SYM-AM-18-059

PROCEEDINGS
OF THE
FIFTEENTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

WEDNESDAY SESSIONS
VOLUME I

Acquisition Research:
Creating Synergy for Informed Change

May 9–10, 2018

Published April 30, 2018

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

DoD'S Software Sustainment Ecosystem: Needed Skill Sets and Gap Analysis

Forrest Shull—is Assistant Director for Empirical Research at Carnegie Mellon University's Software Engineering Institute. His role is to lead work with the U.S. Department of Defense, other government agencies, national labs, industry, and academic institutions to advance the use of empirically grounded information in software engineering, cybersecurity, and emerging technologies. He has been a lead researcher on projects for the U.S. Department of Defense, NASA's Office of Safety and Mission Assurance, the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation, and commercial companies. Dr. Shull serves on the IEEE Computer Society Board of Governors and Executive Committee. [fjshull@sei.cmu.edu]

Michael McLendon—is an Associate Director at Carnegie Mellon University's Software Engineering Institute. Previously, he served as Senior Advisor in the Office of the Assistant Secretary of Defense for Systems Engineering. He was also a principal in the Office of the Assistant Secretary of Defense for Program Analysis & Evaluation and also in the Office of the Under Secretary of Defense for Policy. He was a professor at the Defense Systems Management College and a career Air Force officer, serving in a range of leadership and management positions in system and technology development and acquisition as well as the federal level and the private sector. [mmclendon@sei.cmu.edu]

Christopher Miller—is a Senior Researcher at Carnegie Mellon University's Software Engineering Institute. Dr. Miller's expertise is in software metrics, measurement, and estimation of software intensive systems. His quantitative analysis background is focused on lifecycle cost estimation, evaluating project feasibility measures, establishing performance measurements, and providing analysis for the optimization of systems. Dr. Miller served as the Chair of the International Council on Systems Engineering (INCOSE) Measurement Working Group (MWG) for seven years and is a certified trainer for Practical Software and Systems Measurement (PSM). He earned a Master's of Engineering Management and PhD in Systems Engineering at the George Washington University and is currently a member of the adjunct faculty in the School of Engineering and Applied Science (SEAS). [clmiller@sei.cmu.edu]

Introduction

Software is the foundational building material for the engineering of the Department of Defense (DoD) systems—the principal means for delivering almost 100% of the integrated functionality of kinetic weapon systems. Software is also the means for creating warfighter competitive advantage in today's net-centric warfare environment, where the flow of information in real time is critical to the execution of the DoD's mission across all domains. There is no plateau in sight for the advancement of software technology and its extensive use by the DoD in new systems, as well as to enhance the capabilities of legacy systems and extend their operational value far beyond their designed service life.

To maintain its competitive edge, it is imperative that the DoD have the capability and capacity to affordably acquire and sustain software-reliant systems to continually operate and achieve mission success in a dynamic threat, cyber, and net-centric environment. However, the DoD is strategically challenged to produce high-quality software more affordably and efficiently across the system lifecycle, as noted by the Defense Science Board (2000) and others (National Research Council [NRC], 2010a). The acquisition and sustainment of software, particularly for distributed real-time and embedded systems, remains high risk and more problematic as individual system and system-of-systems complexity continues to grow.

As long recognized, successful acquisition of software-intensive systems by the DoD is driven to a significant degree by the competencies of the DoD's organic software engineering workforce in applying evidence-based knowledge and practice throughout a system's lifecycle (Software Engineering Institute [SEI], 1998). In a prior study, we emphasized the need to better address software sustainment issues, particularly by engaging appropriate software expertise at the right points early in the acquisition lifecycle, when critical engineering decisions are made (Shull & McLendon, 2017). This means that the DoD organic software engineering sustainment community must be an active participant early in the requirements and engineering process and that the product support manager in acquisition programs must be knowledgeable and proactive in representing software sustainment equities.

Achieving this early engagement to influence software design-for-sustainability requires DoD organic software engineering staff who are not just knowledgeable about software but also "street-smart" in system acquisition. Many DoD sustainment programs with which we have interacted over the last few years have been separately developing software workforce competencies to enable effective engagement early in the acquisition process.

In this paper, we synthesize what we have learned to date regarding an initial model to assist the DoD in thinking about DoD software engineering competencies. We emphasize that this is an initial model recognizing that defining workforce competencies is complex and also dynamic given the nature of software and system sustainment policies.

Research Goal, Scope, and Methodology

Our research goal was to characterize the state of the practice regarding the DoD's software sustainment workforce with respect to the range of roles and related skills required, from which an initial model of the relevant competencies could be created. We also captured some of the recurring challenges related to workforce issues and the role of contractor versus the DoD organic software sustainment workforce in addressing those challenges.

This work was conducted in the context of ongoing work focused on software sustainment in weapons systems; therefore, the direct applicability of our results are limited to that domain. Software in this domain can typically be characterized as embedded software (i.e., software that interacts with physical components to provide functionality for the overall weapons system). Acquisition of embedded software presents some of the most technically difficult and resource-intensive software engineering challenges because of tightly coupled interfaces, integration with unique hardware, real-time requirements, and very high reliability and assurance needs due to life-critical and mission-critical demands. However, the DoD has a substantial amount of software across many other domains: business systems; mission support systems (e.g., test equipment, mission planning, engineering models, and simulations); mission-critical, non-embedded systems; and modeling and simulation, among others. While our initial results can be used to understand the software workforce issues for other types of software-intensive systems, a more detailed description of how to tailor results for those domains is a subject of future work.

Our team leveraged multiple streams of data and information for this study.

- Literature Search—The body of knowledge related to software engineering is extensive. However, there has been limited systematic study focused on DoD software sustainment; therefore, there is no organized set of literature and ongoing study or research agenda to create and refresh a software sustainment body of knowledge
- SEI DoD Engagements—The SEI has been actively engaged with the military services for three decades to provide technical expertise to enhance organizational capabilities (processes, practices, and competencies) for

software engineering across the lifecycle and solve technical challenges for specific weapon system and information system programs.

- Interviews With Key Leaders—The SEI complemented its research with information from meetings with key leaders across all four Services, including (1) those in the Senior Executive Service (SES), (2) senior managers and staff in the Office of the Secretary of Defense (OSD), and (3) those from industry. This study was conducted at the unclassified level, and our interviews with DoD sustainment staff were conducted under the conditions of non-attribution to enable an open exchange of perspectives with senior leaders, managers, and staff engaged in software sustainment.

Context: Workforce Issues in the Software Sustainment Ecosystem

Results from our prior research indicate that the DoD's software sustainment infrastructure is best described and understood as an *ecosystem* composed of interrelated elements. We found over and over that the factors that drive software sustainment are highly interrelated. For example, it is difficult to discuss the workforce needed to perform necessary sustainment activities without first understanding the business model in terms of public-private partnerships, which activities can be done by contractors, and which activities need to remain in the organic DoD workforce. Decisions about the nature and types of these business models may also be influenced by the degree to which the government has provisioned for and exercised its technical data rights for a given program at the time of developing an acquisition strategy and contract. These decisions have implications for the scope of the software sustainment system. Because of the high degree of connectivity that exists among the drivers and factors, we use the metaphor of an "ecosystem" to describe the interdependencies among these elements; decisions made at any point are affected by and affect whole series of other decisions.

Based on our research, we created a framework that describes the software sustainment ecosystem, depicted in Figure 1. We abstracted the issues raised in our discussions with DoD sustainment stakeholders into *six demand drivers* and 10 *ecosystem elements*, which were described more fully in a prior paper (Shull & McLendon, 2017).

The six demand drivers, shown in the outer ring of Figure 1, represent requirements that are generated by changes in the weapon system's mission profile, funding availability, evolution of the underlying technologies, and so forth. These drivers capture the fact that DoD systems exist in an environment that is highly dynamic, where there is a need to respond to constantly changing threats and mission needs. This dynamism drives many of the system changes that must be made during software sustainment. For many of these changes, the most cost-effective way of implementing the new capability relies on the unique flexibility of software.

The 10 ecosystem elements, shown as interconnected "bubbles" in Figure 1, are the tightly interconnected factors that sustainment organizations must manage to effectively and continuously engineer the software. The drivers and elements of this ecosystem represent a virtual spider web of linkages and relationships.

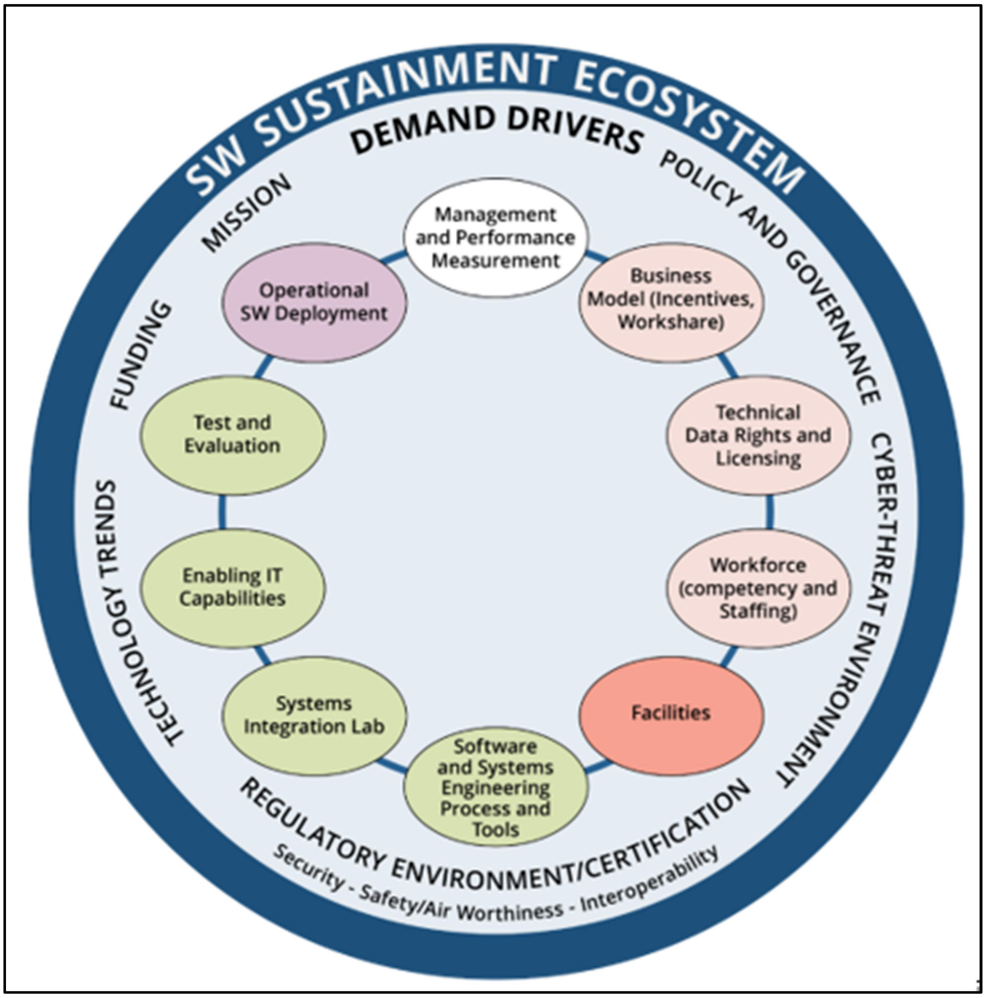

Figure 1. The DoD Software Sustainment Ecosystem Framework

Among these ecosystem elements, the three **knowledge and expertise** elements (shown in light orange in Figure 1) are most closely related to workforce skill sets. These elements include the factors that describe how the necessary skill sets are brought to bear for sustainment activities, and how the government grows its organic workforce and accesses necessary technical information—perhaps with some level of interaction with the private sector—to deliver and deploy the capabilities that must go to the warfighter. They consist of the following:

- **Workforce (Competency and Staffing)—**The means of accessing a sufficient workforce with appropriate skill sets, as well as a balance of organic and non-organic staff
- **Business Model (Incentives, Workshare)—**The strategic decision regarding which parts of the work will be done by the organic workforce and which by contractors, and how the overall work is managed both technically and contractually
- **Technical Data Rights and Licensing—**The tactical decisions governing what technical information is necessary to be accessed by the organic workforce, and the mechanisms by which they have access and the ability to maintain their working knowledge

Historical Context of DoD's Software Workforce

Several DoD studies dating back to 1982 have raised concerns about the technical competencies and size of the DoD's software workforce.[1] The key threads from previous relevant studies are summarized below. We argue that the DoD today remains challenged to find the highly skilled systems and software engineers needed now and in the future.

As early as 1993, the DoD Acquisition Management Board identified the need to review the DoD's software acquisition management education and training curricula, which was the first attempt by the DoD to establish a set of software acquisition management key competencies for the acquisition workforce. At that time, no existing DoD workforce functional management group was responsible for identifying the software competencies needed in the workforce. The board asserted that no new career field was needed for software acquisition managers and also made a key assumption. The board assumed that some personnel in acquisition programs clearly require more knowledge of software development and acquisition management than others, and that within each program there was an experienced individual fulfilling that role.

By 2001, the same concerns regarding the software competencies of the DoD acquisition work-force surfaced again. The DoD Software Intensive Systems Group, then in the Office of the Deputy Under Secretary of Defense for Science & Technology, conducted a software education and training survey of the acquisition workforce (SEI, 2017a). The findings from this study led to three specific recommendations: (1) Institute mandatory software-intensive systems training for the workforce, (2) develop a graduate-level program for software systems development and acquisition, and (3) require ACAT 1 programs to identify a chief software/systems architect.

A year later in 2002, Congress mandated in the NDAA for fiscal year 2003 that the DoD establish a program to improve the software acquisition processes. Subsequently, each Service established a strategic software-improvement program (Army 2002, Air Force 2004, and Navy 2006). These Service initiatives have continued at some level; however, with the sun setting of the Software Intensive Systems Group at the OSD level, the enterprise focus on software has waned.

In 2006, the DoD once again recognized that the sound application of modern software technologies and the use of sound software engineering practices over the acquisition lifecycle was critical to program execution given the increasing reliance on software in DoD systems. As a result, the DoD sponsored an industrial base study (Chao, 2006) to assess the nation's software workforce. The study concluded that while the nation's overall supply of software engineers may be adequate for the near term, there was a significant shortfall in the number of "top tier" software managers, architects, and domain experts. More importantly, the study estimated that perhaps as few as 500 engineers had the skills to develop the DoD's complex, software-intensive systems. This study did not specifically address the DoD's demand for government software engineers in acquisition

---

[1] Defense Joint Service Task Force Report on DoD Software Action Plans, 1982; Report of the Defense Board Report on Military Software, July 1987; Adapting Software Development Poli-cies to Modern Technology, Air Force Studies Board, National Research Council, 1989; DoD Information Systems Workforce Education, Training, and Career Development, Executive Re-sources Task Force Report, October 1992; DoD Software Master Plan, DAB S&T Committee, February 1990.

and sustainment, but as recognized by the DoD, it reported that these “shortfalls in top tier talent are evident there as well.” The National Defense Industrial Association echoed similar concerns about the need for software knowledge and skills in its 2008 Report on Systemic Root Cause Analysis of Program Failures.[2]

During this same period, the Navy started the Software Process Improvement Initiative (SPII), which identified issues preventing software-intensive projects from meeting schedule, cost, and performance goals. This initiative highlighted the lack of adequately educated and trained software acquisition professionals and systems engineers. Subsequently, the Navy SPII Human Resources Focus Team recommended that the DoD use the findings from the Navy’s report as a baseline to analyze the software competencies of the acquisition workforce.

As the result of this focus on the software workforce, the OSD issued guidance to create the Software Acquisition Training & Education Working Group (SATEWG) with a charter to affirm required software competencies, identify gaps in Defense Acquisition Workforce Improvement Act (DAWIA) career fields, and develop a plan to address those gaps. This group was composed of representatives from the Services, the OSD, and other organizations, including the SEI. The group developed a software competency framework that identified four key knowledge areas and 29 competencies that could inform the different acquisition workforce managers about the software competencies to be integrated into their existing career field competency models (Lucero, 2010). There has been no follow-on effort to evaluate the progress of the SATEWG or its outcomes.

More recently, each Service, as well as at the software sustainment organizational level, has evolved its own approach or model for identifying software competencies for its workforce. For example, one model in the DoD is based on establishing a software competency based organization with skilled people, processes, tools, mission facilities, and core technologies to support program teams and other customer needs. This model is enabled by a standard skills package that provides a description of the unique competency skills and associated criteria necessary for individuals to gain certification at one of three levels. In this competency-based organizational model, software staff are assigned as appropriate to serve as members of a program office functional engineering team or a software sustainment organization. As of 2018, the DoD Information Technology (IT) Functional Integrated Product Team (FIPT) has responsibility for DoD software workforce competencies.

This historical context highlights two key points. First, the DoD has long recognized the challenges of addressing the technical competencies and size of the software workforce across the lifecycle. However, there is limited evidence these different efforts had any lasting impact or resulted in meaningful outcomes. Second, this history clearly indicates that acquiring software human capital and equipping that workforce with the necessary competencies is a persistent and dynamic challenge that demands a continuous enterprise strategy. Our engagements with the DoD’s software-sustainment organization clearly demonstrate the strategic and practical challenges in dealing with these issues.

---

[2] https://www.ndia.org/-/media/sites/ndia/divisions/systems-engineering/ndiasrcareportfina18dec2008.ashx?la=en

Challenges in the State of the Practice

A key challenge today is that there is no visibility into the number of personnel in the DoD's software sustainment organic workforce, and even less insight into the skills and background that they bring to their job.

Figure 2 shows 2016 data (the most recent we could find) that identifies the DoD's engineering workforce by occupational code and size as well as the number of personnel who are considered to be part of each acquisition engineering career field. (Those personnel engaged specifically in software sustainment represent a subset of these numbers.)

From this view, the software workforce in the DoD, whether in acquisition programs or organic sustainment organizations, cannot be accounted for at the DoD or Service enterprise levels. It is also not clear if all engineers across the DoD engaged in software sustainment are known. Based on our interviews, the principal engineering occupational codes most represented in the software sustainment workforce are 0855, 0801, 1550, 0854, and 0850. However, a list of all government personnel in these codes does not capture all government personnel performing software engineering duties.

DoD-Wide

Engineering (Non-Construction)

Civilian Occupational Series & Description	Count
0801 - GENERAL ENG	16,493
0802 - ENG TECHNICAL	10,691
0806 - MATERIALS ENG	840
0818 - ENG DRAFTING	2
0830 - MECHANICAL ENG	11,129
0840 - NUCLEAR ENG	2,430
0850 - ELECTRICAL ENG	3,458
0854 - COMPUTER ENG	3,486
0855 - ELECTRONICS ENG	16,413
0856 - ELECTRONICS TECHNICAL	5,574
0858 - BIOENG AND BIOMEDICAL ENG	99
0861 - AEROSPACE ENG	4,287
0871 - NAVAL ARCHITECTURE	866
0873 - MARINE SURVEY TECHNICAL	118
0881 - PETROLEUM ENG	1
0893 - CHEMICAL ENG	807
0895 - INDUSTRIAL ENG TECHNICAL	993
0896 - INDUSTRIAL ENG	1,044
0899 - ENG AND ARCH STUDENT TRAINEE	1,197
GRAND TOTAL	79,928

Engineering (Non-Construction)

Component	Count
Army	19,025
DoN	41,687
Air Force	15,381
4th Estate	3,835
GRAND TOTAL	79,928

Defense Acquisition Workforce

Acquisition Engineering Career Field

Civilian Occupational Series & Description	Count
0855 - ELECTRONICS ENG	10,730
0801 - GENERAL ENG	7,869
0830 - MECHANICAL ENG	5,976
1550 - COMPUTER SCIENTIST	3,496
0861 - AEROSPACE ENG	2,907
0854 - COMPUTER ENG	2,523
0850 - ELECTRICAL ENG	1,423
1515 - OPS RESEARCH ANALYST	659
1310 - PHYSICIST	553
0893 - CHEMICAL ENG	499
OTHER (INCLUDING ACTIVE DUTY MILITARY)	4,690
GRAND TOTAL	41,325

Acquisition Engineering Career Field

Component	Military	Civilian	Total Count
Army	0	9,063	9,063
DoN	224	21,019	21,243
Air Force	1,403	7,546	8,949
4th Estate	0	2,070	2,070
GRAND TOTAL	1,627	39,698	41,325

Data Sources:
Engineering (Non-Construction) – Defense Civilian Personnel Data System, 31 March 2016
Acquisition Engineering Career Field – USD(AT&L) Defense Acquisition Workforce Data Mart, 31 March 2016

Figure 2. DoD Engineering Workforce

It is clear that the DoD's software-sustainment organizations place a high priority on software human capital across the cycle of recruitment, retention, and training in what is a highly competitive market. Since the DoD organizations engaged in software work are distributed across the country, geographic constraints (i.e., locations in parts of the country without substantial commercial software industry) can be challenging. However, there are numerous examples of innovative DoD approaches to building relationships with colleges and universities to enhance recruiting and provide for continuing education.

Our engagements with software-sustainment stakeholders identified several challenges these organizations face in their ability to hire, develop, and retain the skills of this critical organic workforce. The most relevant of these challenges are highlighted below.

- Each software-sustainment center is challenged by the fact that there can be great diversity in knowledge and understanding about software engineering among new hires. Such new hires come from different engineering disciplines and educational programs, where there may be limited emphasis on software engineering. As a result, there are often significant gaps in knowledge and practical skills. These gaps must be filled to enable a new hire to be productive in an organization that has standards, practices, and a defined software engineering lifecycle development process. During our study, we noted and confirmed with software engineering managers that entry-level engineers do not appear to have been exposed to secure coding practices or vulnerable code detection as part of their education or previous on-the-job experience. Further, these entry-level engineers tended to know about vulnerabilities in code but were not aware of how these vulnerabilities could be exploited, the impact of that exploitation, or how to detect and fix these vulnerabilities.

  There is a larger issue at hand regarding the diversity of knowledge and understanding of new hires coming into the DoD software-sustainment workforce. Cyber-physical systems (including weapons systems) pose exceptional technical challenges to systems and software engineering practitioners. Many software engineering academic programs emerged out of computer science- and math-focused programs, requiring little in the way of classical engineering courses in physics, electronics, chemistry, and mechanics. Systems engineering academic programs grew out of the classical engineering programs, requiring little in the way of software engineering competencies. As a result, systems and software engineering graduates are well prepared to work on computational systems, but fewer graduates are well prepared to work on cyber-physical systems (e.g., weapon systems). Further complicating this challenge is that those trained in computer science and those trained in software engineering have different skill sets.

  The root cause of this issue is beyond the ability of the DoD's organic software engineering and sustainment organizations to solve. However, this issue highlights the significant challenge faced by software sustainment centers in filling the gap in terms of the practical competencies required for continuous engineering of software intensive systems. How to best and affordably fill this workforce competency gap is a DoD and Service enterprise challenge.

- The number of different software languages and versions of those languages used in the DoD's legacy systems is staggering and creates significant challenges in achieving and sustaining critical competencies. Within this diversity of programming languages, the use of the Ada language presents a critical challenge to the software-sustainment centers because Ada still represents a significant portion of the software code base in use within the DoD. This is problematic for the DoD across the workforce since Ada is no longer commonly taught or supported outside of legacy DoD applications. Thus, there is no college or university pipeline for training and education or ongoing development of tools. Further, the DoD is no longer the driver of the technology marketplace as it was decades ago, so it has limited ability to influence the selection of programming language within the supply chain.

The graph in Figure 3 highlights this point. This data is taken from a snapshot of DoD software data that has been collected from certain programs and analyzed by the SEI (2017b). By far, the C family of programming languages dominates in terms of the software in DoD systems. (The C family includes C, ANSI C, C++, C#, C/Assembly, and C# Net languages.) Ada represents another substantial subset and, therefore, will continue to be a challenge.

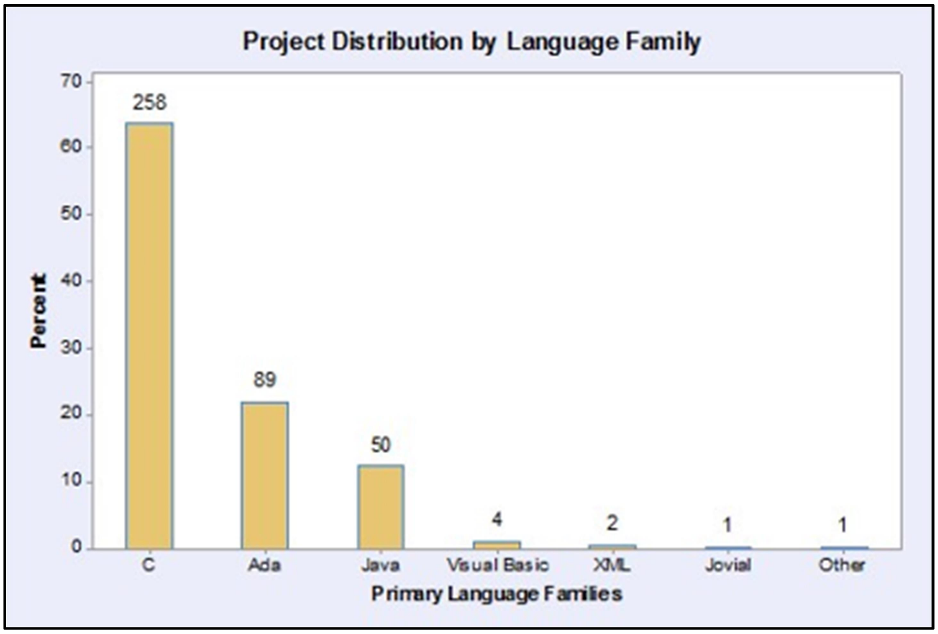

Figure 3. Distribution of Software Languages

- Managing the dynamics of an aging workforce in the DoD is not unique to the software-sustainment workforce. However, our view is that this fact-of-life issue for the sustainment community may be exacerbated by several factors. The DoD must continually make adjustments to accommodate a decline in the acquisition of new systems while the service life of legacy systems is extended in the force structure. This, in turn, creates a demand for the workforce to be continually refreshed in legacy system technical knowledge and skills. The software sustainment environment is inherently dynamic due to technology and mission demands, the evolving nature of program-by-program decisions regarding public-private partnerships, and cyber demands. Finally, there is lead time associated with acquiring and training software human capital, which means it is critical to plan for the organic software-sustainment workload as early as possible in the acquisition process.

  A challenge we heard repeatedly from all levels of organizational leadership and management was the slowness of the government hiring process. Analysis of the talent acquisition process was beyond the scope of this study, but those we interviewed cited many examples of this problem. In a competitive marketplace, interested recruits are unlikely to stay available for the weeks or months required for the DoD human resources process to complete. In our view, this behavior is out of sync with the tenets of the DoD's

Better Buying Power policies, which emphasize imperatives such as greater productivity and efficiency.

A Model for Analysis of Inherently Governmental Responsibilities and Needed Skills

To facilitate DoD programs thinking through their software workforce issues, we propose that the DoD first focus on identifying critical organic engineering competencies needed for specific programs, domains, and technologies. The DoD should use this list of competencies to identify gaps in the current organic workforce and ensure that a pipeline of talent is constantly being recruited. What we mean by *workforce pipeline* is a mechanism by which junior personnel are explicitly mentored by senior personnel to avoid the risks that skill gaps open up when personnel leave the project for any reason. An important part of this analysis is understanding what skills must be established and maintained in a government software engineering organization for it to perform inherently organic software engineering functions. A key element in this analysis is determining the software engineering functions that can be appropriately performed by a supplemental workforce.

This proposed approach is based on recognition that software sustainment is an *engineering activity*, a very different model from hardware sustainment. In many instances, software changes directly enable weapon system capabilities and/or overall system performance in support of maintaining national security. Therefore, there must be certain functions that are inherently governmental (i.e., required for the government to perform) to understand the technical baseline and then exercise technical authority to make appropriate engineering decisions. This implies the need for a model describing the engineering functions, capabilities, and competencies needed to perform sustainment and continually refresh the software technical baseline.

As an initial model, Figure 4 depicts one view of key weapons systems depot-level software sustainment functions, which the SEI study team developed. The software engineering functions in the center of Figure 4 represent the basic processes that create software. These activities are based on current software engineering standards, which were derived from ISO/IEC 2167a. The functions on the perimeter of Figure 4 represent activities related to the ecosystem elements and other functions the SEI team identified during Phase I and Phase II activities and site visits of DoD maintenance facilities.

Not all the functions depicted in this model are performed by every software sustainment organization. These functions can be decomposed and analyzed to identify associated technical task requirements. These requirements can then be analyzed to determine the competencies (skills, knowledge, and experience) necessary to execute those tasks. Following this logic leads to defining a baseline set functions, tasks, and competencies.

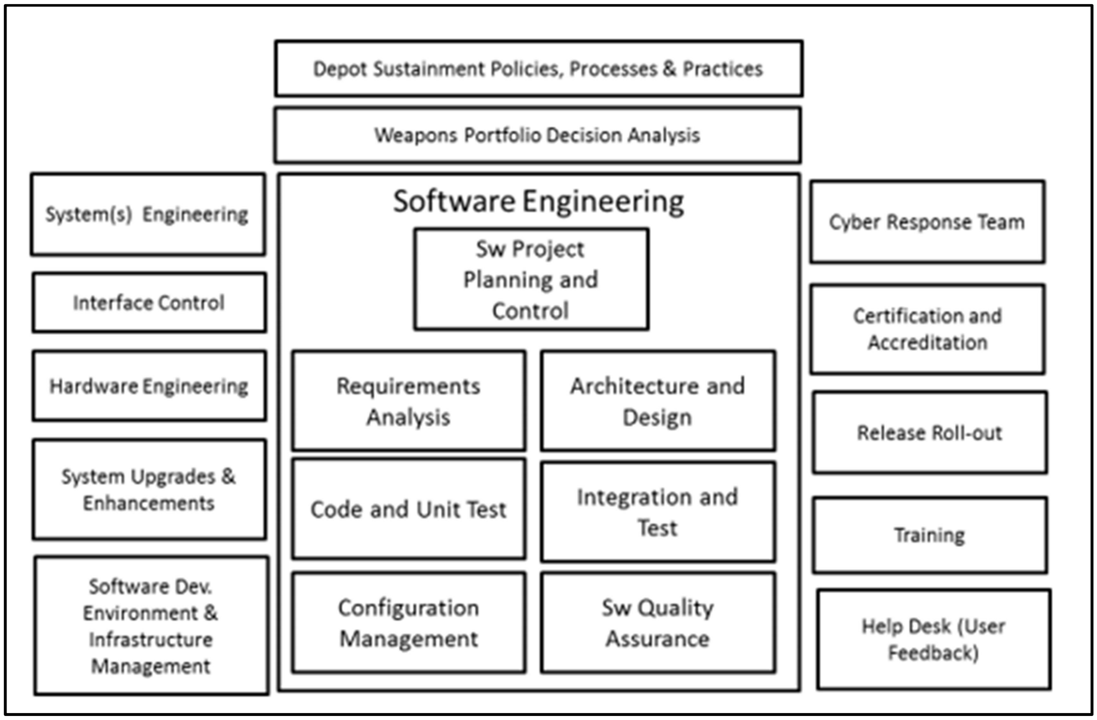

Figure 4. Weapons Systems Depot-Level Software Sustainment Functions

Applying this function-based model requires knowledge and understanding of the technical baseline of the specific system. Each function can be decomposed into a more detailed description of the work content involved, and specific and relevant work flows, processes, and practice. These functions and the details of each function may vary in scope and degree depending on specific functionality and system domains.

It is important to understand that a critical consideration in applying this model is identifying which software-sustainment functions are most critical from a national security perspective. Since software engineering functions involve changing the software baseline, a working knowledge and capability to perform these functions is probably high on the list of functions to staff organically.

The activities on the left side of Figure 4 represent system and technology influences on the operational software baseline. For weapon systems that experience a frequent rate of change driven by threats and technology imperatives, the DoD may elect to employ an organic workforce to ensure overall weapon system readiness. For systems that have stable interfaces and infrequent refresh cycles, the DoD may elect to employ a mix of organic and contracted staff based on best value considerations. In these situations, the government will likely want to establish a minimal set of competencies in these functions so it can maintain technical authority in making decisions and provide some level of organic software sustainment to mitigate changes in the software sustainment supply chain.

Another critical consideration in applying this model relates to addressing engineered-in-security, mitigating vulnerabilities via rapid deployment of security patches, and accommodation of the rapid pace of technological change. During our study, we observed that the DoD's software-sustainment community is acutely aware of the need to enhance software workforce competencies for software assurance.

For each function, careful attention must be paid to ensuring that the capabilities that are inherently governmental functions are maintained in the organic workforce and understanding which ones are candidates to be outsourced to a supplemental workforce. The inherently governmental functions then must be managed accordingly. The requisite education, skills, domain knowledge and system experience must be documented, and a deliberate process to hire, train, retain, and grow organic personnel must be put in place. This approach ensures that the government is always capable of (1) understanding the technical baseline for the system and (2) making appropriate, long-term decisions about engineering alternatives.

A key factor is applying this model is judging the appropriate DoD program official regarding the choice of using organic government software engineering capabilities, relying on defense industrial base capabilities, or selecting some mix of these capabilities to execute the sustainment mission. These choices are driven by a number of considerations, such as national security, affordability, and what the DoD believes is in its best interest in the long term.

Summary

A key takeaway message is that software sustainment is an engineering task. Almost any non-trivial change to the software requires analyzing the change and the current system, tracing the impact of the change on the existing requirements and design, and developing a new solution. For these reasons and others, policies and practices that are based on hardware sustainment, which can be treated as a discrete series of activities intended to restore form, fit, and function, do not apply well to software nor to understanding the requirements for the software workforce.

Executing the DoD software engineering sustainment mission demands a keen focus on defining and continually refreshing the DoD’s software-engineering competencies to drive workforce development and organization performance.

In this paper, we highlighted an initial functional model for thinking about software engineering competencies. We recognize that defining these competencies is a complex task that is a continuous activity that must be aligned with the nature and pace of technology change. Defining these competencies nests within the total workforce acquisition, development, and management strategy and plan.

References

Chao, P. (2006, October). *An assessment of the national security software industrial base.* Center for Strategic and International Studies. Retrieved from https://www.csis.org/analysis/assessment-national-security-software-industrial-base

Defense Science Board. (2000, November). *Report of the Defense Science Board Task Force on defense software.* Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA385923

Level of Repair Analysis (LORA). (2017, March 15). In *Acquipedia*. Retrieved from Defense Acquisition University website: https://shortcut.dau.mil/acq/lora

Lucero, D. S. (2010, May/June). Influencing software competencies across the DoD acquisition workforce. *CrossTalk.* Retrieved from http://static1.1.sqspcdn.com/static/f/702523/9185115/1288380566797/201005-Lucero.pdf?token=eT0HIzSVufpRpLIqCts6pKvgnvk%3D

National Research Council. (2010a). *Critical code: Software producibility for defense.* The National Academies Press. Retrieved from https://doi.org/10.17226/12979

National Research Council. (2010b). *Achieving effective acquisition of information technology in the Department of Defense.* The National Academies Press. Retrieved from https://doi.org/10.17226/12823

Software Engineering Institute. (1998, June). *Review of DoD policy impacts on the Software Acquisition Management Education Program.*

Software Engineering Institute. (2017a, February). *DoD Software Sustainment Study Phase I: DoD's software sustainment ecosystem.*

Software Engineering Institute. (2017b, April). *Department of Defense software factbook.* Retrieved from https://resources.sei.cmu.edu/library/asset-view.cfm?assetid=502651

Shull, F., & McLendon, M. (2017). *The policies and economics of software sustainment: DoD's software sustainment ecosystem*. Presented at the Acquisition Research Symposium, Monterey, CA.

Acknowledgments

During the course of this study, SEI researchers interacted with a range of senior leaders, key managers, and staff across the DoD's software-sustainment organizations. Universally, the Services and those we engaged were generally responsive to our data and information requests; they candidly shared their experiences and perspectives on this critical and complex issue. We are exceedingly grateful for the many thoughtful conversations and insights we received in the course of this work.

Disclaimer and Distribution Statement

This material is based upon work funded and supported by the Department of Defense under Contract No. FA8702-15-D-0002 with Carnegie Mellon University for the operation of the Software Engineering Institute, a federally funded research and development center.

The view, opinions, and/or findings contained in this material are those of the author(s) and should not be construed as an official Government position, policy, or decision, unless designated by other documentation.

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

www.acquisitionresearch.net