairing multiple frameworks together may allow new and legacy code to be integrated seamlessly into a common simulation and achieve an ideal state for a mission engineering analysis process.

Conclusions/Recommendations

Using behavioral models in addition to the typical system performance models is advancing mission-level assessment capability. Building the behavioral models from the system architecture products created by the programs of record is recommended. Using architectures, such as DoD Architecture Framework (DODAF) products, to define the behavioral models ensures traceability and aids in validation of the models. If a change is made in a system architecture used in a behavioral model, the model will also reflect this change. This is important for predicting how the system behaviors will affect system performance in the context of a mission. Of particular interest would be to predict behavior patterns or element/system states that lead to a degradation in system performance. Once system behaviors can be predicted, system M&S efforts can focus the use of high-fidelity models to fully interrogate and solve the system interoperability issues unveiled by the high level model. The ability to characterize the system behavior by predicting the interactions of the system in order to predict system performance would allow the acquisition community to optimize investment strategies for future system development.

In conclusion, although the OSM framework is still in the research stage, it shows great potential to be used to support future mission engineering efforts. The OSM framework is currently undergoing formal software validation and design utilizing NSWCDD internal investment funding. Once the validation is complete, the framework can be freely distributed within the Navy and across government agencies. Using a common software framework to allow the interaction of behavioral models created by separate entities, while maintaining the intellectual property of each model, will go a long way toward full collaboration on future mission engineering programs. ⚓

Mission Level Test and Experimentation:
Drive Mission Level Performance During Early Development

By Neil Baron, Darren Barnes, and Dr. James D. Moreland, Jr.

Since the first test shot was fired over the Potomac River Test Range (PRTR) in 1918, the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), has answered the nation's call to support the warfighter. In today's environment, naval systems are more complex than ever with the need to integrate many systems in order to provide full mission capability. How these systems work and communicate with each other is critical to understanding warfare systems performance. Instead of waiting for shipboard integration and testing to assess integrated capability, NSWCDD has developed the USS Dahlgren capability.

USS Dahlgren connects the PRTR, which provides real target data in a littoral environment to our plan-detect-control-engage-assess labs and systems for end-to-end testing at NSWCDD. Using USS Dahlgren, scientists and engineers are able to plan, detect, identify, track, engage and assess sensor-weapons capabilities in a real world environment prior to shipboard integration and delivery to the Fleet. USS Dahlgren also allows us to evaluate new capabilities and assess the benefit to the warfighting system prior to full scale acquisition and development.

Background

Mission Level Test and Experimentation (MLT&E) is a system-of-systems (SoS) approach for validating the development of individual systems by evaluating these systems in a representative operational environment with the other systems that they must operate with to achieve an integrated warfighting capability. The intent of this approach is to gain technical insights on integration and interoperability (I&I) challenges as well as determine the derived requirements for individual systems based on mission success criteria during early development. Individual systems do not produce warfighting capabilities unto themselves but rely on the interaction of multiple systems to execute an effects/kill chain effectively and safely. By addressing I&I issues earlier in the acquisition cycle, we have a better chance at reducing expensive rework and expediting fielding capabilities to the warfighter without delay. MLT&E plays a critical role in determining the right requirements, assessing I&I wholeness for

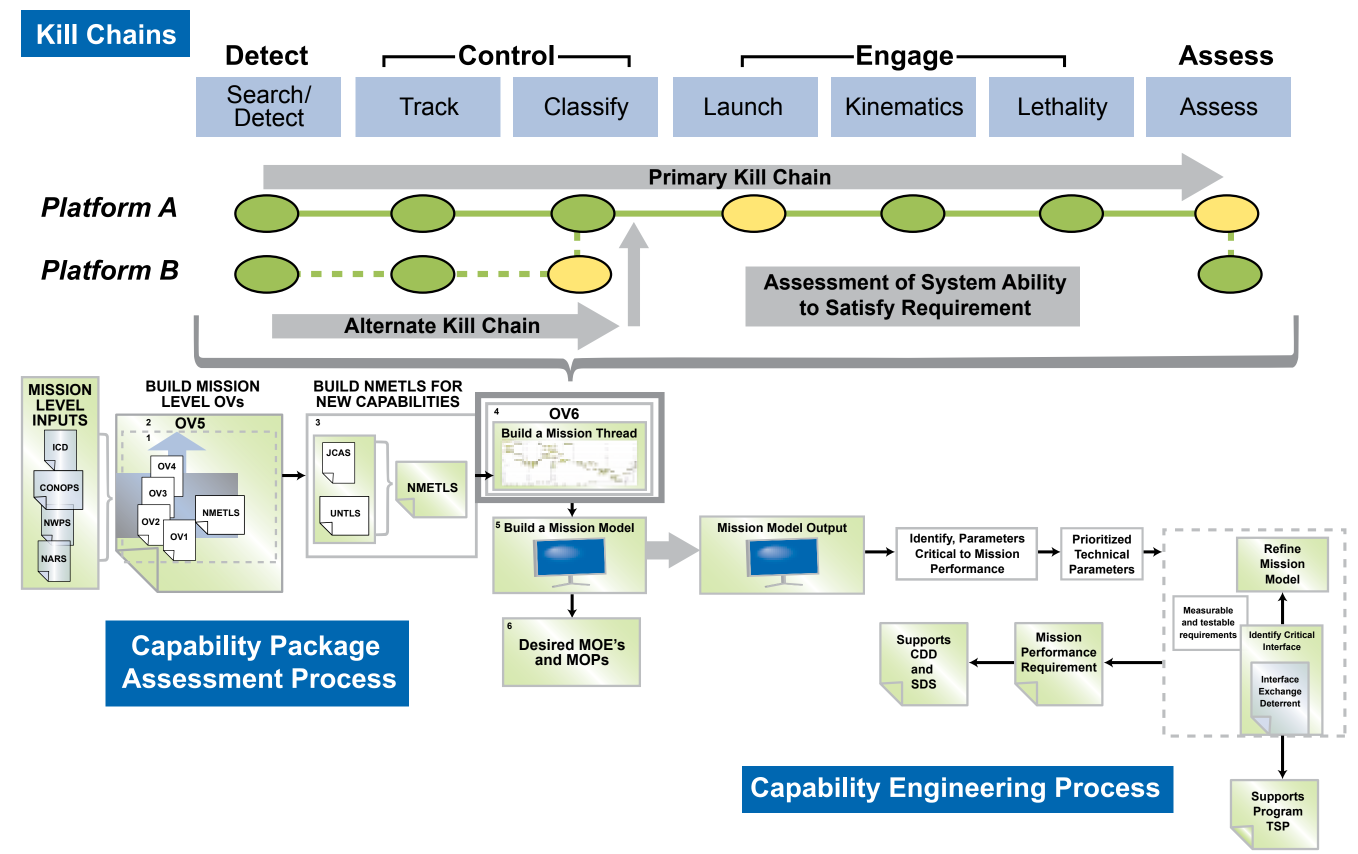


Figure 1. Interoperability & Integration/Warfare Capability Baseline

integrated capabilities, and solving issues early, on the left side of the Systems Engineering "V" model, to reduce cost, thus making capabilities more affordable. The technical insights gained are also used to develop the Mission Technical Baseline (MTB) and Integrated Capability Technical Baseline (ICTB) architecture products, which serve as the technical reference documents to drive acquisition development of systems.

In today's environment, the majority of test and experimentation activities occur for single systems to exercise that system's ability to meet requirements irrespective of the mission success criteria. This focus on single system testing has driven us down a path of sub-optimizing individual systems and losing focus on the operational context in which the systems will operate when transitioned to the Fleet. As individual systems are matured independently, the integration of these systems within the required SoS has fallen on the Fleet at delivery. In addition, the assessment of Fleet-prioritized effects/kill chains indicates a compelling need to address I&I problems from an end-to-end mission thread perspective to consider all interfaces and relationships across many systems. Figure 1 illustrates a notional effects/kill chain with linkages to architectural products used in the acquisition community for developmental purposes.

NSWCDD leadership developed a forum, Integrated Lab Council (ILC), to provide technical guidance across all departments in order to link the right labs together to make the USS Dahlgren concept a reality. The ILC provided a cross-departmental vision and a strategic plan for integrating NSWCDD Research, Development, Test and Evaluation (RDT&E) resources into a cohesive, net-centric engineering environment. A key aspect of this capability includes connectivity to the PRTR assets to leverage and incorporate real-time, live data from outdoor experiments. This end-to-end integrated capability will foster collaborative RDT&E demonstrations, experiments, integration events, and engineering development tests to accelerate and improve NSWCDD core technical capabilities and products for warfighter use.

USS Dahlgren Definition

In 2011, the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), embarked on establishing the USS Dahlgren construct. In response to the driving need to evaluate the Naval fire-control-loop through RDT&E that spans all aspects of the kill chain in a land-based test environment, NSWCDD has established a virtual ship, the USS Dahlgren. As our naval systems continue to increase in complexity and the fire-control-loop continues to expand within and between naval platforms, the need to integrate and conduct MLT&E in a laboratory environment is fast becoming a necessity. Additionally, an emphasis is shifting Test and Evaluation (T&E) to the left in the development cycle to identify design flaws and preferred design alternatives prior to full-scale development or shipboard integration. This shift results in cost effectively meeting performance goals and eliminating corrections after fielding. Although not an uncommon approach in some development cycles, it has proven to be a less common approach when looking across the kill chains and mission threads of larger scale distributed weapon system platforms. The USS Dahlgren envelopes not just one ship combat system variant but all ship combat/weapon system variants that can be assembled utilizing the current distributed laboratory infrastructure. The entire fire-control-loop must be developmentally exercised in the distributed laboratory environment and not for the first time onboard the intended platform(s). USS Dahlgren is the integration of NSWCDD RDT&E resources into a cohesive, real-time, deterministic, net-centric engineering environment, capable of replicating many of the fire-control (FC) systems including, sensor, command and control (C2), and weapons systems found onboard naval platforms. The unique aspect of USS Dahlgren is the ability to integrate and test new systems or their modification to existing systems early in the development cycle interoperating side-by-side with their already deployed counterparts. USS Dahlgren provides the infrastructure for early verification that fire-control systems perform in standalone and distributed environments, supporting identification of integration issues such as timing, data latency, and throughput early in the development cycle, in a high-fidelity environment. This environment provides for continuous testing across the acquisition life cycle, off-site connectivity to investigate ship, battle force, and joint force integration via Joint Mission Environment Test Capability (JMETC); and the ability to replicate the fleet environment to address issues observed at sea.

Recent focus has been on the interconnectivity of the existing labs as a means to exercise an overall federated warfighting capability capable of supporting multiple mission areas of interest. The USS Dahlgren capability spans the six technical departments at NSWCDD as well as corporate networks, and includes remote connections via the JMETC to include other warfare/system center laboratories as well as our sister service laboratories for joint experimentation and testing.

USS Dahlgren Components

The USS Dahlgren is composed of the many laboratories that house the developmental and in-service systems utilized in the effects/kill chain as found on deployed naval platforms (see Figure 2). Integration of the laboratories is facilitated through local and global secure network connectivity, modeling and simulation environments to generate and exercise the synchronized warfighting scenarios across the disparate locations, and representative architectural lay-downs of the effects/kill chain within (and between where necessary) platforms that house the warfighting capability.

Results from exercising the USS Dahlgren on a specific mission thread scenario can then be evaluated with other model-driven, experimental, and at-sea test data to evaluate the overall performance of the

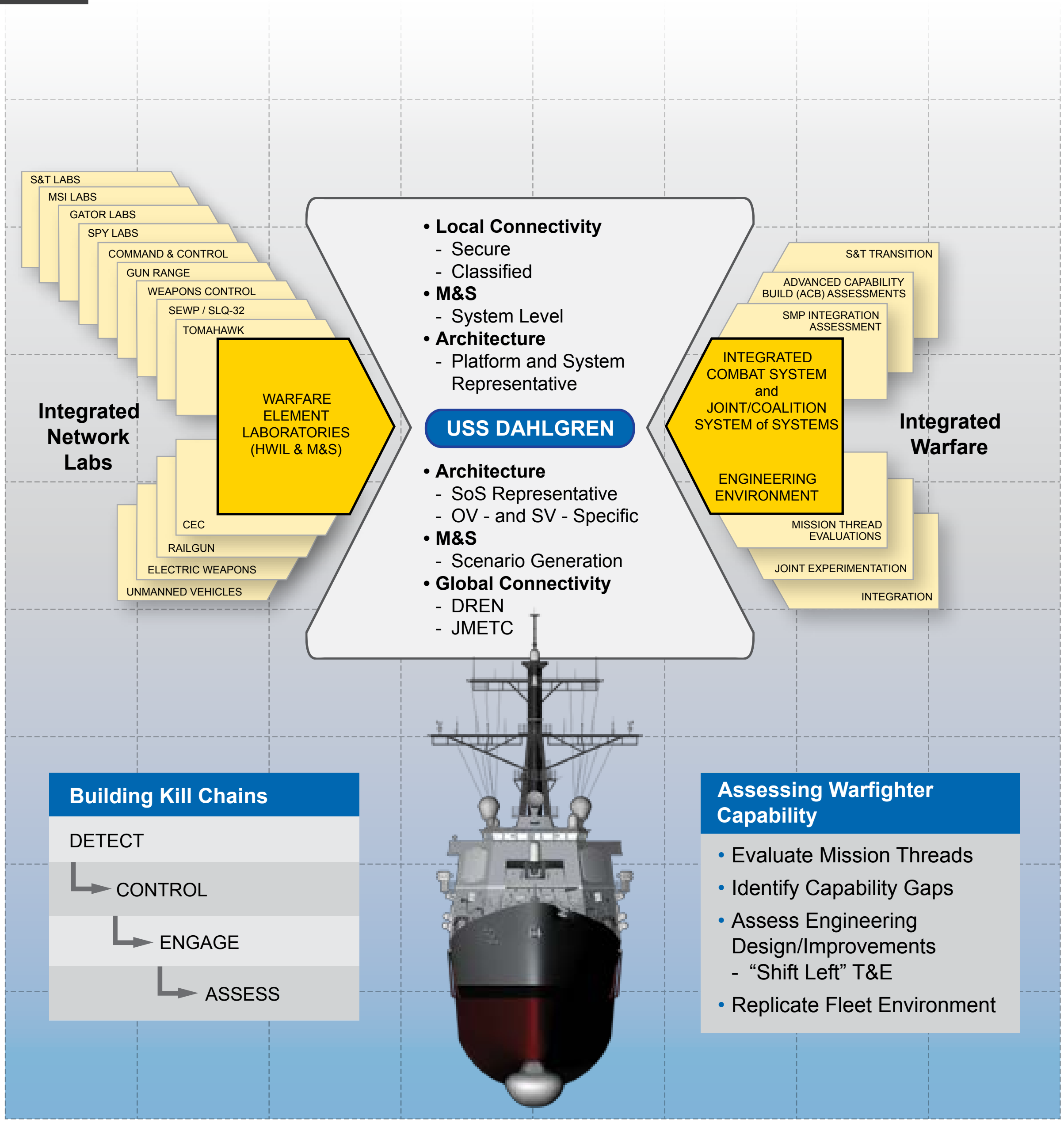


Figure 2. USS Dahlgren - An Integrated Lab Environment

integrated mission capability. In this way, warfighter capability can be assessed earlier in the development cycle, and warfighter expectations can be demonstrated with high precision while still in development (where the cost of modification is minimized) and before taking final products to sea.

Mission Level T&E Utilizing The USS Dahlgren

There is an urgent need in the naval warfare centers and acquisition communities to develop techniques and procedures to map mission operational demands with system and SoS hardware and software capabilities. This has become increasingly relevant as emerging SoS are required to create, consume, and fuse a vast amount of data with the intent of informing a future decision maker about an operational scenario that has not been fully defined. The MLT&E environment through USS Dahlgren is providing that mechanism to postulate how to map an operational architecture to the system architectures to investigate I&I problems.

MLT&E provides the scientists/engineers a venue to obtain technical insights on I&I issues while executing representative operational mission threads in a system-of-systems environment. This critical information is used to drive system requirements, specifications, and architectures in the acquisition community which thereby increases confidence in early development decisions. In today's environment, systems are tested individually to determine Technology Readiness Levels (TRLs) that focus on the maturity of individual systems. This level of evaluation is necessary but not sufficient to field integrated warfighting capabilities involving dependencies across many systems. USS Dahlgren provides the ability to link all effects/kill chain systems to evaluate and demonstrate performance across an end-to-end mission thread.

The operational test community evolved the test environment from an individual system focus to mission-based test. To prepare the newly developed systems for operational tests in this mission-focused domain, the systems need to be thoroughly tested while being developed under those complex mission conditions. This requires good use of experimentation resources on the left side of the Systems Engineering "V" model. Rather than waiting until late in the acquisition life cycle to perform operational test for the integration of SoS, many I&I issues can be eliminated during system development to make mission-based test a much easier milestone for the transition of capabilities to the Fleet.

Lastly, the operational community can leverage the USS Dahlgren environment to investigate the performance of an SoS under different situations for the development of Tactics, Techniques, and Procedures (TTPs) as well as doctrine. These non-material drivers provide the details on how to operate systems within an operational context while working across legacy and new systems. At the same time, the operational warfighters get a chance to train on new systems under development from the beginning so that human systems integration can be handled as human systems engineering thereby ensuring that the operators' needs are part of the overall design rather than an added piece.

USS Dahlgren Applications

Utilizing a crawl, walk, run strategy, NSWCDD began the USS Dahlgren initiative in September of 2012 with an initial experiment utilizing the secure connection of an Aegis Combat System baseline located in one building with the Mk 160 Gun Fire Control System located in another building and the Mk 45 Mod 4 Naval gun on the gun line. The combat system generated a firing order, which was passed to the fire-control system, and the gun was fired at a test target at a range of over 8,000 yards on the Potomac River Test Range. As seen in Figure 3, this test was a

Figure 3. Target Barge, USS Dahlgren Testing

success yielding multiple hits on the target. This first experiment exercised command and control, weapons control, gun control, river range control and multi-level security through a Cross Domain Solution (CDS) between the laboratories.

In 2013, the USS Dahlgren experimentation campaign continued to advance with the inclusion of an Unmanned Air Vehicle (UAV) in the mission thread providing target information messages and video

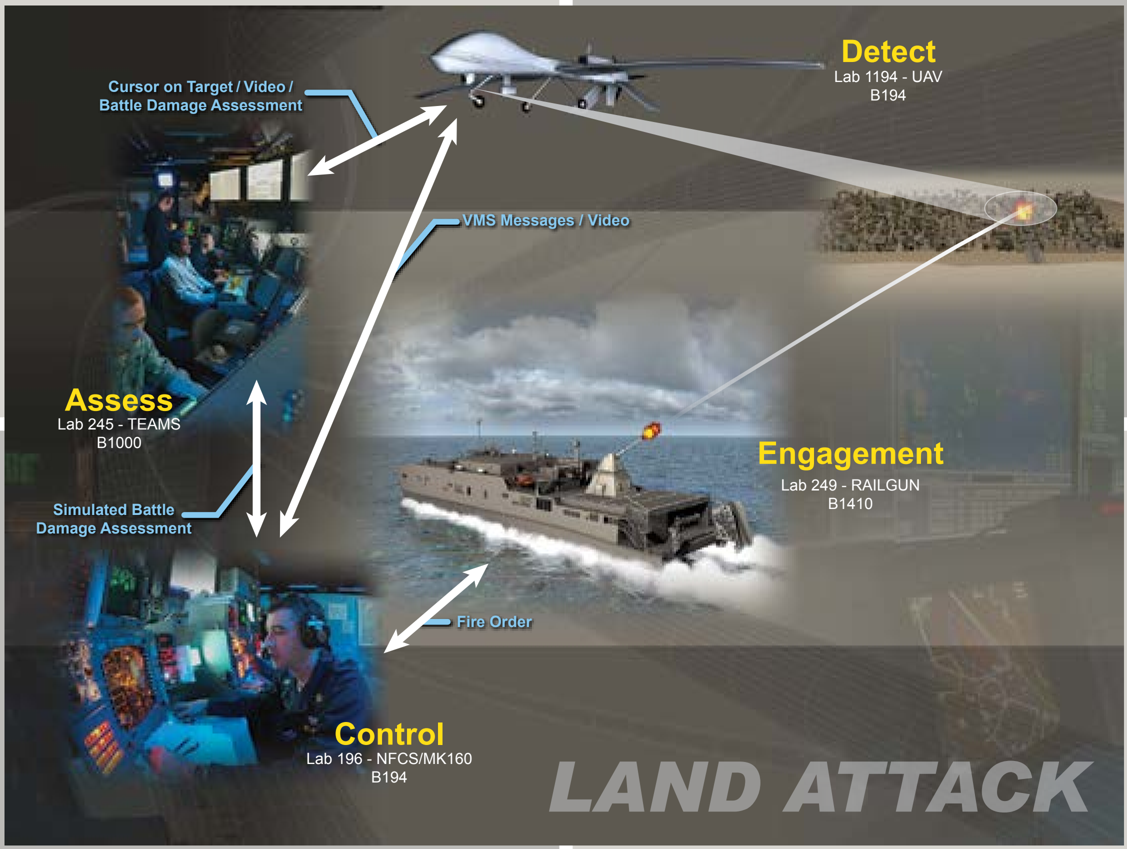


Figure 4. USS Dahlgren Land Attack Mission Operational View

utilizing cursor-on-target technology. The information passed a target object to the Naval Fire Control System in one laboratory, which then, through voice command, sent a firing order to the electromagnetic Railgun in another facility to engage the target. The UAV, still on station, was then utilized to stream video for battle damage assessment to a third assessment laboratory. A high-level operational view of this land attack mission thread is shown in Figure 4.

Currently, NSWCDD, sponsored by the Office of Naval Research, is investigating the Railgun as one of the next generation electric weapon system development programs. The Railgun uses electromagnetic power to achieve kinetic kill capabilities with a significant increase in speed and range and reduced cost per shot. The U.S. Navy has committed to testing the Railgun aboard a Joint Homeland Security Vessel in 2016; however, before testing commences, a significant amount of RDT&E will be performed at NSWCDD, to include testing of the Railgun on the PRTR. Advancement of the USS Dahlgren laboratory integration construct will include early development of systems such as the Railgun to assure other critical system elements of the mission thread are integrated.

In addition to the Railgun, the technological advancement of lasers as another electric weapon system capability is also continuing. The Laser Weapon System Quick Reaction Capability (LaWS QRC) was tested onboard the USS Ponce (AFSB (I) 15) in late 2014. This testing serves as the first of what is likely to be the eventual wide spread introduction of a High Energy Laser system into the U.S. Navy. Combat System integration of the laser capabilities into warfighting threads will be key in developing and fielding a true directed energy capability at sea. In addition to tackling laser integration issues during the early phases of development through the USS Dahlgren capability, other aspects of the effects/kill chain will be exercised. A laser weapon system can be utilized as both a weapon and as a very high quality sensor for the ship thus able to satisfy multiple elements of many mission threads. LaWS and its follow-on laser weapon system variants are being designed for use against asymmetric threats to include small boats and UAVs, both of which have been tested in the PRTR environment with the USS Dahlgren.

Railgun and LaWS serve as two prime examples of systems early in their development cycle that will benefit from being exercised via MLT&E. Mission testing via the USS Dahlgren does not simply focus on combat system integration, but fully exercises the systems end-to-end capability where other non-material aspects of overall performance can be investigated. Non-material aspects of tactics, training and human performance can also be evaluated in the USS Dahlgren capability.

Challenges and Way Ahead

Under the working capital fund model, Warfare Centers receive and are authorized to execute specific task orders for particular sponsors. The resources required to modify/build infrastructure and laboratories to perform MLT&E are not currently considered a necessity in task statements to get the job done. This is amplified by a fiscally constrained environment where infrastructure investments for extended capabilities are taking a back seat to satisfying immediate tactical needs. In addition, it is extremely difficult to coordinate schedules across multiple labs which all have their individual demands.

It is also a tremendous challenge to fully replicate a shipboard environment at sea in a laboratory environment. This operational context can only be simulated with the major focus of the MLT&E environment devoted to the technical execution of systems across an end-to-end mission thread. The involvement of warfighters in this environment provides a great deal of operational insight while they receive beneficial training on the new systems under development.

NSWCDD continues to develop the infrastructure architecture products to accurately represent the physical laydown of all assets. This allows leadership to develop a prioritized plan on infrastructure upgrades to make the best decisions on impacting operational developments with the largest return on investment from a military worth and affordability perspective. This includes the necessary trenching for logical wiring and physical connections required across individual labs to represent the functional areas of effects/kill chains. In addition, NSWCDD is defining the critical mission threads through effects/kill chain products to provide the logical sequencing and connection points of individual systems for end-to-end mission thread execution.

Conclusion

MLT&E in a laboratory environment is fast becoming a necessity, and even more so during the early phases of development to identify potential I&I issues as early as possible. The ability to resolve these issues early in the Systems Engineering acquisition cycle provides a better chance of getting the right requirements under affordable conditions resulting in integrated warfighting capabilities. ⚓

Strike Force Interoperability Officer (SFIO) Program

By Commander Matthew Carroll, USN

Preparing a Carrier Strike Group (CSG) or an Expeditionary Strike Group (ESG) for deployment is a complex undertaking from a program level perspective. Regardless of complexity, successful preparation is traditionally bound by three elements: time, cost, and quality. The ship's deployment cycle defines the time period of maintenance and modernization to meet the ship's objective as delineated by the government. The cost is the component represented not only by the fiscal cost of modernization but also by the personnel costs associated with both those onboard and those in supporting functions ashore to train and certify the group. With regard to the quality of the group, it is more than the sum of the individual ship's capabilities; it is the ability of those ships and aircraft to operate as a cohesive team, i.e., to be interoperable.

Dating back to the late 1990s, technology advances in Command and Control, Communications, Computers, Combat Systems, and Intelligence (C5I) capability, coupled with the need to become more interoperable, significantly impacted the surface force C5I modernization process. Although several capability gains were realized, a number of crippling deficiencies emerged as well at both the Strike Group and individual unit level. These increasingly complex and interdependent systems were developed and installed quickly as the Navy focused primarily on delivering enhanced capability to support commander's missions and objectives. Complicating this process was the decision to transition from proprietary, government-designed equipment to commercial off-the-shelf (COTS) hardware and operating systems. Consequently, developmental shore-based testing of these new commercially procured capabilities did not afford adequate time nor did it represent the shipboard environment in which they were to operate. Some of the most noteworthy consequences of rapid fielding included an Operational Evaluation (OPEVAL) failure of the Advanced Combat Direction System (ACDS) Block 1, the loss of an entire deployment cycle for a number of Aegis Cruisers due to a new Cooperative Engagement Capability (CEC) installation, and an additional Aegis Cruiser failing an operational test of the Advanced Tomahawk Weapon Control System (ATWCS). These failures resulted in system reliability falling well below design specifications for proper operation and employment.

Although the U.S. Navy enjoyed the reputation of having the most modern and capable fleet of ships in the world, they were unable to effectively work together. The introduction of more complex combat systems that now relied on the networking of systems to achieve greater capability exposed a flaw. The realization was that ships working together in a battle group may not be able to operate as a team. Shortly after these deficiencies received national media attention in 1998[1] the Chief of Naval Operations (CNO) charged Naval Sea Systems Command (NAVSEA) with the central responsibility to address battle management and C5I systems interoperability problems within the Systems Commands (SYSCOMs) and Program Executive Offices (PEOs). Specific tenets of this responsibility included the implementation of the following: a common warfare system engineering and certification process; a codified process for defining, controlling, and certifying C5I configurations; interoperability milestones; and earlier testing of future systems with a more capable shore-based testing network. The goal was to deliver deploying assets capable of the highest warfighting readiness absent the distractions resulting from interoperability failures.

Striving for continuous improvement in warfighting readiness makes system modernization necessary for a number of reasons including being able to respond to a newly developed threat such as the development of the Close-In Weapons System (CIWS)

Phalanx Close-In Weapons System (CIWS)

Block 1B surface mode to defeat small boat attacks, upgrading a weapon seeker head upgrade to counter an adversary's new anti-ship missile, maintaining technological superiority over an adversary and thereby enhancing national sea power, and overcoming obsolescence and expensive in service costs-such as the COTS refresh of the Aegis hardware. Additionally, modernization processes are sometimes required to overcome deficiencies of fielded systems that were not apparent during initial test and evaluation activities. These changes vary greatly in their complexity and urgency and are more prevalent in software; but hardware can be impacted as well. The result is a variety of requirements managed by multiple organizations–each with its own asynchronous timeline, resource constraints, and quality standards. Few of these requirements align easily to the Fleet Readiness and Training Plan. Each misalignment results in risk to the quality of the deploying group and ultimately mission success.

Although good policy, tight regulation, and robust certification applied to interoperability using sound systems engineering processes have been in place over the past 16 years to rectify the discrepancies, problems still exist. A lack of organizational ownership over the entire kill chain and the slow pace of rectification efforts for interoperability issues identified in test and evaluation activities were areas that demanded immediate focus. Through the observations of NAVSEA's SFIO team, broad communication between the Fleet and the technical community can significantly improve modernization and interoperability issues described above. It is in this arena that the SFIO team efforts help to coordinate modernization actions and provide a valuable service to the Fleet.

The SFIO team, with officers on each coast and overseas, is the primary interface for the warfighter. They assist with early identification of interoperability issues and advocate for prompt resolution within the technical community. The SFIO team helps warfighters identify and track their issues (or risks) throughout the cycle and provides ongoing support while deployed.

Consisting of uniformed officers and project engineers located in major fleet concentration areas, the SFIO team is a small, but effective resource for the warfighter. The team is managed under Combat Systems Direction Activity (CDSA), an Echelon V command under Naval Surface Warfare Center, Dahlgren Division (NSWCDD). Since 2000, this fleet support effort has crossed SYSCOM boundaries and involved regular coordination with PEOs, Type Commanders (TYCOMs), Numbered Fleet Commanders (NFCs), SYSCOM program offices, In-Service Engineering Agents (ISEAs), Software Support Activities (SSAs), Alteration Installation Teams (AITs), Regional Maintenance Centers (RMCs), Class Squadrons (CLASSRONs), Program Managers' Representatives (PMRs), and others. The SFIO's primary customer is the CSG, ARG/MEU staff N6 or appropriate leadership on independent deployers.

Figure 1 illustrates the cycle of interaction with the Fleet at key periods in the Fleet Response Plan (FRP). Commencing with a C5I status brief delivered prior to planned modernization availabilities, the SFIO team highlights planned capability improvements and identifies potential interoperability and modernization issues for all ships and warfare areas.

The SFIO executes update briefings with ship representatives throughout the FRP and maintains contact with key staff to facilitate emergent issue resolution. Sometimes the fleet interaction role is as simple as assisting a ship with a troublesome equipment casualty by providing the support network contacts, or as complex as influencing the fielding plan for a carrier availability. The latter was achieved recently for the one of the CSGs where the carrier was scheduled to deploy without the Accelerated Midterm Interoperability Improvement Program (AMIIP) upgrades. The upgrade consisted of a series of software updates to the host combat system and other interdependent systems that allow for improved coordinated tactical picture compilation. The improvements are often best described as an "all or nothing" upgrade.

Synchronization of program test, certification, and fielding plans allowed completion of this important

Figure 1. Strike Force Interoperability Officer Fleet Response Plan Interaction

upgrade on the cruiser and all of the destroyers in the deploying group. Each responsible organization worked its individual program's resources, testing, and fielding plans with good systems engineering to meet the policy guidelines for each platform of system within their purview. When viewed holistically, it became apparent that raising the priority on the carrier would result in a vastly improved capability to the warfighter during the upcoming deployment. The SFIO team successfully advocated for the change to go ahead on behalf of the strike group and thereby improved the probability of mission success.

Interoperability issues pose a potential risk to the quality of the deploying group. By acknowledging the risks, the Navy can assess, track, and manage interoperability using traditional treatment methods. Treating risk through elimination, i.e., including AMIIP on the carrier, removes the possibility of mission failure by eliminating the risk of a poor tactical picture.

Management of interoperability risks across C5I systems requires a range of traditional risk control measures. Examples of these controls include: "substitution" as an appropriate control for a software installation that is rolled back to a previous version following discovery of significant issues post roll-out, and "engineering" as an appropriate control which might entail a minor software change to a host combat system software that prevents certain Variable Action Button action from placing the combat system into

an unsafe mode. This is not an ideal treatment, but suitable, most times, as an interim measure. When changes to hardware or software cannot be implemented immediately, due to schedule or budget constraints, "administrative" and "behavioral" controls are put in place in the form of Tactics, Techniques, and Procedures (TTPs).

TTPs or workarounds for a system limitation are at best, temporarily effective; the ultimate goal should be to design out the problem. Unfortunately, in the real world we are constrained by resources and must determine if the investment to achieve such a solution is warranted. Often, training people in the techniques to limit the impact of the interoperability issue and provide an awareness and education to the operational commander and the team is the most cost effective solution.

Another significant factor in the treatment of interoperability risks is an understanding of the context in which the risk may present itself. The Strike Group Interoperability Capabilities and Limitations (SGI C&L) team, managed out of NSWC Port Hueneme, maintains a database of the known issues for each unit and potential strike group combination. This data is a valuable resource to the warfare commander in managing the risk that interoperability poses on deployment. Being at sea on an operational deployment creates a dynamic environment, and the commander continually evaluates the mission risk based on changing operational circumstances. Consequently, the interoperability risk must constantly be re-evaluated and the strike group optimized to manage that risk. This is particularly relevant when the composition of the strike group changes during the deployment as a result of the incorporation of an independent deployer or loss of a unit due to a significant defect. In addition to the SGI C&L database, for timely analysis, the ability to reach back to the shore support organizations is an important service provided by the SFIO team. With links and a wide network of relationships across SYSCOMs and PEOs, the team can help the Fleet "connect the dots" on interoperability or support issues that might otherwise distract the deployed Sailor from the mission.

The ultimate goal of course, is to mitigate the impact of interoperability issues and risks to shorten the feedback loop between the fleet and the technical communities. This dynamic knowledge gathering and analysis becomes even more important as the continual constrained fiscal environment forces heavier reliance on integrated joint and coalition groups.

So where do we stand today? The message from the CNO in 1998 charged NAVSEA with the central responsibility for coordinating the resolution of C5I interoperability problems within the Fleet. Despite the establishment of robust policy and regulation that was imposed on the acquisition community to consider the interoperability of C5I systems during system design and integration, problems still persist. Perhaps the greatest achievement since the 1990s is the acknowledgment of the complex integrated fleet and the need to manage rather than solve interoperability. The dynamic operational environment in which the Navy is required to raise, train, and sustain surface strike groups around the world will always result in capability gaps and incompatibilities. The goal of the SFIO team is to educate, mitigate, and advocate for the best possible outcome that reduces the interoperability risk for the warfighter in a way that provides a value-added service to the Fleet and respects the fiscal and programmatic challenges the technical community faces. ⚓

References

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Throughout these articles, you have read how we have parlayed our traditional systems engineering disciplines that develop highly integrated and interoperable shipboard combat and weapon systems with an expanded view to the overall warfighting mission at the Naval and Joint Force levels. A much greater focus on "Technical-to-Tactical" is evolving across the Navy Enterprise, and we at NSWCDD are quickly ramping up to answer the call for Surface Warfare.

"We turn ships into warships."

Captain Brian Durant
Commanding Officer
Naval Surface Warfare Center
Dahlgren Division

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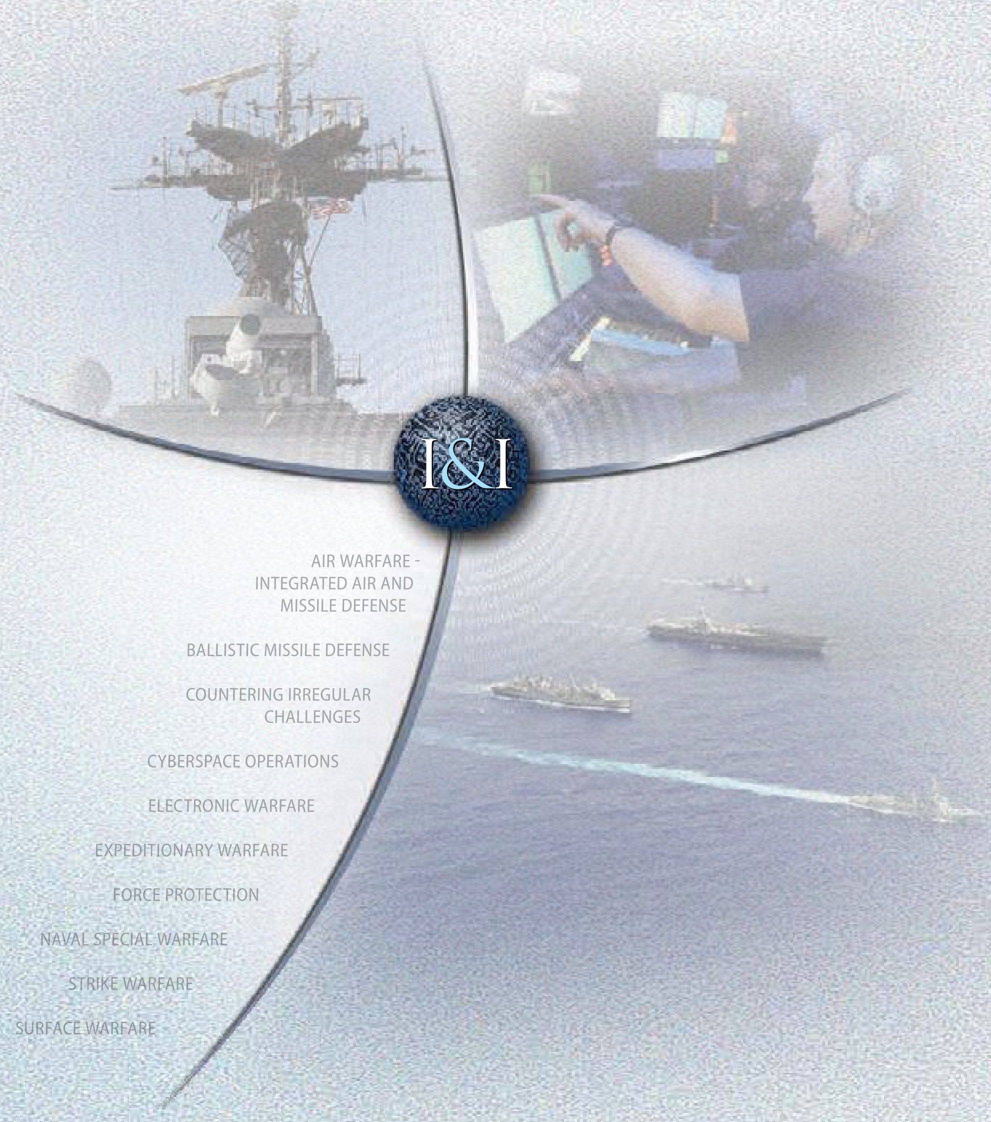

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Fallen Warriors

Here we honor those who died
while serving their country.

NAVSEA WARFARE CENTERS DAHLGREN
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