NPS-AM-10-074

EXCERPT FROM THE PROCEEDINGS

OF THE

SEVENTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM THURSDAY SESSIONS VOLUME II

Acquisition Research
Creating Synergy for Informed Change
May 12 - 13, 2010

Published: 30 April 2010

Prepared for: Naval Postgraduate School, Monterey, California 93943

The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

To request Defense Acquisition Research or to become a research sponsor, please contact:

NPS Acquisition Research Program
Attn: James B. Greene, RADM, USN, (Ret.)
Acquisition Chair
Graduate School of Business and Public Policy
Naval Postgraduate School
555 Dyer Road, Room 332
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
E-mail: jbgreene@nps.edu

Copies of the Acquisition Sponsored Research Reports may be printed from our website www.acquisitionresearch.net

Creation of a System of Systems Portfolio Management and Technology Selection Methodology

Richard Volkert—Mr. Richard Volkert is employed by the Space and Naval Warfare (SPAWAR) Systems Center-Pacific as the ISR Departments Lead Systems Engineer supporting SPAWAR and as the PMS 420 Deputy Technical Director. Mr. Volkert has over 27 years of service in the government, including twenty years as an active duty Naval officer with service as an engineering duty officer and in submarines. Over 19 years of that time he has been involved in the fields of research, development, acquisition, and systems engineering. He possesses degrees in Aerospace Engineering and Acoustical Engineering and is presently enrolled in a PhD program for Systems Engineering.

Rich Volkert
SPAWAR Systems Center -Pacific
Commanding Officer, SSC-Pacific, 53560 Hull St (BS Bldg 1 Rm A526), San Diego, CA 91977
richard.volkert@navy.mil
Phone: 619 553-1616

Carly Jackson—Ms. Carly Jackson is a Systems Engineer at SPAWAR Systems Center Pacific. She is currently supporting the Littoral Combat Ship Mission Module Program Technical Director's office, primarily tasked with the implementation of product and process commonality across complex Systems of Systems and Systems Engineering preparations for the impending Milestone B. Ms. Jackson earned simultaneous BS and MS degrees in Mechanical Engineering from UCLA in 2002 and an MBA in Business Administration from Pepperdine University in 2007. She is Level I certified by DAU in SPRDE-Systems Engineering, Test and Evaluation, Program Management, and Production, Quality, and Manufacturing.

Carly Jackson
SPAWAR Systems Center -Pacific
Commanding Officer, SSC-Pacific, 53560 Hull St (BS Bldg 1 Rm B519), San Diego, CA 91977
carly.jackson@navy.mil
Phone: 619 553-1492

Peter Gentile—Mr. Peter Gentile is an Associate Systems Engineering Fellow for the Northrop Grumman Corporation, currently working as the Technical Director and Chief Engineer for the Littoral Combat Ship Mission Package Integration program. His 42 years of engineering includes wide involvement in the design of electronics, computers, software, and systems for platforms covering sea to space. Mr. Gentile earned a Bachelor's degree in Electronics Technology from NY Institute of Technology and a Master's in Systems Engineering from The Stevens Institute of Technology in Hoboken, NJ.

Lance Harper—Mr. Lance Harper is employed by the Northrop Grumman Corporation, where he works as a Systems Engineer supporting the Littoral Combat Ships Mission Package Integrator (LCS MPI) contract. Mr. Harper has been working for 10 years on government contracts, focusing on research, development, and systems engineering. He earned a Bachelor's degree in Electrical Engineering from the Johns Hopkins University.

Lance Harper
Northrop Grumman Corporation
300 M St SE, Suite 100, Washington DC 20003
lance.harper@ngc.com
Phone: 202 799-3132

Art Van Nostrand—Mr. Art Van Nostrand is currently a systems engineer at Northrop Grumman Corporation, working on the Littoral Combat Ship (LCS) Mission Package Integrator (MPI) Program. Mr. Van Nostrand has over 30 years of systems engineering experience. He has worked on both DoD and civilian systems development. He has a BS degree in Physics from Long Island University, an ME in Systems Engineering from Stevens Institute of Technology, and an MBA in Finance from Dowling College. Mr. Van Nostrand is a member of the International Council on Systems Engineering (INCOSE), and is a Certified Systems Engineering Professional (CSEP) with the DoD Acquisition Extension.

Art Van Nostrand
Dept/MS (03790/W28-035), 925 South Oyster Bay Road, Bethpage, N.Y. 11714-3582
art.vannostrand@ngc.com
Phone: 516 575-3794

Tom Sondi—Mr. Tom Sondi is an Engineering Manager for the Northrop Grumman Corporation, currently working as the Systems Engineering Integration and Test (SEIT) lead for the Littoral Combat Ship Mission Package Integration program. His 30 years of engineering and management includes a wide involvement in systems engineering in the areas of requirements development, requirements analysis, system design, integration and test of systems for military platforms covering sea to space. Mr. Sondi earned a Bachelor of Engineering degree in Electrical Engineering from Manhattan College.

Tom Sondi
Northrop Grumman Corporation
Dept/MS (03674/W28-035), 925 South Oyster Bay Road, Bethpage, N.Y. 11714-3582
tom.sondi@ngc.com
Phone: 516 575-1646

Kenneth Michaud—Mr. Kenneth Michaud assumed his current responsibilities as Vice President of Pioneering Evolution in July 2009. Prior to joining Pioneering Evolution, Mr. Michaud was the Acquisition Manager for Littoral Combat Ship Mission Modules Program Office (PMS 420) under the PEO LMW from 2004 through his departure from Government service in July 2009. He served as a Subject Matter Expert in Program Management and Acquisition Management within the Government for over 18 years. Mr. Michaud is a graduate of Defense Acquisition University's Executive Program Management course (PMT 401) and the recipient of the Meritorious Civilian Service Award from the Department of the Navy.

Kenneth Michaud
Pioneering Evolution, LLC
1316 Independence Avenue SE, Washington, DC 20003
Kmichaud@pioneeringEvolution.com
Phone: (202) 546-0096 Ext. 5

Abstract

As OSD seeks to field new capabilities while working to reduce cost and risk, it becomes imperative that systems engineering tools evolve. Traditionally, cost/schedule monitoring, technology assessment, and performance analyses have been conducted as independent activities focused on systems. However, as systems become more complex and entwined into operating as components of System of Systems (SoS), the need for more insight during the design and development stages increases. This dictates the need for a

methodology for SoSs that allows for fully integrated analysis and trade-offs of the technical, cost, and schedule design spaces.

The US Navy (PMS 420, SSC Pacific), Northrop Grumman, and the Stevens Institute of Technology are collaborating to develop such a comprehensive financial and portfolio management methodology for SoSs. The concept leverages the System Readiness Level (SRL) as a measure of SoS development and coalesces a system performance monitoring approach that provides insight into both current and anticipated performance. Additionally, a methodology for understanding the impact of technical trades within a SoS is introduced. Together, these tools allow for a true trade-off analysis capability that can be used to examine the extent to which a set of technology options either meet budget constraints or maximize performance.

The Challenges of System of Systems Management

The Department of Defense (DoD) has seen a growth in the acquisition of SoSs over the last few decades. This trend is expected to continue as the DoD increases focus on capabilities without changing its system oriented acquisition organization. While providing significant opportunities for extending mission capabilities through the integration of existing and new capabilities into a synergistic SoS, there exists significant systems engineering challenges related to the integration and management of SoS. These engineering challenges are discussed in the *Systems Engineering Guide for Systems of Systems* (ODUSD(A&T)SSE, 2008).

One example of the challenge presently facing SoS Program Managers (PMs) is the understanding of the SoS technical maturity. Historically, the Technology Readiness Level (TRL) methodology has been a key gauge of the technical maturity for individual systems within the DoD for the better part of two decades. However, when TRL is applied to components within a SoS, the model of using individual technology maturity as a measure of readiness for SoS development quickly breaks down. TRLs simply do not account for integration maturity or the complexity of bringing together any number of independent technologies to function as a SoS.

Similar problems also become apparent with many other systems engineering and program management tools when applied in a SoS context, including Technical Performance Measures (TPMs) as used to track progress toward achieving Key Performance Parameters (KPPs) and Earned Value (EV) Management (to track cost/schedule). Existing tools simply do not provide sufficient insight into SoS development, contributing to a rash of complex development and acquisition projects that have gone astray. In a 2006 study (GAO, 2006, September 14) the Government Accountability Office (GAO) noted that a lack of insight into the technical maturity of complex systems during development has contributed to an environment of significant cost overruns, schedules slips leading to program delays, canceled acquisition efforts, and reduced system performance at fielding. In case after case, failure is most commonly not found at the technology development level, but rather at the point of a combination of two or more elements.

This paper provides insight to the methodologies and tools being developed and used by the Littoral Combat Ship (LCS) Mission Modules Program Office (PMS 420) to assist the PM and his staff in meeting the SoS development challenge.

The Mission Modules Program—An Acknowledged SoS Example

Acknowledged System of Systems Definition

The DoD *System of Systems Engineering Guide* defines an acknowledged SoS as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities. An acknowledged SoS has recognized objectives, a designated manager, and resources. Within an acknowledged SoS, the constituent Mission Systems (MS) retain their independent ownership, objectives, funding, development and sustainment approaches. Changes in the MSs are based on collaboration between the SoS PM and the MS PM. This complicates the task of a SoS PM and system engineer who must navigate the evolving plans and development priorities of the SoS constituent systems, along with their asynchronous development schedules, to plan and orchestrate evolution of the SoS toward SoS objectives.

The LCS Mission Modules Program as an Acknowledged System of Systems

The LCS Mission Modules Program Office (PMS 420) was established by the Assistant Secretary of the Navy for Research, Development, and Acquisition (ASN RD&A) on October 1, 2003 within the Program Executive Office–Littoral and Mine Warfare (PEO LMW) for the development, acquisition, and sustainment of the modular Mission Packages (MPs). The initial focus of PMS 420 was to take existing independent capabilities in the fields of surface warfare (SUW), mine countermeasure (MCM), and anti-submarine warfare (ASW) and to integrate and modularize those capabilities to provide deployable and swappable warfighting capabilities for the LCS. Thus, the LCS MPs meet the definition of being a SoS as they are made up of individual MSs, including vehicle, communication, sensor, or weapon systems; support equipment, including support containers, or vehicle cradles; software; mission crew detachments; and aviation systems; these are then integrated into a larger system to deliver unique capability. As the charter of PMS 420 is to acquire, integrate, modularize, and sustain focused warfighting capabilities from existing program lines, PMS 420 primarily serves as a Ships Acquisition Program Manager (SHAPM) with a focus on acquiring the individual mission systems from Participating Acquisition Resource Managers (PARMS) who manage existing product lines and programs of records. This lack of direct management responsibility for the individual mission systems means that the SoSs comprising the MPs are an acknowledged SoS.

Mission Package Explained

The hierarchal MP concept, illustrated in Figure 1, is best described in three layers.

These layers are:

- Mission System (MS) = a single Vehicle, Communication, Sensor, or Weapon System
- Mission Module (MM) = a combination of mission systems + Support Equipment + Software that provide a unique mission capability
- Mission Package (MP) = the collection of MMs + Mission Crew Detachments + Support Aircraft that provides the required ability to conduct a focused

warfighting mission as required by the LCS Capability Development Document (CDD).

A MP consists of MSs integrated into warfighting responsive MMs, mission crew detachment and mission configured aircraft with their composite aviation crew detachment. MMs combine MSs (vehicles, sensors, weapons) and support equipment that install into the Seaframe via standard interfaces.

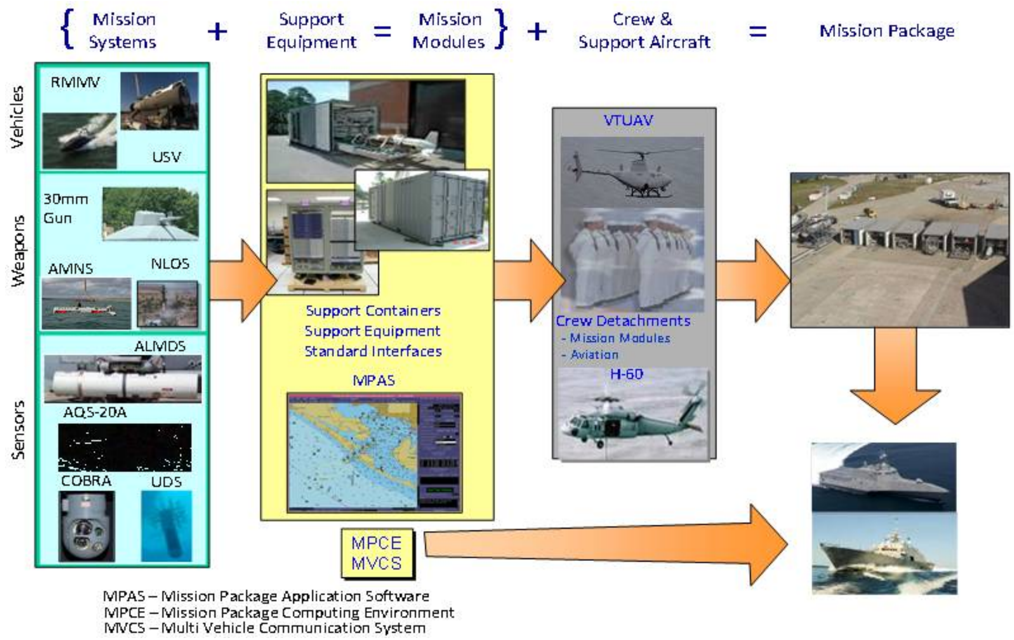

Figure 1. Mission Package Defined

MSs are sized to fit inside standard ten- or twenty-foot International Organization for Standardization (ISO) support containers (SCs), or on ISO compliant flat racks and vehicle cradles. Using ISO SCs simplifies shipping, storage, availability of correct handling equipment, and container movement from shore to ship and ship to shore as the Navy is able to leverage the intermodal transportation resources used for shipping commercial cargo worldwide. MP reconfiguration will occur in homeport or overseas, using pre-positioned MPs or MPs that have been transported into theater by air or sea and staged near the LCS operating area.

MPs can be swapped in order to reconfigure the ship for a different mission in a short period of time, giving a Combatant Commander a uniquely flexible response to changing warfighting requirements. To achieve this flexibility, the Navy is developing and procuring specific numbers of MPs to meet the Fleet's warfighting requirements. The quantity of each MP type differs based on analysis of projected operational needs.

Mission Package Status

The first two LCS ships, USS Freedom (LCS-1) and USS Independence (LCS-2), have been delivered to the Navy along with prototype MPs to the Navy for use in testing the designs and the concept of modular warfighting capability. The LCS MM Program (hereafter referred to as "the program") is presently proceeding to a Milestone B acquisition decision. The first three MPs (1 each of SUW, ASW, and MCM) have completed Design Readiness

Review (DRR) and are engaged in further developmental testing of their capabilities either independently in End-to-End (E2E) testing and/or by being integrated onto the LCS and tested as part of the Seaframes integrated warfighting capability. The rollout for the first MCM MP was on September 14, 2007. Phases 1 and 2 of E2E testing for MCM MP 1 were completed September 25, 2008, and August 19, 2009, respectively. Phase 3 of E2E testing for MCM MP 1 is scheduled for Summer 2010. The first ASW MP was rolled out on September 19, 2008. E2E testing for ASW MP 1 was completed April 3, 2009. ASW MP 1 Developmental Test (DT) is scheduled for Summer 2010. The first SUW MP was rolled out on July 11, 2008. E2E testing for SUW MP 1 was completed in July 2009. The first SUW MP was recently called on for an early deployment mission. In February 2010, LCS 1 deployed with the first SUW MP augmented with a prototype Maritime Security Module (MSM) to provide Visit, Board, Search, and Seizure (VBSS) capability to the Southern Command.

PMS 420 Progress on Addressing the Management Challenges for SoS Programs

PMS 420, since its founding, has recognized the challenge of leading an acknowledged SoS development and quickly began development of novel system engineering tools and methodologies, designed to ultimately reduce risk and provide enhanced management (technical, cost, schedule) insight into the SoS problem. Four initial areas of traditional programmatic concern have been developed to date. Lessons learned by PMS 420, approaches used and their benefits will briefly be discussed within this paper. These tools/processes include the areas outlined below.

1. SRL Used to Determine SoS Maturity Analysis: The System Maturity Model (SMM), developed by the Stevens Institute of Technology (SIT) and Northrop Grumman under funding provided by PMS 420. The SMM has been applied for the purpose of monitoring the maturity and integration status of individual technologies within the MP SoSs for PMS 420 and will be discussed in Section 3.1.
2. Requirements Management & the Drive towards Commonality in a SoS World: Requirements management is a significant challenge within an individual system development effort. This becomes even more challenging within the interrelated development environment of the three SoSs that PMS 420 faced. As an acquiring PM, PMS 420 has limited ability to impact Life Cycle Cost (LCC) of acquired capabilities. However, through implementation of an effective centralized and consolidated requirements management capability, PMS 420 is using commonality as a means to drive down cost. This approach will be expanded upon in Section 3.2.
3. Expanding Financial Management past EV: Financial and task management within a SoS is a complex task. PMS 420 required new processes and tools that could improve the PM’s ability to monitor and review task execution and earned value, support multi-year pre-planning of research, development, procurement, and sustainment efforts at warfare centers and contractors. In addition, there was a need for greater insight into the cost of risk management activities and a desire to reduce funding document touch-time and rejections rates. PMS 420 has developed such a tool, and a description of the tool and approach used by PMS 420 to accomplish this will be expanded upon in Section 3.3

4. Understanding and Influencing SoS Reliability: Traditionally, system reliability has been determined through the calculation of independent critical component reliability in the system and defined by the value of Operational Availability (A_o). In a SoS, especially in a mission-focused area, this approach may no longer be the best metric for use. PMS 420 has been evaluating an approach based on mission completion and the use of reliability block diagrams developed to represent mission strings, which will be expanded upon in Section 3.4.

In addition to the tools that have been developed to date, two additional areas will be presented that PMS 420 is presently investigating that are designed to further enhance the PM's ability to gain insight into understanding the status and risks associated with SoS development. These tools, while still under development and evaluation by PMS 420, are designed to assist the SoS PM in the areas of conducting capability tradeoffs and in the understanding of the ability to achieve required performance. Specifically, these tools are designed to provide insight into areas listed below.

1. Evaluating the Impact of Technology Insertion: One of the strengths envisioned from the MP SoS is their perceived ability to adapt to and rapidly and effectively incorporate new technologies that can provide increased warfighting capabilities. If the integration and maturation risks are not fully understood, a perceived improvement could actually lead to a decreased capability or significantly increased programmatic costs. To avoid these negative effects, PMS 420 has been developing a methodology to assess the impact of technology insertions in support of conducting tradeoff analysis. This proposed approach will be expanded upon in section 4.1.
2. Predicting SoS Performance: One of the challenges of an acknowledged SoS, is that the SoS PM may have little ability to monitor performance development of the individual systems. This issue is further complicated by the fact that individual system performance, when integrated into a SoS, may be different. How, then, can the SoS PM determine if they are on track to satisfy the KPPs for the SoS? PMS 420 has been developing a Performance Level Monitoring Model that seeks to provide the PM with this form of insight. The proposed approach will be expanded upon in section 4.3.

Systems Engineering Management and Insight in SoS Programs

As discussed in the previous sections of this paper, a SoS usually does not directly control the development of the majority of the technologies comprising the acknowledged SoS. This is a common situation and poses significant challenges to management in understanding where the end capability of a System stands with respect to providing the required level of performance as specified in the KPPs and the TPMs and in understanding the level of developmental and integration risk of the individual technologies composing the SoS. To resolve this area of engineering management concern, PMS 420 started the development of a portfolio of SoS Management tools. This section of the paper discusses some of these tools and lays the foundation for the later discussion of future efforts.

SRL Used to Determine SoS Maturity Analysis

LCS MPs will deliver required capability via the fielding of a series of incremental MPs until full capability that satisfies the LCS CDD is reached. For example, Increment 1 of the MCM MP provides capability for the detection and neutralization of volume and bottom mines. Increment 2 of the MCM MP introduces inshore detection capability via the Coastal Battlefield Reconnaissance and Analysis (COBRA) system. Increment 3 introduces additional MCM capability to the Fleet, including a magnetic and acoustic sweep capability to address the bottom/buried mines threat using the AN/ALQ-220 Organic Airborne and Surface Influence Sweep (OASIS) system. The full MCM baseline capability will be achieved by Increment 4 in FY17, which introduces the AN/AWS-2 Rapid Airborne Mine Clearance System (RAMICS), that neutralizes near surface and floating mines.

As presented to this symposium last year, in order to gain insight and manage the development maturity of these incremental deliveries, PMS 420 has implemented an emerging concept known as the SRL (Forbes, Volkert, Gentile & Michaud, 2009). By pairing the traditional TRL scale with a new series of criteria known as the Integration Readiness Level (IRL), a more complete look at true system maturity can be obtained (Sauser, Ramirez-Marquez, Magnaye & Tan, 2008). Under this methodology, the readiness of each technology is still considered, but instead of being a stand-alone metric for determining readiness for incorporation, it is analyzed in concert with both its integration requirements and the maturity of other technologies with which it interfaces. The calculation of SRL is described in the above-referenced papers. The SRL methodology has been highly successful on the program and has paid dividends in terms of both increasing decision-maker visibility into true system status and allowing for pre-emptive actions to be taken to mitigate potential developmental issues.

An example of the use of this approach by PMS 420 in understanding the impact to the program of technology options is shown in Figure 2, where the SRL for the initial configuration (on the left side of the figure) of the MCM MP number 1 is calculated as 0.57. In this configuration, one system component, the Multi-Vehicle Communications System for the Remote Multi-Mission Vehicle (MVCS (RMMV)), is early in its maturity and is lagging most other components, both in its technology and its integration readiness. This configuration resulted in a lower than acceptable overall SRL of 0.57, beyond the risk threshold of the program.

The program evaluated the replacement of this lagging component with the combination of a Data Link System (DLS) both on-board and on the RMMV, each of which have both better TRLs and IRLs. This is shown on the right side of Figure 2. In this manner, the overall SRL of the MCM MP 1 increased to 0.67, now within the range acceptable to the established risk threshold of the program.

The program has used this methodology to monitor developmental status by incorporating it into a continuing quarterly evaluation of the SRL level for each of the mission packages. This consistent evaluation allows the PMS 420 PM to better understand maturation of the individual MP SoS and of each increment within the SoS. In turn, this provides him with a greater understanding of the program's technical status, enabling the PM to better maintain and manage the development risk of the MPs as they progress through design and development.

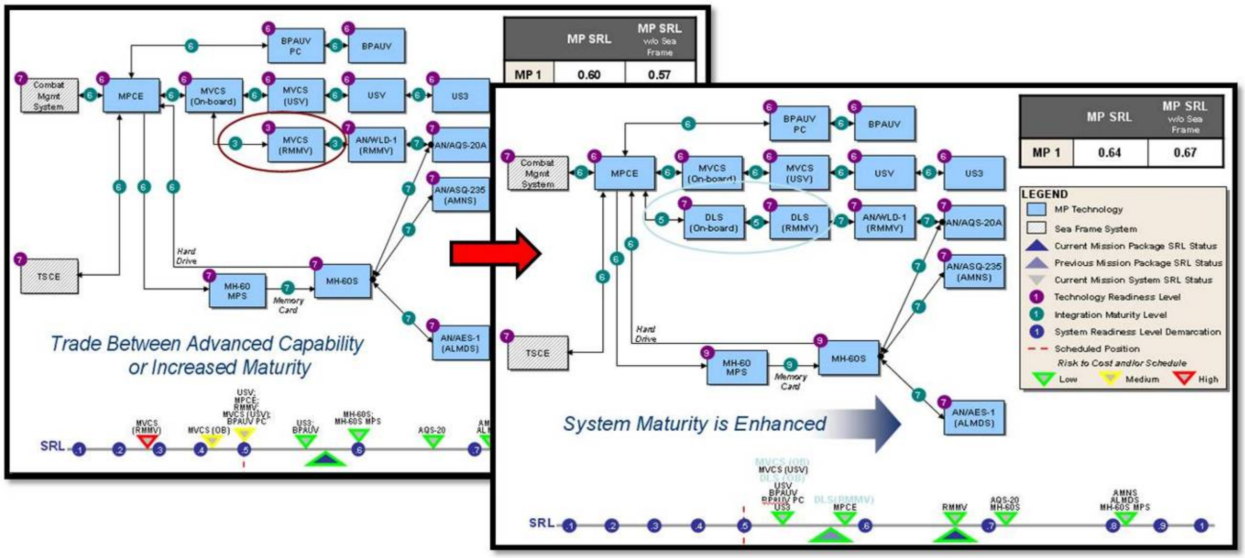

Figure 2. Initial and Enhanced Readiness of MCM MP 1

An example of the progress of the SRL level for two increments of the SUW MPs is illustrated in Figure 3 for the SUW MP. The graph demonstrates how the SRL value of different increments can be affected by both similar and [different] systems that make up the increments. The main dip in the graph (4-5) indicates a problem that was identified with a shared system between the increments discovered during interface testing, while the rise in the graph (5-6) demonstrates the results of correcting that identified problem. The lower overall SRL of the SUW Increment 2 is associated with the lower maturity level of one its component technologies, which is being consistently monitored by PMS 420.

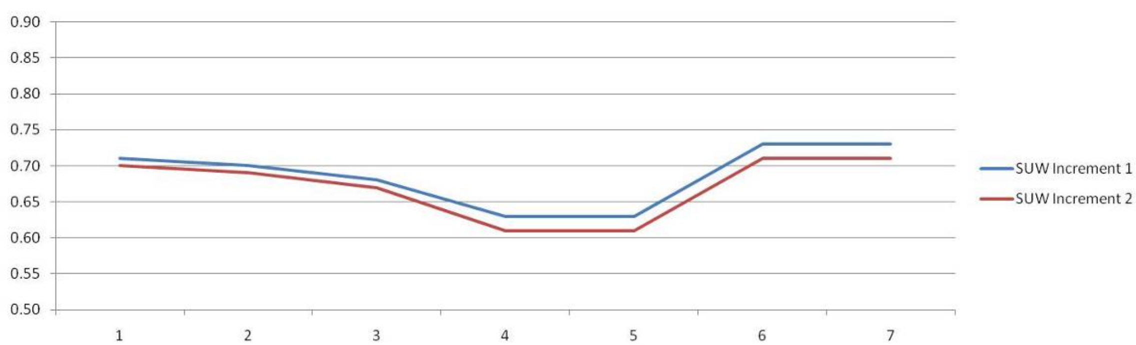

Figure 3. SRL Values Over Time

Since the initial presentation of the SRL method, the program has developed and documented a comprehensive process for System Maturity Assessments (SMA) and described its application to generic SoSs. The SMA process is iterative with a structured set of well-developed tasks that are described in detail in the *System Maturity Assessment Guide* (PMS 420, 2009) and illustrated in Figure 4. The first three steps of this process need only be conducted during initial system architecture development. Once the system architecture and subsequent system designs have been placed under configuration control, successive assessment iterations need only review the previous TRL and IRL criteria for any updates due to development progress and then recalculate the SRL with updates to reporting mechanisms conducted as needed. The fundamental basis of the SMA process is the proper creation of an assessment framework to include technologies, integrations, and their resulting architecture. It is also imperative that buy-in from all stakeholders be obtained in order to ensure common understanding among all participants with regard to both what will be evaluated and in what manner.

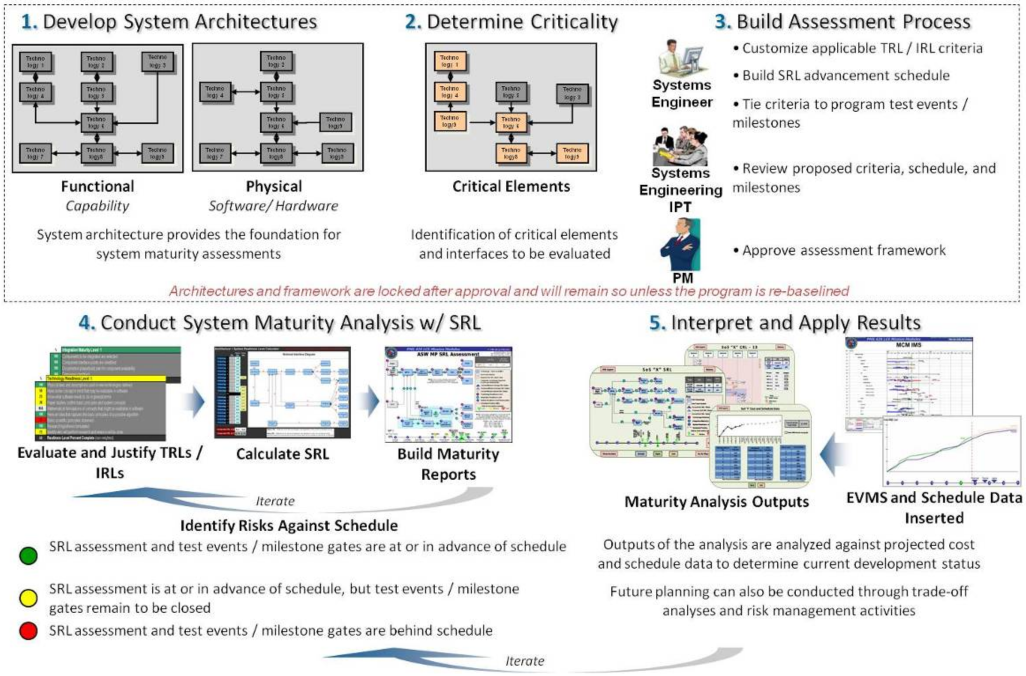

Figure 4. SMA Development Process Flow

Requirements Management & the Drive Towards Commonality in a SoS World

One of the more challenging of the SoS systems engineering tasks is the management of requirements. This is particularly acute in acknowledged SoS, where the PM does not have complete control of many of the constituent systems that are integrated into the SoS. For the program, this issue was made more acute by the initialization of the program on a “come as you are basis” based on the desire to explore the concept of modular MPs supporting a Seaframe using defined interfaces before fully investing in a full up acquisition program. This resulted in technologies being selected to satisfy the original performance requirements on a package-by-package basis. As the entire LCS program (Seaframes and MMs) developed, this concept of an experimental development morphed into a traditional acquisition program. The legacy of the initiation was a set of MPs with minimal commonality between the packages, as indicated on the left side of Figure 5. This approach, if continued, would result in increased LCCs for the support of the three MPs. While the way this issue was initiated for the LCS is slightly unique, the challenge of seeking to reduce LCC for a SoS in which the PM may not have direct control over the individual MSs and their designs is not.

The program is addressing this problem through the implementation of a structured and controlled process designed to introduce increasing levels of commonality across the various mission packages. The objective is to achieve a more flexible and controlled requirements and specification environment throughout the lifecycle development of MPs. To do this, the PMS 420 Systems Engineering Integrated Product Team (SE-IPT) established the objective of moving towards a target documentation structure, illustrated in the right-hand side of Figure 5. This structure is designed to provide a migration path over time towards common capabilities. Initially, each package defined its separate capabilities with a package-level performance specification. Due to the initial compressed developmental schedule and the drive to use existing Program of Record solutions, duplicative or near duplicative common capabilities were often observed across the other MPs, as illustrated on the left-hand side of the figure.

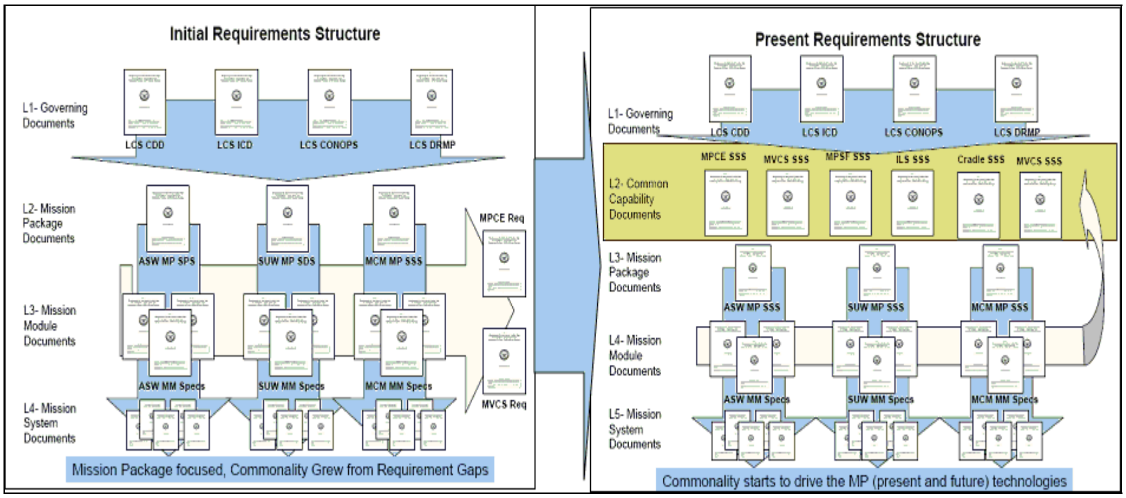

Figure 5. Modularizing the Structure of the Documentation Database

PMS 420, through the SE-IPT, has established a process to define commonality and modularize capabilities to support consistent re-use across MPs. In the first iteration of this process, several common MP components were isolated and established as a common set of requirements at the next level of specification below the governing requirements documentation. This adds a common layer that spans capabilities across individual MS boundaries, as illustrated on the right side of Figure 5, modularizing the designs and fostering re-use of capability. This objective was implemented early in package development, even while the three MPs were being developed under an accelerated schedule. While the limitations in technology and time prevented the implementation of desired common capabilities such as a common Unmanned Surface Vehicle (USV) between the MCM and ASW MPs, some commonality was achieved and implemented, including the design and use of a common USV cradle, common aviation support container designs, and other components.

In other areas, while the need for commonality across all three MPs was defined early, the ability to reach a common capability took time. These common capabilities included a modularized Mission Package Computing Environment (MPCE), and a common off-board unmanned vehicle communications capability, the Multi-Vehicle Control System (MVCS). Each of these common capabilities, i.e., MPCE has its own System/Subsystem Specification (SSS) and lower-level documentation. While PMS 420 designated these as common cross package capabilities to fulfill the identified needs of the three MPs, they have matured into requirements constraints on the existing packages. PMS 420 uses the development of a common set of interface requirements for defining the trade space for evaluating the value of incorporating new technologies within existing MPs.

This methodology, used for developing and transitioning MPCE and MVCS is now, through the use of an established requirements management and allocation process, being extended to extracted common requirements and supporting capabilities in such areas as Integrated Logistics Support (ILS), Safety, Shock and Vibration, and others. As this method continues to mature, it will provide the basis for defining the totality of the interface requirements that a new mission package would need to met to be effectively and efficiently integrated into the LCS MP SoSs. The next phase beyond that will be to extend the push for commonality down to the MM and MS levels to include the identification, development, and specification of common MSs across the MPs, including shared capabilities such as remote unmanned vehicles. It is anticipated that this will allow for increased modularity and re-use of other Commercial Off The Shelf/Government Off The Shelf (COTS/GOTS) technology.

Steady progress has been made in reaching this planned requirements structure of the DOORS database. The requirements allocation analyses for the Flight 0 CDD, Flight 0+ CDD and the LCS Interface Control Document (ICD) have been completed and the Level 2 MPCE and MVCS SSS documents and the Level 3 MP SSS documents are in the final stages of PMS 420 Configuration Control Board (CCB) approval. Formal configuration management (CM) process are used in updating and tracing the SSS documents to the CDD and ICD allocated requirements, which provides impact and traceability analysis capability to the MP level.

Cost Prediction and Monitoring of SoS

PMS 420 has been developing a SoS Online PM Tool that significantly improves the ability to manage the program. Its advantages are numerous, including:

a. Earned Value Management at all SoS levels, including the ability to examine the data across various cross-sections of the program, and forecast cost and schedule overruns at an early stage;

b. Support of multi-year planning of research, development, procurement, and sustainment efforts;

c. Risk management that associates risk with cost and impact;

d. Integrates a formal program change management process across all levels of the program;

e. Allows senior program management the ability to conduct what-if financial impact analysis without changing the baseline [what's the impact if system (A) is replaced with system (B)];

f. Links the Integrated Master Schedule (IMS) to task planning and task execution both at the system level and the SoS level;

g. Links the Acquisition Program Baseline (APB) to execution data. This gives the program manager critical insight into how lower-level system performance will impact the overall success of the SoS; and

h. Integration of the System Maturity Model into the Earned Value Management System (EVMS).

PMS 420 uses this tool in its monthly drumbeat process, shown in Figure 6. The web-accessible, CAC-enabled Online PM Tool integrates program planning and execution data (cost, schedule, and performance), ensuring proper visibility into who is doing what, how well it is being done and what has to be done next. Detailed task planning and execution data, coupled with clever organizational and reporting capabilities, have allowed the PM to connect program priorities and goals with past EV performance and future EV forecasting. The Online PM Tool provides the framework and business rules to establish and maintain process discipline. PMS 420, executing activities, and cross-functional stakeholders all have a "seat at the table." The real-time data availability promotes two-way communication and concurrence, enabling a successful egalitarian approach that would not be possible without the open web-based tool environment. This provides the PM with insight into potential challenges and has helped avoid and/or minimize program errors.

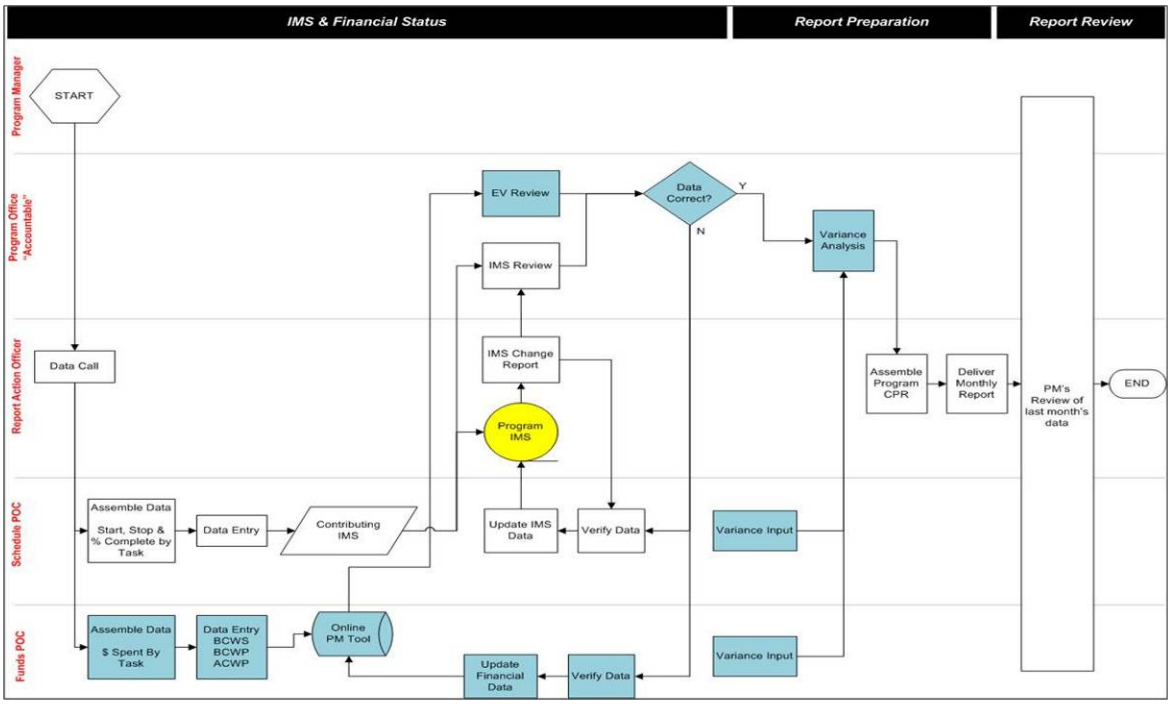

Figure 6. Monthly Drumbeat Process, Work Performance Insight and Reporting

The Online PM Tool has been developed using a process that incorporates key stakeholder requirements. Processes are mapped to distinct decision points and controls implemented to ensure results are achievable. The development team used an incremental build methodology to develop the Work Breakdown Structure (WBS), record processes, review tool development and obtain user feedback. The PMS 420 WBS is used as the unifying element for program information and all information in the Online PM Tool is associated with a specific WBS element. Individual task statements are assigned a specific WBS element and funding is then allocated to executing activities associated with the specific task statements. Execution data (earned value data and variance analyses) is reported against specific WBS elements, which are then displayed in EV reports. The detailed use of EV and detailed work plans identifies areas that require closer scrutiny, and have provided the PM with increased insight into work performance, as shown in Figure 7. Areas with excess or un-executable funds are also more easily identifiable, allowing those funds to be reallocated to other program priorities, as required.

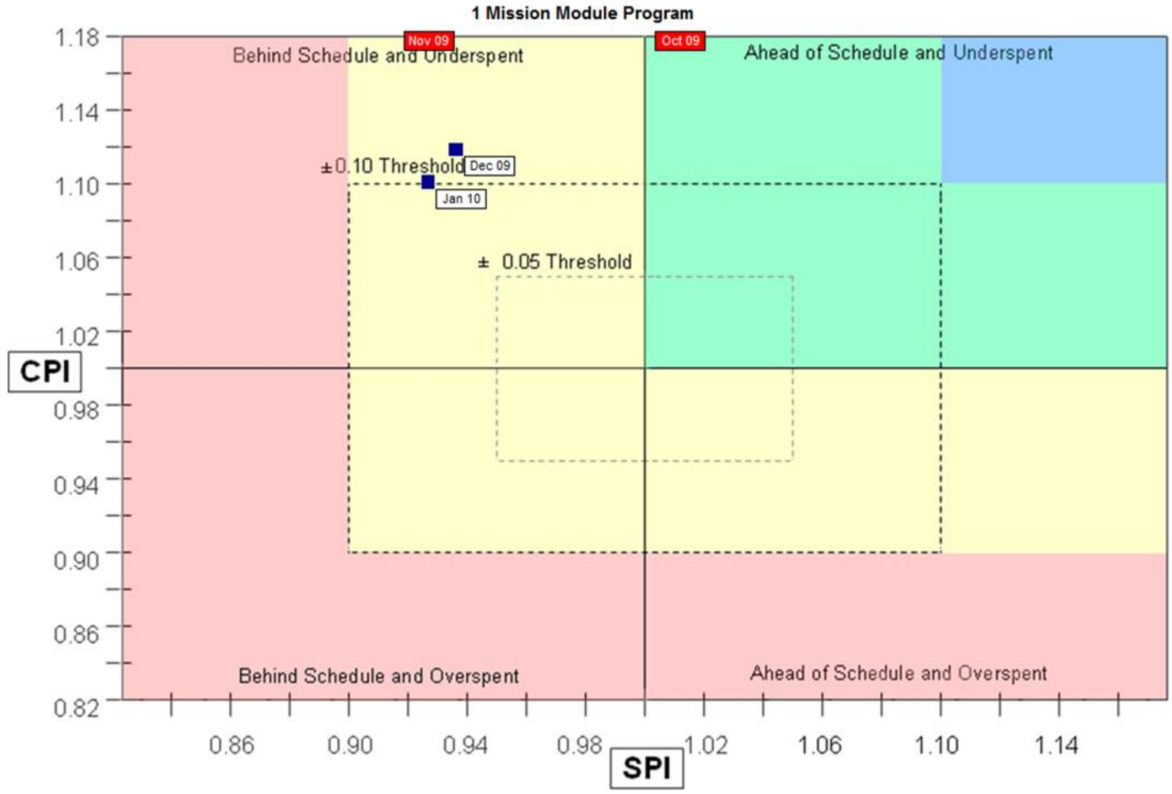

Figure 7. Work Performance Insight

PMS 420 uses the Online PM Tool to display, discuss and digest data during monthly drumbeat meetings. This has enabled the monthly drumbeat to evolve from a tool-centric execution status meeting to a more generalized program management meeting where Cost, Schedule, Risk and Performance are reviewed. This meeting has come to replace other routine meetings, concentrating PM efforts into a single day and freeing program office staff to do other work. Snapshot documents, i.e., program Cost Performance Report and Integrated Master Schedule, are created using the tool to summarize and synthesize data into information, record this information for historical purposes, and provide senior management with real-time status of program health.

PEO-level reporting is accomplished through a PEO Dashboard, which provides senior executive-level insight into all programs in the PEO. Senior management has the ability to view planning and execution performance data across program offices, executing and performing activities, contractors, enterprise mission capabilities, lifecycle stages, and across SoS and Families of Systems. PEO Quarterly Execution Reviews (QER), previously an arduous process of data collection and validation, are accomplished through the use of the PEO Dashboard and Online PM Tool. The PM can generate a PEO-level summary of the same data used to manage the program, and the PEO can request deep-dives into areas of interest or concern.

Understanding and Influencing SoS Reliability

Availability is a more complex problem for the SoS than in traditional systems. This arises primarily out of two attributes of many SoSs; the use of modular systems design, and the ability of the SoS to accomplish multiple mission capabilities using various components of the SoS. The program has been addressing this availability issue through several analysis approaches and the development of tailored methods linked to the planned operational concepts of the MP SoSs.

The use of traditional availability and reliability tools, such as reliability block diagrams (RBDs), Failure Mode Evaluation and Criticality Analysis (FMECA), and others are well understood and there is much experience in industry with their application. However, in a SoS, these methods are faced with two added demands. First, the introduction of modularity, open system design, and remote operations produce increasing number of components and, therefore, more opportunity for component to component failures. Some of the impacts on operational availability in such extended systems are indicated in the list below:

- The mission component string is inherently less reliable because we increase the number of serial components in the mission/operational function;
- Extended Unmanned systems require set up time and the potential for damage is increased because of the increased handling, in addition the deployment and recovery environment and handling systems design introduce opportunities for damage;
- Infrastructure Over-head can be over whelming in the particular adaptation of modular Plug and Play (P&P) design approach (weight, extra services, handling operations, software and hardware overhead); and
- Deployment of remote systems have security challenges (physical and data related).

The second added demand is that of multiple mission capabilities and flexibility in configurations to achieve them. Simply stated, we typically have more capabilities provided by the SoS, and can execute the capability with several combinations of components. Some of the challenges introduced by this flexibility are described in the list below:

- Operational use is constrained during a specified time period;
- Operational use may use a small percentage of the mission suite, depending on the mission, e.g., for MCM, mapping, identification, clearing; and
- Operational environment may call for a different subset of equipment to be used in a deployment.

In the case of the program, we have the following specific issues that we must address:

- The majority of the elements of a MP are different and widely distributed interfaces will affect the availability;
- The organic off board vehicles can be utilized differently each mission;
- The utilization of mission equipment per mission will vary—alternative mission equipment may be substituted;
- The deployment and utility times will vary based on operational mission goals;
- Ship Availability is a component of the MP architecture; and

- Software reliability in MPCE and MVCS needs to be considered.

An additional issue for the program (and becoming prevalent in other SoS) is that the requirement for MP availability is defined in terms of a Materiel Availability KPP. Materiel Availability (A_m) for the LCS MPs is established with a threshold of 0.64 and an objective of 0.712. There is no specified separate requirement for the traditional A_o, since the LCS CDD indicates that "it is embedded in the Materiel Availability KPP." A novel methodology has been applied to analyze and decompose A_m, resulting in an approach that separates A_m into two components. The first, called Active Availability (A_a), is a factor that is a function of fleet-level support design, including such components as depot-level repair requirements, fielding, deployment, and support strategies. The second is the traditional A_o, defined at the fleet level and computed as the average of squadron or unit level A_o.

In this fashion, a clear definition of A_m for the program is developed and represented by $A_m = A_a * A_o$. Monte Carlo simulations and support parameter investigations are being used to determine the impact on MP A_m. Initial results indicate that target parameters for A_a and A_o with their impact on A_m could be established as given in the example in Table 1.

Table 1. Example LCS MP A_m Composition

CDD Requirement	Target A_a	Target A_o	Target A_m
Threshold .64	0.887	0.738	0.655
Objective .712	0.887	0.809	0.718

Using this A_m decomposition and simulation method, it is possible to establish requirements for both A_a and A_o that can be allocated to the MPs and further decomposed to their individual MM and MS components. The primary use of the A_m decomposition method is to establish support concepts and strategies that will establish a defined level of A_a. After A_a is clearly established, A_o can be determined using the equation $A_o = A_m / A_a$. This provides target A_o requirements that can be allocated to the MPs and their components. To address the above issues, Operational component strings for the various mission functions are defined. An example of this is shown in Figure 8

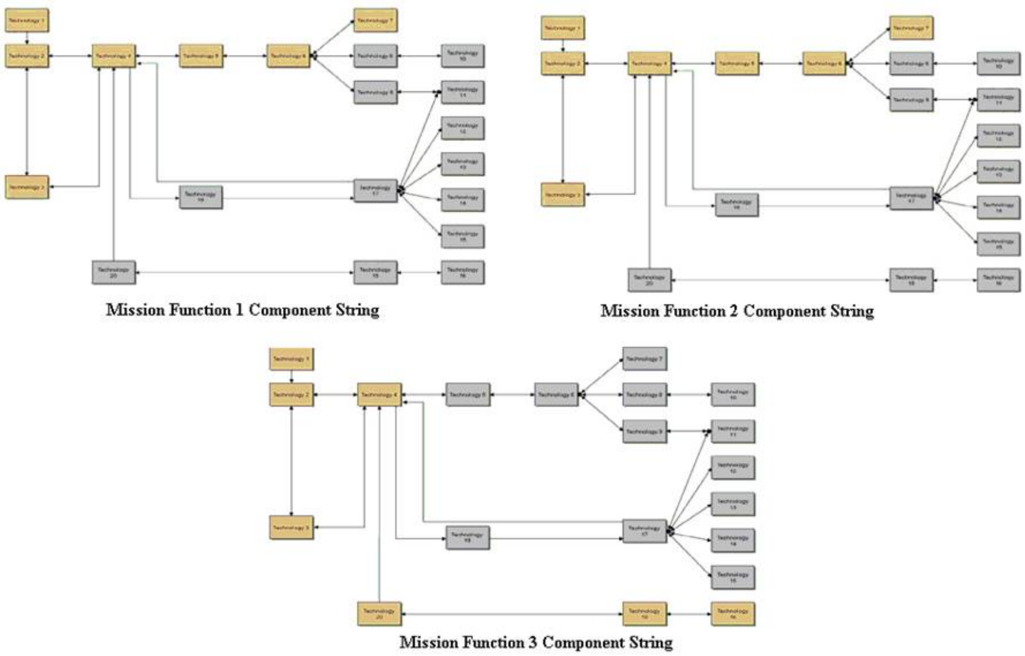

Figure 8. Mission Function Component Strings

The following steps are then performed on the individual mission strings:

- Operational strings were analyzed to identify the components required to execute independent mission functions of the system;
- An assessment of the string to achieve a Mission A_o contribution is performed;
- Common components (nodes) that form a critical function in more than one mission function are identified, and operational time is calculated for each mission it touches over the deployment cycle; and
- Allocation of the Mission A_o decomposes to an A_o requirement at the component, Line Replaceable Unit (LRU), level.

Currently, the program is evaluating the use of the mission function strings, decomposition of the A_o for the mission to individual components, and a Monte Carlo simulation for mission A_o analysis. The goal is to determine individual component A_o requirement targets and determine the impact of these on MP A_o and, therefore, on the A_m threshold and objective requirements.

Expanding the Tool Set—Technology Trades & SoS Performance Predictions

The existing tool set has been invaluable to enabling the PM to gain increased insights into the developmental status and risks associated within a complex SoS. PMS 420 has now begun working to expand upon the foundation of those tools and the system readiness monitoring capabilities provided by implementation of the SMM methodology and is seeking to expand the technical and programmatic tools and methodologies available for the PM. Specifically, there exists the need for tools to assist the PM in understanding the impacts of technology insertion options and to gain insight into predicted SoS performance, enabling the more effective conduct of tradeoff analysis. This analysis would assess SoS performance and capability objectives and provide recommendations enabling the PM to make choices that optimize the SoS on the basis of cost, technical risk, or anticipated performance.

Technology Insertion & SoS Analysis

One of the primary benefits of the modular approach to SoS development is that new technologies capabilities can be rapidly incorporated to improve reliability, performance, or reduce LCCs. However, comparable technologies when integrated may result in significantly different integration risks, performance impacts across the SoS, and reliability or cost impacts. How to decide on what technologies to change and which technologies to select is an area of critical interest to PMS 420 as the MPs mature from development and enter their operational lifecycles.

As the SoS technologies reach their designed or actual limits (of cost, performance, etc.), they should be reviewed for replacement by newer or more robust technologies that would provide improvement to the SoS optimization, performance, and capabilities. The existing methodologies and incorporation of tools developed to date by PMS 420 have provided the program with an unprecedented view into the details of the status of the SoSs. The difficulty lies with combining the various details to provide the PM with a current composite view into the SoS to support analysis and impacts related to changing technologies within the existing SoS. A composite view would enable the PM to determine if a proposed Technology would generate performance beneficial or detrimental to the SoS, would have a budget that is proportional to established values—that is, reaching the end of its lifecycle— would bring too much risk to the SoS, would be within the physical constraints (size, mass, etc.) of the SoS, and more.

The question is how to review several technologies that could be added to the SoS and determine the best candidate based upon the desires of the PM. To make this decision consistently and without bias, a modified version of the Analytical Hierarchical Process (AHP) will be utilized. With AHP, PMS 420 can assign several categories and sub-categories that the various technologies will be rated against, such as Cost, Physical Constraints, SRL, Reliability, etc. The scores from the categorical comparison of the technology ratings will then be weighted by the needs and desires of the PM (e.g., budgetary constraints). The result will be a list of the current and potential technologies ranked in order of recommended choice. A basic example of this hierarchical calculation is shown in Figure 9.

Technology Analysis and Insertion Tool Development

The difficulty with utilizing the technology analysis and insertion calculation is its complexity and the need to allow for easy modification to the weighting parameters and ratings of technologies. In the complex world of program acquisition, there are times that this calculation will need to be finished in a relatively short period of time, demanding an implementation that is prompt, dependable, unbiased, and accurate. Much of the data that is needed for the calculation is spread out in many tools and locations and would need to be accessed for the calculation to produce meaningful results.

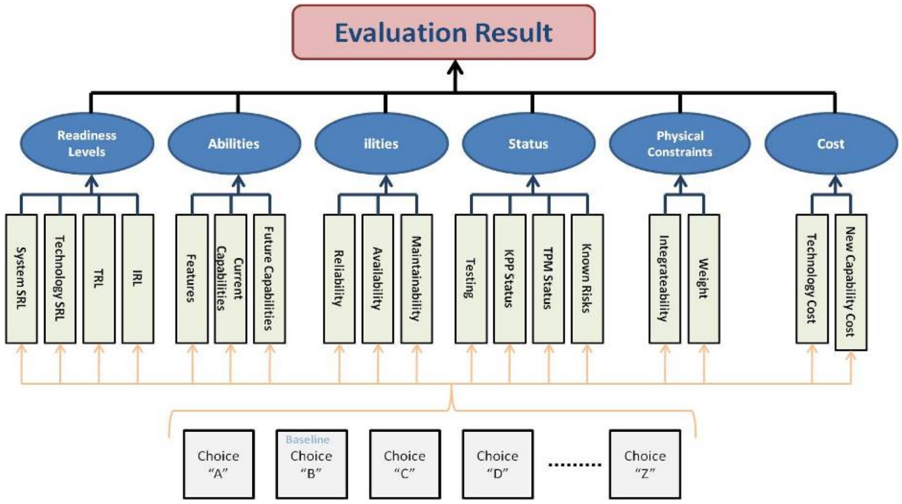

Figure 9. Technology Analysis Hierarchy

The solution to these issues is to maximize the usage of the current tools while minimizing the footprint of a new one. We have been working with the SIT to develop and test a SRL calculation plug-in for an architecture tool, as a distributable example. Building off of this starting point, we have designed this trade-off tool to act as a substantial plug-in to the program's already established architecture modeling tool. By leveraging the SoS architecture that is already developed and being maintained and by adding small changes to the architecture tool's data model, the new trade-off tool will function with the established architecture tool, greatly reducing the learning curve.

The small modifications to the architecture tool data model will not impact any of the existing programmatic data that is currently captured, nor will it impact the normal architecture review cycles. (As the data model can easily be expanded to incorporate the new fields, it can be designed to fit into DODAF 1.x and 2.0 versions.) The modified fields will capture the ranking data that relates to the Technology Analysis and Insertion calculation in the configuration controlled environment of the Architecture Model. The information for technologies that are not currently part of the SoS would be populated into the architecture tool. A small modification to SIT's existing SRL calculation plug-in, will enable it to work in this design (different architecture tool's commands). The weighting values for the criteria will be entered by the PM and securely stored. The outcome of the calculation will be a ranked list of choices for the position within the SoS. A basic representation of the tool is shown in Figure 10.

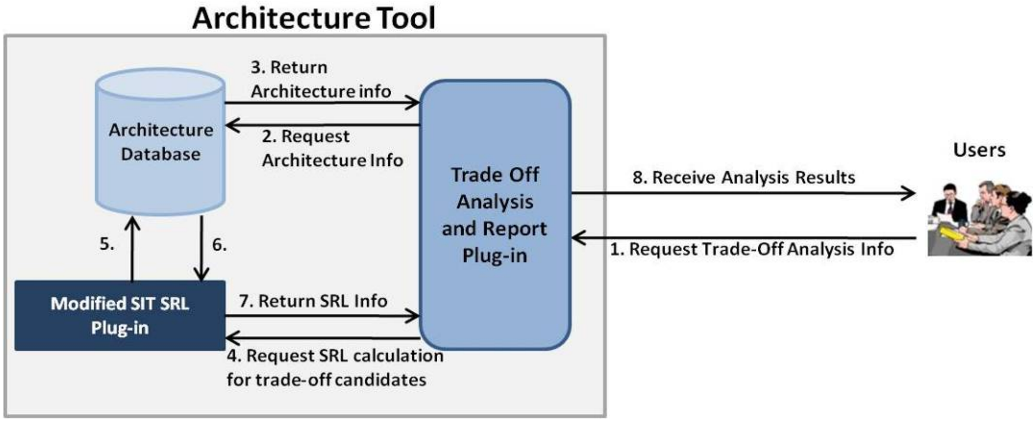

Figure 10. Technology Analysis and Insertion Tool

Prediction of Performance Using a Performance Level Monitoring Methodology

Through system development, PMs are expected to quantifiably justify that their program will result in the delivery of a system with the required performance. The traditional PM has several technical and program management tools at their disposal, including TPMs, Modeling and Simulation, etc., that provide insight and predictive capability in system performance. When the program matures to a point at which actual test data can be gathered, it is compared against expected system performance. Due to the complex nature of SoS interdependencies, PMs are especially challenged when asked to quantifiably justify the investment in time, personnel, financial, and material resources in the program during SoS development.

Traditional program and technical management tools must be extended to provide the necessary insight to the acknowledged SoS environment. Given that the performance of a SoS is directly dependent upon the performance levels of the individual systems composing the SoS, as these capabilities are being independently developed by PARMS (over which he has limited directional authority and who may be developing the capabilities to fulfill a different set of performance metrics or may be unwilling to share detailed technical status with external organizations). Even where the individual MS performance may directly translate to a SoS KPP area, the nature of MP SoS and its Concept of Operations does not mean that it provides the total answer. In various scenarios, the individual MP KPPs can be achieved through using various combinations of the systems within the SoS. For example, the LCS may decide to engage Fast Inshore Attack Craft (FIAC) with either the LCS's core gun, capabilities onboard the MH-60 helicopter, the 30mm Gun Mission Module (GMM) (of the SUW MP), or eventually the missiles of the Surface to Surface Missile MM (of the SUW MP). All of which can in full or in combination satisfy individual KPPs for the SUW MP. This estimation of performance difficulty is further complicated when the SoS is being developed in an incremental manner. Again using the SUW MP as an example, the first SUW MP is currently installed onboard LCS-1 and includes two 30-mm Gun Mission Modules, an Aviation (MH-60R armed helicopter) MM, and a prototype MSM. The first SUW MP does not include the Surface-to-Surface Missile MM (based on the NLOS-LS), which will be added in Increment 2. Understanding the capability provided by MP increments and ultimately whether the baseline (full capability) MP will satisfy the full set of performance requirements is of interest to the PM. A final complication is that when conducting SoS and incremental acquisition of this nature, complete E2E test and evaluation (T&E) may not be feasible and computer intensive modeling and simulation may not be practical in a schedule driven environment or where the SoS PM may not have the full technical models of the individual systems. So within these limitations, how can the PM gain insight into, and predictive capability for, determining the ability of the SoS to achieve required performance?

To answer these questions, PMS 420, in conjunction with SSC-Pacific, Northrop Grumman, and the SIT, has been expanding the SMM to incorporate a Performance Level Monitoring (PLM) methodology. The PLM is being developed to understand if the performance will satisfy the KPPs and to understand the deltas in performance between the initial MPs and later MP increments, which will provide the full-up MP capability. Ultimately, this tool will also support the analysis of mission threads using different MP configurations, i.e., providing insight in performance capability of the MCM MP if one of its USVs is down for maintenance and/or as a tool for evaluating the impact of incorporating new capabilities or changing existing capabilities within a MP.

Performance Level Monitoring Explained

The PLM strives to apply a modified TPM type approach to a SoS construct. However, instead of focusing on a measurable technical value that can be monitored during development within a individual system, the PML links the SoS KPPs to individual component capabilities, their maturity, and their potential usage. The SMM, Concept of Operations (CONOPS), and usage rate variance analyses are all considered in the PLM calculation.

To implement this process, significant up-front evaluation will be required by the SoS program office. The first step of the methodology is to define the SoS MP in terms of it component MSs and to map those systems and their capabilities to their projected impact on satisfying the MP KPPs. The individual MS capabilities are then adjudicated by the SoS PM in terms of their maturity and inclusion within an individual MP, breaking them into three generic categories of Advanced Developmental Models (ADM), Engineering Development Modules (EDM), and Production Models (PROD) that are mapped to their expected maturation points over the analysis timeline. This adjudication of systems is represented through the use of a weighting function to represent the individual capability's maturity (real or anticipated) for each level of development. While this method works well for MS that are not integrated with others to deliver required capability, such as the GMM, this becomes more complex when two or more systems must come together to provide a level of capability such as a MM, for example the combination of the ASW USV MS and the USV Towed Array System (UTAS) to provide a passive search capability. Fortunately, the ongoing development of the SMM concept allows for a potential approach by using the value calculated for the MM SRL. The individual technologies can then be weighted in terms of their contribution to the accomplishment of the capability and be combined into a series of capabilities or MM values. The integrated MM capabilities can be expressed as a single value where the level of capability that the module comprised of capabilities (x, y, and ..) that can contribute towards the satisfaction of the MP KPP requirement given the level of maturity of the capability in the MP.

The next stage of the PLM is to define the impact of various CONOPS on the ability of the SoS to satisfy the KPP requirements. As one of the strengths of a SoS is its inherent flexibility where component systems can be organized to solve the capability problem, this can often be translated to where the individual capabilities may be used in varying ways to accomplish the same mission. These varying CONOPS result in increased complexity for the analyst in trying to predict what level of performance is being achieved. While modeling and simulation tools can be used to conduct this type of analysis, the variations would make this an expensive and time-consuming process for the program and would not provide the PM with the rapid insight into options that maybe required. To address this issue, the PLM seeks to develop a set of scenarios for each of the MP SoS that represent the range of potential operational usage concepts for the individual capabilities (or modules) within the SoS as applicable to each KPP and incremental MP. This enables the derivation of a set of equations relating the KPPs to their component technologies and to a specific CONOP. The set of CONOPS, each reflecting an anticipated level of performance and technical maturity/integration of a specific capability (x) at a specific point (for this example as represented by a specific mission package) in time (n) are then matrixed together to enable a calculation of the overall predicated performance of the SoS across a range of scenarios. When conducting the analysis, the exact usage rate for each of the MS/MM may be unknown. In this case, running the analysis for each CONOPS using a minimum, maximum, and average anticipated usage rate for each capability/module can be used to develop a set of error bars in performance predictions. As a tool for the management of risk and for predicting when performance will be achieved or to understand the potential impact of changes, a graphic similar to the traditional TPM graphic can then be constructed by calculating composite KPP values for each MP increment and plotting the composite level of performance against time.

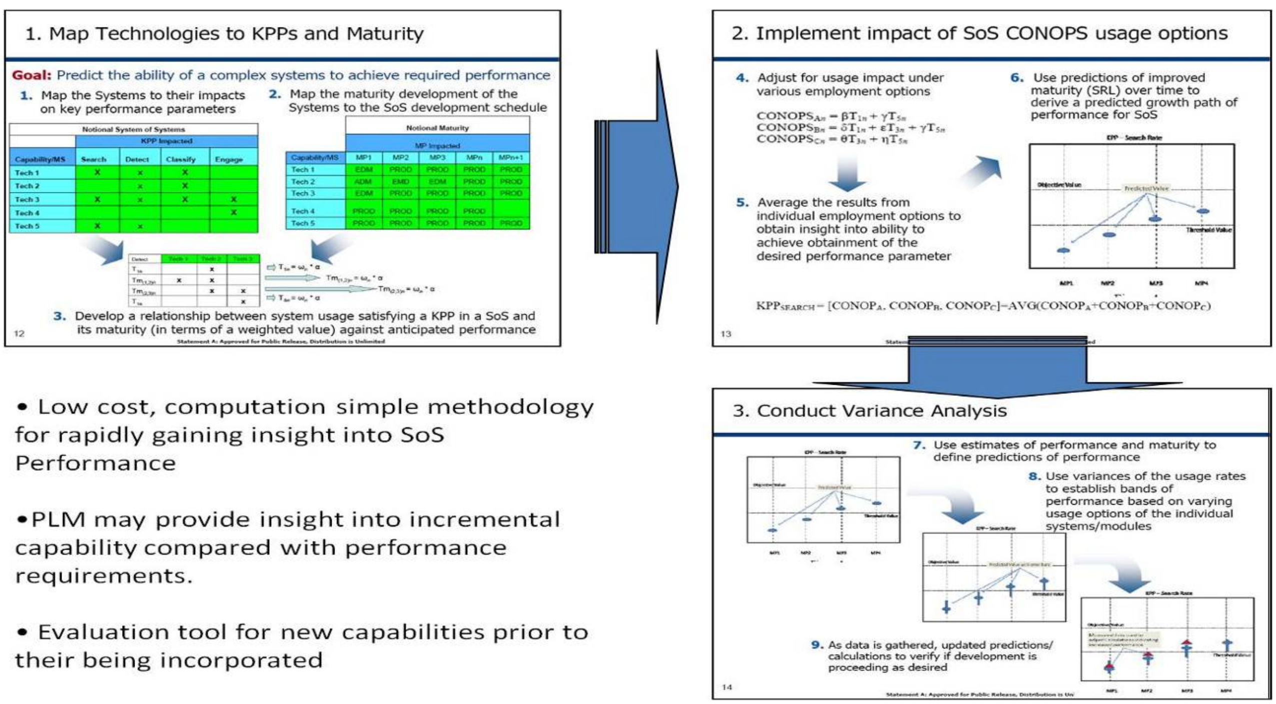

Figure 11. Performance Level Assessment Methodology

The intent behind the PLM is to provide the PM necessary insight into incremental capability compared with CDD performance requirements. As with all predictive models, the analysis will need to be compared against measured test data as it becomes available to verify predictions and identify if the program is on course to meet CDD performance requirements. Figure 11 provides a graphical flow of the methodology described above and a more detailed description of this methodology can be found in *Notional Assessment Methodology for KPP Accomplishment in a SoS: Proposed Methodology for Measuring Performance Progress within a System of Systems (SoS)* (Volkert, 2009). This methodology has been further expanded upon by SIT at this symposium (Tan, Sauser, Ramirez-Marquez, Magnaye, Nowicki & Deshmukh, 2010). A projected further expansion of this methodology will be to allow for the evaluation of new capabilities prior to their being incorporated into a planned upgrade or replacement of an existing capability.

Conclusion

The increasing use of the System of Systems (SoS) model for the fielding of new and improved warfighting capabilities poses new management challenges for the DoD. To support the Program Manager, the US Navy (PMS 420, SSC Pacific), Northrop Grumman, and the Stevens Institute of Technology have been collaborating on the development and verification of a set of comprehensive financial and portfolio management methodologies for acknowledged SoSs. The tools and capabilities that are being developed, discussed, and expanded by PMS 420 reflect the real-world challenges facing a SoS PM and reflect valuable lessons learned to date within the LCS Mission Modules program. Starting with the field of technology maturation, the team has developed the standard TRL methodology into a concept that develops a System Readiness Level (SRL) measurement as a measure of SoS integration and maturity. This methodology has been demonstrated and has been used as the developmental springboard into an approach for determining and predicting the probability of achieving system performance and for understanding the impact of technical option trades. Financial tools have been developed and implemented that allow the PM to gain insight beyond that afforded by traditional EV reporting and that can provide management assistance in resource allocation in dynamic programs. The maturation of the requirements management process for a SoS was discussed and the capabilities of using it as a tool for reducing Life Cycle Cost presented. The process described dictates the need for a methodology for SoSs that allows for fully integrated analysis and trade-offs of the technical, cost, and schedule design spaces. While SoS show great promise for providing flexible and cost-effective provisioning of capabilities to the DoD, the evolution of management tools will need to continue to advance in order to allow for the more efficient application of scarce resources from the conception of program initiation. Otherwise, SoS Program managers may be forced to continue to face many of the challenges PMS 420 has been through and will need to expend resources in solving those management challenges vice applying the resources to product development.

References

Forbes, E., Volkert, R., Gentile, P., & Michaud, K. (2009). Implementation of a methodology supporting a comprehensive systems-of-systems maturity analysis for use by the littoral combat ship mission module program. In *Proceedings of the Sixth Annual Acquisition Research Symposium*. Monterey, CA: Naval Postgraduate School.

GAO. (2006, September 14). *Best practices: Stronger practices needed to improve DOD technology transition processes* (GAO-06-883). Washington, DC: Author.

PMS 420, Littoral and Mine Warfare, US Navy. (2009). *System maturity assessment guide*. Scientific and Technical Reports, Littoral Combat Ship Mission Package Program. Washington, DC Navy Yard.

ODUSD(A&T)SSE. (2008). *Systems engineering guide for systems of systems* (Vers. 1.0). Washington, DC: Author.

Sauser, B.J., Ramirez-Marquez, J.E., Magnaye, R.B., & Tan, W. (2008). System maturity indices for decision support in the defense acquisition process. In *Proceedings of the Fifth Annual Acquisition Research Symposium*. Monterey, CA: Naval Postgraduate School.

Tan, W., Sauser, B., Ramirez-Marquez, J., Magnaye, R., Nowicki, D., & Deshmukh, A. (2010). System capability satisficing in defense acquisition via element importance measures. In *Proceedings of the Seventh Annual Acquisition Research Symposium*. Monterey, CA: Naval Postgraduate School.

Volkert. (2009, September). *Notional assessment methodology for KPP accomplishment in a SoS: Proposed methodology for measuring performance progress within a system of systems (SoS)* (PMS 420 White Paper).

2003 - 2010 Sponsored Research Topics

Acquisition Management

- Acquiring Combat Capability via Public-Private Partnerships (PPPs)
- BCA: Contractor vs. Organic Growth
- Defense Industry Consolidation
- EU-US Defense Industrial Relationships
- Knowledge Value Added (KVA) + Real Options (RO) Applied to Shipyard Planning Processes
- Managing the Services Supply Chain
- MOSA Contracting Implications
- Portfolio Optimization via KVA + RO
- Private Military Sector
- Software Requirements for OA
- Spiral Development
- Strategy for Defense Acquisition Research
- The Software, Hardware Asset Reuse Enterprise (SHARE) repository

Contract Management

- Commodity Sourcing Strategies
- Contracting Government Procurement Functions
- Contractors in 21st-century Combat Zone
- Joint Contingency Contracting
- Model for Optimizing Contingency Contracting, Planning and Execution
- Navy Contract Writing Guide
- Past Performance in Source Selection
- Strategic Contingency Contracting
- Transforming DoD Contract Closeout
- USAF Energy Savings Performance Contracts
- USAF IT Commodity Council
- USMC Contingency Contracting

Financial Management

- Acquisitions via Leasing: MPS case
- Budget Scoring
- Budgeting for Capabilities-based Planning

- Capital Budgeting for the DoD
- Energy Saving Contracts/DoD Mobile Assets
- Financing DoD Budget via PPPs
- Lessons from Private Sector Capital Budgeting for DoD Acquisition Budgeting Reform
- PPPs and Government Financing
- ROI of Information Warfare Systems
- Special Termination Liability in MDAPs
- Strategic Sourcing
- Transaction Cost Economics (TCE) to Improve Cost Estimates

Human Resources

- Indefinite Reenlistment
- Individual Augmentation
- Learning Management Systems
- Moral Conduct Waivers and First-tem Attrition
- Retention
- The Navy's Selective Reenlistment Bonus (SRB) Management System
- Tuition Assistance

Logistics Management

- Analysis of LAV Depot Maintenance
- Army LOG MOD
- ASDS Product Support Analysis
- Cold-chain Logistics
- Contractors Supporting Military Operations
- Diffusion/Variability on Vendor Performance Evaluation
- Evolutionary Acquisition
- Lean Six Sigma to Reduce Costs and Improve Readiness
- Naval Aviation Maintenance and Process Improvement (2)
- Optimizing CIWS Lifecycle Support (LCS)
- Outsourcing the Pearl Harbor MK-48 Intermediate Maintenance Activity
- Pallet Management System
- PBL (4)
- Privatization-NOSL/NAWCI
- RFID (6)

- Risk Analysis for Performance-based Logistics
- R-TOC AEGIS Microwave Power Tubes
- Sense-and-Respond Logistics Network
- Strategic Sourcing

Program Management

- Building Collaborative Capacity
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Collaborative IT Tools Leveraging Competence
- Contractor vs. Organic Support
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to AEGIS and SSDS
- Managing the Service Supply Chain
- Measuring Uncertainty in Earned Value
- Organizational Modeling and Simulation
- Public-Private Partnership
- Terminating Your Own Program
- Utilizing Collaborative and Three-dimensional Imaging Technology

A complete listing and electronic copies of published research are available on our website: www.acquisitionresearch.org

THIS PAGE INTENTIONALLY LEFT BLANK

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL
555 DYER ROAD, INGERSOLL HALL
MONTEREY, CALIFORNIA 93943

www.acquisitionresearch.org