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WEDNESDAY, MAY 11, 2022 SESSIONS
VOLUME I

Acquisition Research:
Creating Synergy for Informed Change

May 11–12, 2022

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Acquisition Research Program
Department of Defense Management
Naval Postgraduate School

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WELCOME: DR. ROBERT (BOB) MORTLOCK, PRINCIPAL INVESTIGATOR, ACQUISITION RESEARCH PROGRAM

Dr. Robert Mortlock, PhD, CMBA, PMP, PE, COL USA (Ret), — Dr. Mortlock is the Principal Investigator, Acquisition Research Program, Naval Postgraduate School, managed defense systems development and acquisition efforts for the last 15 of his 27 years in the U.S. Army, culminating in his assignment as the project manager for Soldier Protection and Individual Equipment in the Program Executive Office for Soldier. He retired in September 2015 and now teaches defense acquisition and program management in the Graduate School of Business and Public Policy at the Naval Postgraduate School in Monterey, California. He holds a Ph.D. in chemical engineering from the University of California, Berkeley, an MBA from Webster University, an M.S. in national resource strategy from the Industrial College of the Armed Forces and a B.S. in chemical engineering from Lehigh University. He is also a recent graduate from the Post-Doctoral Bridge Program of the University of Florida's Hough Graduate School of Business, with a management specialization. He holds DAWIA Level III certifications in program management (PM), test & evaluation (T&E), and systems planning, research, development & engineering (SPRDE).

WELCOME: DAVID H. LEWIS, VICE ADMIRAL, U.S. NAVY (RET), ACQUISITION CHAIR, ACQUISITION RESEARCH PROGRAM

Vice Admiral David H. Lewis, USN (Ret.) took the helm as the Naval Postgraduate School Chair of Acquisition. As chair, he will lead the Acquisition Research Program (ARP) in the Graduate School of Defense Management and connect NPS with leaders and policymakers in the acquisition community.

Lewis graduated from NPS in 1988 with a Master of Science in Computer Science, and we're pleased to welcome him back to campus in this leadership role. Lewis is replacing the founding Chair of Acquisition, Rear Admiral, USN (Ret.) Jim Greene, who retired this June.

Most recently, Lewis served as Director of the Defense Contract Management Agency, managing over $7 trillion in defense contracts. In this role, he oversaw the agency's efforts to ensure that supplies and services contracted for by the Department of Defense are delivered on time and in line with contract performance requirements.

During his career at sea, Lewis served as a communications officer, fire control and missile battery officer, and combat systems officer aboard destroyers and guided-missile cruisers.

Upon selection to flag rank in 2009, Lewis served as Vice Commander, Naval Sea Systems Command and then served four years as Program Executive Officer, Ships, where he directed the delivery of 18 ships and procurement of another 51 ships. From 2014-2017 he served as Commander, Space and Naval Warfare Systems Command where he led a global workforce of 10,300 civilian and military personnel who design, develop and deploy advanced communications and information capabilities.

Lewis's extensive experience in shipbuilding has given him a unique understanding of the full acquisition lifecycle. He has delivered ships as a program manager and program executive officer, then later sustained and modernized them as a fleet engineer and systems commander. He will bring valuable perspective to NPS students and faculty, as well as the broader acquisition innovation community working to get superior capabilities into the hands of our warfighters.

Lewis's expertise in product delivery will amplify ARP's ability to execute its mission of delivering the real-time information and analytical capabilities needed by today's acquisition professionals and policymakers. Adding VADM Lewis to the team also demonstrates NPS's continued commitment to providing world-class defense-focused education and research...

WELCOME: ANN E. RONDEAU, ED.D, VICE ADMIRAL, U.S. NAVY (RET.), PRESIDENT, NAVAL POSTGRADUATE SCHOOL

Ann E. Rondeau, Ed.D, Vice Admiral, U.S. Navy (Ret.), was appointed as President, Naval Postgraduate School on January 29, 2019. She brings to the assignment an unparalleled record of leadership and achievement within the military and academia in the areas of education, training, research, executive development, change management, and strategic planning. Prior to her appointment, Adm. Rondeau served as the sixth president of the College of DuPage. Her most recent military position was as the President of the National Defense University, a consortium of five colleges and nine research centers in Washington, DC.

Rondeau has extensive leadership experience in significant military and educational roles. In 1985, she was selected and served as a White House Fellow in the Reagan Administration and went on to serve as the Deputy Commander of the U.S. Transportation Command in Illinois, Pentagon Director/Chief of Staff for the U.S. Navy Staff, Commander of the Navy Personnel Development Command in Virginia, Commander of the Naval Service Training Command at Great Lakes, Ill., Pacific Fleet Staff Chief of Staff in Hawaii, Commanding Officer of Naval Support Activity in Tennessee and other staff and commanding responsibilities with policy, planning, Fleet support, joint logistics, training and education. Rondeau retired from the U.S. Navy as a three-star admiral in 2012 and was the second woman to have achieved that rank in the Navy. She then served as a partner and later an independent consultant with the IBM Watson group.

President Rondeau's leadership has served many, both past and present, to include: Board of Directors, United States Institute of Peace; Board of Directors, German Marshall Fund; Board of Directors, The Atlantic Council; Board of Directors, National Museum of the American Sailors; Board of Directors, Council of Higher Education Accreditation; Board of Directors, Chicago Regional Growth Corporation; Board of Directors, Choose DuPage (regional development organization for Chicago northwest suburbs); Tennessee/Mid-South Economic Development Board; DoD liaison to the Center for the Study of the Presidency; Military Advisory Board (studying energy and environment impacts on national security); Flag Officer Advisory Council for Arizona State University, the National Naval Officers Association Senior Advisory Panel, the Eisenhower Memorial Commission and the National Cold War Veterans Memorial Design Steering Committee among others.

Rondeau holds a B.A. from Eisenhower College (NY), an M.A. from Georgetown University (DC) and an Ed.D. from the College of Education at Northern Illinois University in DeKalb. She also holds an honorary Doctorate in Public Service from Carthage College (Kenosha, WI) and an honorary Doctorate in Humane Letters from Rosalind Franklin University of Medicine and Science (Chicago, IL)....

KEYNOTE SPEAKER: THE HONORABLE ANDREW P. HUNTER, ASSISTANT SECRETARY OF THE AIR FORCE FOR ACQUISITION, TECHNOLOGY, AND LOGISTICS

The Honorable Andrew P. Hunter, Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics, is currently performing the duties of Under Secretary of Defense for Acquisition and Sustainment (PTDO USD(A&S)). In this role, he is responsible to the Secretary of Defense for all matters pertaining to acquisition; contract administration; logistics and materiel readiness; installations and environment; operational energy; nuclear, chemical, and biological defense; the acquisition workforce; and the defense industrial base.

Prior to his confirmation in February 2022, Mr. Hunter was a senior fellow in the International Security Program and Director of the Defense-Industrial Initiatives Group at the Center for Strategic and International Studies. He focused on issues affecting the industrial base, including emerging technologies, the defense acquisition system, defense trade, and industrial policy.

Mr. Hunter previously served as a senior executive in the Department of Defense from 2011 to 2014. Appointed as Director of the Joint Rapid Acquisition Cell in 2013, his duties included fielding solutions to urgent operational needs and leading the work of the Warfighter-Senior Integration Group to ensure timely action on critical issues of warfighter support. From 2011 to 2012, Mr. Hunter served as the Chief of Staff to the Honorable Ashton B. Carter and the Honorable Frank Kendall, while each was serving as Under Secretary of Defense for Acquisition, Technology, and Logistics. Additional duties while at the Defense Department included support to the Deputy's Management Action Group and examining ways to reshape acquisition statutes.

From 2005 to 2011, Mr. Hunter served as a Professional Staff Member of the House Armed Services Committee, leading the committee's policy staff and managing a portfolio focused on acquisition policy, the defense industrial base, technology transfers, and export controls. From 1994 to 2005, Mr. Hunter served in a variety of staff positions in the House of Representatives, including Appropriations Associate for Congressman Norman D. Dicks; Military Legislative Assistant and Legislative Director for Congressman John M. Spratt, Jr.; and staff member for the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China.

Mr. Hunter holds a Master of Arts degree in Applied Economics from The Johns Hopkins University and a Bachelor of Arts degree in Social Studies from Harvard University.

PANEL 1. NEW PRIORITIES, FAMILIAR CHALLENGES: DEFENSE TRENDS IN BUDGETS, APPROPRIATIONS, AND CONTRACT OBLIGATIONS

Wednesday, May 11, 2022	
8:15 a.m. – 9:30 am.	**Chair: Hon. David Berteau,** President & CEO, Professional Services Council **Panelists:** **David Norquist,** President and Chief Executive, National Defense Industrial Association, and former Deputy Secretary of Defense **Shannon Hines,** Senior Vice President, Government Affairs and Washington Operations, Textron, and former Staff Director, Senate Appropriations Committee **Eric D. Chewning,** Partner, McKinsey & Co., Inc, and former Chief of Staff to the Secretary of Defense

Hon. David Berteau—Mr. Berteau is PSC President and CEO, with 400 member companies of all sizes providing federal contract services. Mr. Berteau was ASD for Logistics and Materiel Readiness and served 14 years in the Defense Department, under six defense secretaries. Earlier, Mr. Berteau was at the Center for Strategic and International Studies (CSIS), Syracuse University's National Security Studies Program, and SAIC. He is a Fellow of the National Academy of Public Administration and taught graduate courses for 14 years at the Maxwell School, Georgetown, and the LBJ School.

David Norquist—served as the 34th Deputy Defense Secretary from July 31, 2019, until Feb. 9, 2021.

Mr. Norquist was born November 24, 1966, in Concord, Massachusetts. He is a 1989 graduate of the University of Michigan, where he received a Bachelor of Arts in Political Science and a Master's Degree in Public Policy. He also holds a Master's Degree in National Security Studies from Georgetown University and is a Certified Government Financial Manager (CGFM).

Mr. Norquist has 30 years of experience in federal financial management and national security. He began his career as a Presidential Management Fellow and a Program Budget Analyst for the Department of the Army. During his eight years with the Army, he worked at Army Headquarters, U.S. Army Intelligence and Security Command, and as the Director of Resource Management at Menwith Hill Station in the United Kingdom. In 1997 he became a professional staff member on the House Appropriations Committee, Subcommittee on Defense. He served from 2002-2006 as the Deputy Under Secretary of Defense in the Office of the Comptroller, where he received the Secretary of Defense Medal for Outstanding Public Service.

In 2006, Mr. Norquist was selected by President George W. Bush to be Chief Financial Officer at the Department of Homeland Security (DHS). He was the first Senate-confirmed Chief Financial Officer for the Department. For his leadership, he received the Secretary of Homeland Security Outstanding Service Medal.

Prior to his current tour in the Department of Defense (DOD) Mr. Norquist was a Partner with Kearney and Company, a certified public accounting (CPA) firm focused exclusively on the federal government.

Mr. Norquist was appointed as the Under Secretary of Defense (Comptroller)/Chief Financial Officer on June 2, 2017, and served as the principal advisor to the Secretary of Defense on all budgetary and financial matters. He supported the National Defense Strategy (NDS) through the development and execution of the Department's annual budget of more than $680 billion. Mr. Norquist strengthened accountability to the taxpayer by implementing DOD's first department-wide financial statement audit.

Shannon Hines—joined Textron in February 2022 as Textron's senior vice president – government affairs & Washington operations. She is responsible for leading Textron's Washington-based government affairs activities, managing the corporate strategies and activities that maximize Congressional and Executive Branch support for programs and issues of interest to Textron and its business units.

Hines joined Textron following a career on Capitol Hill. She was most recently Republican staff director for the Senate Appropriations Committee. In this role, Hines served as chief advisor to Sen. Richard Shelby of Alabama and was the primary liaison between the Appropriations Committee and Senate and House leadership, the White House and federal agencies. Hines previously served as staff director for the Senate Rules and Administration Committee, senior professional staff to the Senate Banking, Housing and Urban Affairs Committee and Republican staff director for the Senate Subcommittee on Commerce, Justice, Science and Related Agencies Appropriations. She has also served as chief of staff and legislative director for Senator Shelby.

She received her B.A. in Politics from Wake Forest University.

Eric D. Chewning—co-leads McKinsey's Aerospace & Defense Practice in the Americas.

He has 20 years of experience advising decision makers in national security markets, and supports clients in the areas of growth strategy, strategic due diligence, M&A advisory, corporate portfolio management, supply chain resiliency, and strategy-based transformation.

Eric's experience spans the public and private sectors. Eric was the chief of staff to the Secretary of Defense. In this role he led the secretary's executive team, working across the military services, Joint Staff, Combatant Commands, and senior civilian political appointees. He also provided counsel and advice to the secretary on all matters concerning the department.

Prior to serving as the chief of staff, Eric was the Deputy Assistant Secretary of Defense for Industrial Policy. In this capacity, he was the principal advisor for analyzing the capabilities, policies, and overall health of the defense industrial base. He represented the Department of Defense on the Committee on Foreign Investment in the United States as well as the Hart-Scott-Rodino anti-trust reviews. He also led the federal government-wide review on the U.S. defense industrial base.

Eric is a former US Army military intelligence officer and veteran. Prior to his military service, Eric was an investment banker at Morgan Stanley, where he focused on corporate finance and M&A in the global industrials sector.

Eric's analysis of foreign policy, military strategy, and the defense industrial base have been featured in several national media outlets, including American Interest, Brookings, Defense News, Financial Times, Military Review, The New York Times, The Wall Street Journal, and War on the Rocks. He has testified before the U.S. Congress three times.

Eric received an MBA from Darden School of Business at University of Virginia where he was recognized as a Shermet Scholar. He also earned an MA in international relations and BA with honors from University of Chicago. He is a life member of the Council on Foreign Relations.

PANEL 2. INNOVATING IN ACQUISITION: ORGANIZATIONS, TECHNOLOGIES, AND APPLICATIONS

Wednesday, May 11, 2022	
9:40 a.m. – 10:55 a.m.	**Chair: Lieutenant General L. Neil Thurgood, USA,** Director, Hypersonics, Directed Energy, Space and Rapid Acquisition ***Framework for Organizational Needs of Innovation in the Department of Defense*** Jennifer Taylor, Institute for Defense Analyses ***Gamification in Defense Acquisition Training and Education*** Daniel J. Finkenstadt, Lt Col, USAF, Naval Postgraduate School Erik Helzer, Naval Postgraduate School Ian Larsson, Capt, U.S. Air Force Matthew K. Marshall, Capt, U.S. Air Force Lee M. Whitworth, Capt, U.S. Air Force ***Harnessing the Power of Digital Platforms to Accelerate Adoption Rates of Emerging Technologies and Innovations*** Carly Jackson, Naval Information Warfare Center Pacific Tricia Nguyen, Naval Information Warfare Center Pacific Susan Lai, Naval Information Warfare Center Pacific Nicole Stone, Naval Information Warfare Center Pacific Stephen Dabideen, Naval Information Warfare Center Pacific Krunal Amin, Naval Information Warfare Center Pacific Michael Stuckenschneider, Naval Information Warfare Center ***Exploring the Potential for 3D Printing in Medical Logistics for Medical Supplies in Operational Environments*** Bryan Hudgens, Naval Postgraduate School Kathryn Aten, Naval Postgraduate School Lieutenant Elena Williams, U.S. Navy

Lieutenant General L. Neil Thurgood, USA—is the Director for Hypersonics, Directed Energy, Space and Rapid Acquisition, Office of the Assistant Secretary of the Army (Acquisition, Logistics and Technology), Redstone Arsenal, Alabama. He assumed duties in March 2019.

In this position, LTG Thurgood is responsible for the rapid fielding of select capabilities to deter and defeat rapidly modernizing adversaries, including overseeing development of an Army Long Range Hypersonic Weapon. He leads the Army Rapid Capabilities and Critical Technologies Office mission to rapidly and efficiently research, develop, prototype, test, evaluate, procure and field critical enabling technologies and capabilities that address immediate, near-term, and mid-term threats, consistent with the Army's modernization priorities.

LTG Thurgood most recently served as the Director for Test, Missile Defense Agency, Redstone Arsenal, Alabama. LTG Thurgood most recently deployed from 2017-2018, when he served as Deputy Commander, Combined Security Transition Command-Afghanistan, Operation Resolute

Support/Operation Freedom's Sentinel. Prior to his deployment, he served as the Deputy for Acquisition and Systems Management, Office of the Assistant Secretary of the Army (Acquisition, Logistics, and Technology), in Washington, D.C.

LTG Thurgood enlisted in the U.S. Army in 1983. Following his commissioning in 1986 as an Aviation Branch Officer, he served in multiple company grade and battalion aviation positions in both the U.S. and overseas, including multiple combat deployments. LTG Thurgood was then selected and served in the 160th Special Operations Aviation Regiment (Airborne) as a Platoon Leader, Operations Officer and Company Commander.

After transitioning into the Army Acquisition Corps in 1995, he served in various program offices for conventional and special programs. As a Project Manager, LTG Thurgood served in the Utility Helicopters Office, and as a Program Executive Officer, LTG Thurgood led the PEO for Missiles and Space, at Redstone Arsenal, Alabama. LTG Thurgood participated in operations supporting Operation Enduring Freedom in Afghanistan and Operation Iraqi Freedom in Iraq.

LTG Thurgood holds an undergraduate degree in Business from the University of Utah; a master's degree in Systems Acquisition Management from the Naval Postgraduate School; a master's degree in Strategic Studies from the Air University, Air War College; and a doctorate in Strategic Planning and Organizational Leadership from the University of Sarasota, as well as several professional certifications.

Framework for Organizational Needs of Innovation in the Department of Defense

Jennifer M. Taylor—is a Research Staff Member at the Institute for Defense Analyses (IDA). Jennifer has over 20 years' experience in government, think tanks, and as a consultant, transforming government institutions through strategy, planning, and implementation. She has a personal commitment to building better government institutions through making connections that were hidden from view.

Jennifer served as an action officer five years in the Office of the Undersecretary of Defense for Policy, providing policy advice. She has been working on security cooperation and defense institutional capacity building since 2006 and has seen firsthand the challenges and opportunities of assessing and evaluating the security cooperation programs since that time. She led the outreach and engagement for the 2020 Quadrennial Defense Review.

As a strategy and organizational change management consultant, Jennifer provided a number of institutional assessments for reform and transformation. She led the team that helped create the newest defense institution, the Defense POW/MIA Accounting Agency (DPAA). With senior DPAA leadership, she assessed and evaluated what changes were feasible in order to design an organization that would break down organizational stovepipes, improve processes, and engage employees.

Jennifer also has a background in acquisition reform and government contracting, recently serving as professional staff on the Section 809 Panel evaluating federal acquisition regulations. She is able help translate between contract staff and program staff to ensure the right solutions to policy challenges.

Jennifer has a B.A. from the University of North Carolina at Greensboro. She received an M.A. in international relations from Yale University, and a Master of Applied Security Strategy from the University of Exeter in the UK. [jtaylor@ida.org]

Abstract

The Department of Defense is a performance-based bureaucracy that focuses on time, schedule, and budget to evaluate the performance of its programs. The DoD is driven to perform its national security mission and to maximize results works to make every process and activity as predictable as possible. Bringing cohesion and simplifying communications internally and externally facilitate process, but come with risk for innovation. There is a need for better oversight, with the right kind of performance measures.

This is somewhat at odds with the requirements of innovation organizations (i.e., those organizations with innovation as a primary mission) that must have a high degree of freedom and flexibility in which to develop new approaches. At the same time, innovation efforts are reinforced and accelerated by maintaining consistent processes for contracting, personnel matters, budgeting, and other organizational concerns.

Executive Summary

The Institute for Defense Analyses has developed a framework for understanding the organizational needs to support innovation at the Department of Defense. The framework lays out Bureaucratic Environment Attributes and Innovation Environment Attributes that answer the central question of how to allow innovation to flourish while operating in a large-scale bureaucracy. These attributes describe the elements that need to be considered to support organizational decision-making, whether in realigning the innovation ecosystem, aligning efforts, or developing new strategies. This framework can assist in indicating what pieces should be centralized to allow more freedom for innovation at the Department of Defense—such as hiring, budgeting, administration, acquisition management—that benefit from consistency. This framework may assist to build a case to measure innovation differently from the rest of the Department, but in a way that ensures oversight still occurs. It initiates the conversation to support efforts across the enterprise to consider new concepts of operations, new ideas for how old tools are used, and balance the requirements of the systems.

On the Scene

Innovation at the Department of Defense is a growth industry. There is widespread recognition of the benefits of "innovation" and a willingness to create new organizations to support the effort. In the last decade, the DoD has invested in the Strategic Capabilities Office (2012)[1], the Defense Innovation Unit (2015), and the Defense Innovation Board (2016), among others. The Services have been building on the success of Special Operations Command's SOFWERX (2015)—which connects technology prototypes more directly to potential users in order to determine utility—with the Air Force's AFWERX (2017), the Navy's NavalX (2019). New "shark tank" style competitions—the Army's first Dragon's Lair was hosted in December 2020—have followed the first "Spark Tank" hosted by the Air Force in 2018. These are added to the Department's longstanding innovation efforts like the Defense Advanced Research Projects Agency (DARPA; 1958). The marked uptick in the last decade of these problem solving organizations, create an entirely different challenge—how might the DoD best corral these groups, integrate their contributions, align their efforts, and maximize their effects?

Taken together, they comprise the "Defense Innovation Ecosytem," at its broadest sense made of those hundred plus DoD organizations that have some innovation mandate (Laurent, 2019). MITRE has developed a useful tool—Tap the Innovation Ecosystem— to pull the picture of these organizations together, categorizing innovation "offerings" into Accelerators, Challenge, Connector, Funding Opportunity, Government Contracting Authority, and Incubators (MITRE, n.d.). This is a useful starting point to gaining a site picture of the DoD's innovation organizations. However, the proliferation of innovation organizations with a variety of mandates, without an obvious entry point can be confusing for outside partners and industry who remain unsure of what door to knock on. Vendors do not know where the front door to the DoD is, and they have difficulty knowing who, when and how to engage with the DoD Innovation Ecosystem (Senior Defense Officials, personal communication, July 22, 2021).

Here we look to balance the needs of the system in an attempt to understand how better to support innovation organizationally. There is an interest on the part of current leadership in developing a broad "culture of innovation," (Senior Defense Official, personal communication, January 14, 2022) but those working on establishing this culture decry the frustrations of the system they are working in. From slow contracting to budget challenges, the system is set up for performance and predictability. As the Center for Security and Emerging Technology described in the July 2021, *Ending Innovation Tourism,* "If you were to design an organization to be the exact opposite of a tech startup, the end result would look a lot like the DoD. While young tech companies strive to be freewheeling, fast-moving,

[1] The year the organization was founded.

and disruptive, the military is rigid, regimented, and risk-averse. The department's technology acquisition process is no different" (Flagg & Corrigan, 2021).

The Department of Defense is a performance-based bureaucracy that focuses on time, schedule, and budget to evaluate the performance of its programs. The DoD is driven to perform its national security mission, and to maximize results works to make every process and activity as predictable as possible. Bringing cohesion and simplifying communications internally and externally facilitate process, but come with risk for innovation.

This performance-oriented approach is at odds with the requirements of innovation organizations (i.e., those organizations with innovation as a primary mission) that desire a high degree of freedom and flexibility in which to develop new approaches. While there have been a number of successful innovation organizations at the Department of Defense, there have also been a number of reports that infer those organizations may play too fast and loose with contracts, hiring processes, or even technology in the name of pursuing innovation (Myers, 2021). These beg the question if there is a need for better oversight, with the right kind of performance measures suited to telling the right story of their contributions.

That said, consistent processes for contracting, personnel matters, budgeting, and other organizational concerns can reinforce and accelerate innovation efforts. Regularizing these processes, or developing a small set of tailored processes, rather than reinventing them for each new organization, assists adoption of technologies and innovative thinking, while creating process for process sake, has the opposite effect (Former Defense Official, personal communication, June 9, 2021). Too many rules slow progress and fail to meet the requirements, too few rules run the risk of getting nothing done and producing no outcomes (Bauer, 2016).

There are on-going discussions about reforming the budget process, the acquisition process, and training acquisition professionals to better support innovation. Rather than focus on those issues being addressed elsewhere, the central question is how to allow innovation to flourish while operating in a large-scale bureaucracy? How does the DoD optimize for the overlapping, but different, needs of supporting innovation that drives better outcomes and supporting a "performance based" bureaucracy, those measures that support scaling capabilities? What are the characteristics on both sides of the equation that need to be accounted for? IDA has developed a framework for understanding attributes that need to be balanced between the Department of Defense and its innovation organizations.

The framework was developed over the course of summer and fall 2021. It is informed by a number of key interviews with senior defense officials, attendance at a number of events such as DAU's TEDxDAU "Platforms for the Future" conference, and a review of the innovation and business literature. This framework has a number of potential applications. It might be used, for example, by the Innovation Steering Group (2021) to account for required elements in potential shifts in direction to the innovation ecosystem. It might be useful to the innovation organizations themselves to determine potential adjustments in alignment. It may be appropriate to use in consideration of proposals such as consolidation or expansion of innovation organizations—the Defense Innovation Board's (2016) recommendation to implement a Chief Innovation Officer for the DoD, or in the development of an innovation strategy. In the following pages, we consider the definition of innovation, the need for a framework, and an initial proposal for those attributes that might be considered to support innovation organizations within the DoD.

What is Innovation?

As we begin to consider a framework for innovation in the DoD, it is natural to first ask, what is innovation? Inigo Montoya had two particularly memorable lines in *The Princess Bride,* the second of which is most relevant here, “You keep using that word. I do not think it means what you think it means.” Is innovation the existence of a new technology? The adoption of a new technology? A new concept for something that exists? A new process? Any improvement in the field that demonstrates ingenuity? What about “innovative thoughts?” (Senior Defense Official, personal communication, June 30, 2021). Is it creation? Or the application of creation? Or is it, as one senior defense official stated, something that “will change the way the customer does business and changes the way business is run?” (Senior Defense Official, personal communication, August 13, 2021).

This question is not a new question nor a new challenge, though we may be using new words. The description of transformation from the 2001 Quadrennial Defense Review, sounds quite similar to current discussions around innovations:

> Transformation results from the exploitation of new approaches to operational concepts and capabilities, the use of old and new technologies, and new forms of organization that more effectively anticipate new or still emerging strategic and operational challenges and opportunities and that render previous methods of conducting war obsolete or subordinate. Transformation can involve fundamental change in the form of military operations, as well as potential change in their scale. It can encompass the displacement of one form of war with another, such as fundamental change in the ways war is waged in the air, on land, and at sea. It can also involve the emergence of new kinds of war, such as armed conflict in new dimensions of the battlespace. (DoD, 2001)

The Strategic Capabilities Office takes a combined approach to innovation looking at what we have, marrying with something new, whatever it takes to get to an inventive solution to evolving warfighting challenges. Dr. Will Roper described the approach used by the Strategic Capabilities Office as, “the engineers at SCO do this using one of three approaches—by taking something designed for one mission and making it do a completely different mission, or by integrating systems into teams—‘I can’t solve the problem with system A or system B but by connecting them together I can,’—or changing the game by adding in commercial technology” (Roper, 2016).

One frequently (potentially the most) discussed definition of innovation focuses on technology and technology integration, or bridging the “Valley of Death”—that vast space between prototype and program. Bridging the Valley of Death is at its heart about marrying technology and users within the system—moving from research to application. The chasm is potentially a wide one. Often the DoD acquisition system is blamed for not being able to move quickly enough to create a “market” for potentially interesting technology. Yet, the risk aversion of the acquisition system has value—if immature technology is acquired too soon, others have to deal with that down the line (Senior Defense Official, personal communication, August 13, 2021). Equally culpable, however is the nature of research and development itself—to explore, to discover what is possible, to find a proof of principle—without concern for what might be scalable, marketable, or competitive. This demonstrates why the technology transition rate, a common metric for innovation, is problematic. The emphasis should be on demonstrated impact for the warfighter. An alternative metric to how many things leapt across the Valley of Death is how many programs of record were disrupted in a helpful way?

All of these definitions have merit though some are less appreciated than others. There is a recognition by DoD leadership that innovation is inclusive of, but goes beyond, technology. Further, the DoD recognizes that there are lots of things happening, but not everything is optimized (Senior Defense Official, personal communication, January 14, 2022).

When the DoD's Innovation Steering Group put out a call to map the Department's Innovation Ecosystem last year, they intentionally used as broad as possible a definition of innovation, described in one interview as "self-selection" (Senior Defense Official, personal communication, June 30, 2021). In their call to map the innovation organizations, they declined to define innovation, and instead took the approach of, if your group defines itself as innovative, the ISG wants to include you. The steering group wanted to get an understanding of the myriad ways that the DoD approaches innovation, and who is doing what. This approach benefits the culture of innovation by asking the question in a way that says, "Do you see yourself as part of this ecosystem, and if so, how do you support it?" though it leaves open the question of how the DoD sees innovation today.

A recent proposed definition by Institute for Defense Analyses attempts to reconcile these questions with the following definition:

> New capabilities and practices and changes to existing capabilities and practices that cause disruptive effects: those that, in order to avoid creating a persistent competitive advantage for the adopter(s), mandate either (a) adoption by other competitors, or (b) a corresponding counter-innovation by non-adopters. (Picucci et al., 2021)

Thinking of innovation solely in terms of technology is limiting. This definition provides the opens the discussion to include ways that changes to the bureaucracy itself can be innovative, and when effective, celebrated. By adopting such a definition, attention can be turned from the "what" of innovation being just about technology, to the "how" of innovation within the enterprise.

In the next section we describe the need for framework intended to facilitate the conversation around helping the DoD broadly support, scale, and integrate all aspects of this definition of innovation. This framework can assist in assessing structures for an innovation organization within the DoD. It serves to initiate the conversation to support efforts across the enterprise to consider new concepts of operations, new ideas for how old tools are used, and allows for "breakthrough capabilities for tomorrow's platforms and systems" (Flagg & Corrigan, 2021).

The Needs of the Organizations

Recognizing that innovation organizations must operate within the context of the government's largest bureaucracy. Some have said that the DoD should throw the entire system out and start over, bemoaning slow acquisition or too many regulations. However, it has been demonstrated that the acquisition system can move quickly when there is a need to do so, and the Federal Acquisition Regulations (FAR) have more flexibility than they are given credit (Lofgren, 2022). Tools like Other Transactions (i.e., the authority that allows for non-FAR based contracts) are important, but they are not necessarily how we need to buy everything in the vast purview of DoD procurement.

As a mission-driven organization, it is undesirable and unlikely the DoD will change to completely accommodate the attractive aspects that dominate in Silicon Valley. If we consider some common traits of innovation organizations they are to some extent diametrically opposed to the military culture—tolerance for failure, willingness to experiment, psychological safety, highly collaborative, and nonhierarchical (Pisano, 2019). The DoD is driven to perform its national security mission and to maximize results works to make every process and activity as predictable as possible. To "fail fast" needs to be implemented in the context of the DoD's responsibility to spend taxpayer dollars wisely, which drives a level of early accountability that is not found in the private sector. This is not to say there is not accountability in the private sector, it comes in the form of the market. The early experiments can largely go away quietly. When the tech sector "fails fast" it is not on display on Capitol Hill, the front page of the *Washington Post*, or trending on Twitter—though it happens often, it happens quietly. To be clear, that is not to say the DoD does not need to evolve. While we want to incorporate those aspects from the private sector that serve the DoD's mission—data into decision making, the digital ecosystem, open systems that allow upgrades—we must acknowledge that bureaucratic barriers serve a purpose to manage the DoD's responsibilities while working to reduce barriers in a deliberate manner.

Innovation organizations are comfortable with a high degree of ambiguity and uncertainty, but they also require discipline (Pisano, 2019). Discipline, in this sense, is the management of a product, process, or concept from idea to prototype to adoption. While the DoD excels at some forms of discipline, on the whole the enterprise is challenged by its inability to cull programs once they are established. Those parts of the DoD, such as DARPA, with the reputation of being successful innovators, also know how to end projects that are less promising than others. For basic research and development (R&D), success can be realizing that the path you are going down is not the right one. The DoD is comfortable with this version of fail fast. However, that is planned for, and part of the organization's mission. If one does not "fail" fast enough, if one does not realize the problem at the R&D level, then failing "fast" is still slow enough that resources expended start to draw attention. "Discipline-oriented cultures select experiments carefully on the basis of their potential learning value, and they design them rigorously to yield as much information as possible relative to the costs" (Pisano, 2019). One interviewee stated, "There is no substitute for qualified and experienced leadership" (Senior Defense Official, personal communication, August 13, 2021). What is leadership's ability to develop an R&D plan and learn (in a timely manner) from executing that plan, and shifting when needed. Are they putting together an effective plan and are they making effective decisions to cut?

Innovation efforts are reinforced and accelerated by maintaining consistent processes for contracting, personnel matters, budgeting, and other organizational concerns. That means, if processes are in place that minimize the time and effort spent on issues related to these efforts, the more space is created to allow for innovative connections to take place. If there is a way to regularize these processes across the organizations, that may assist in bringing additional scale to support innovation.

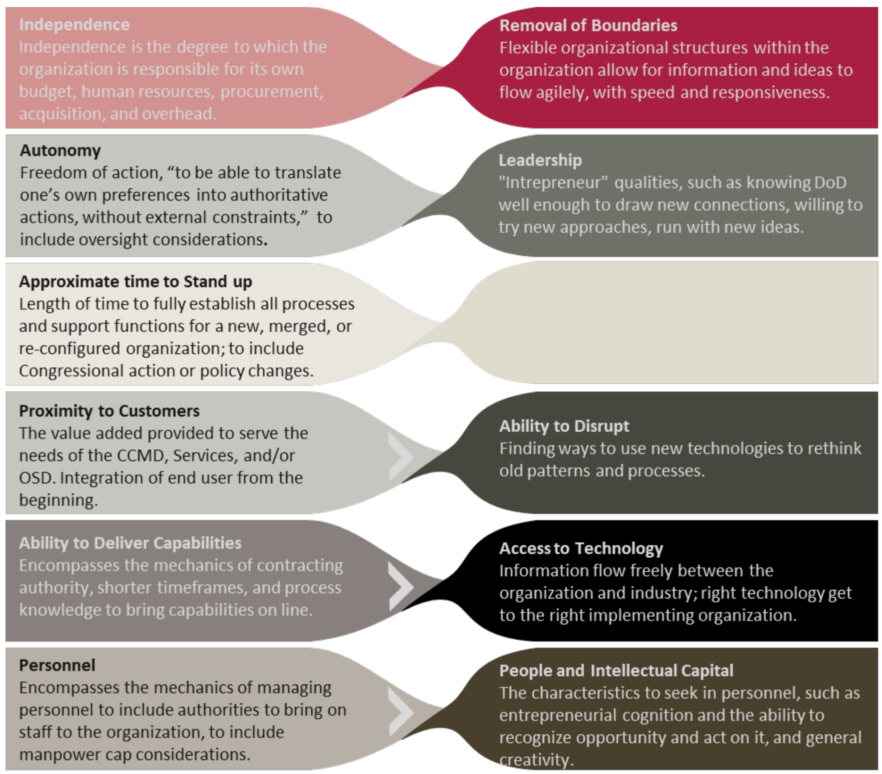
Successful innovation will be driven by organizational structures that encourage: interactions beyond boundaries and stovepipes, continuous learning, creativity, finding new connections, and facilitation of interactions with relevant users (Audretscha et al., 2021). At the same time, organizationally, the DoD is not optimized, except in specific urgent circumstances to: make fast, agile changes, with a sense of urgency, adopt innovative approaches, measure the success of innovation, or support processes that are different from the day-to-day operations. The next section lays out the framework itself.

A Framework for Optimizing Innovation Needs

This framework captures these dynamics—of organization support to innovation—in two categories: Bureaucratic Environment Attributes, that are necessary from the DoD perspective, and Innovation Environment Attributes. DoD Bureaucratic Environment

Attributes are those organizational attributes that are driven by, or largely affected by, placement of the organization within the enterprise (the world in which the organization exists). Innovation Environment Attributes are those that are critical for an innovation organization (what is needed based on purpose/mission). While these attributes may be desirable in all kinds of organizations, they are "must haves" in those focused on innovation and organizational creativity.

The attributes are described next with a proposed measurement tool description—observational, or a description of "what is," vice judgement, whether more or less of something is ascribed to be better or worse—and the attached scale. These are followed by other relevant considerations, details, or key questions. In an organization built for predictable reliable results, how can the DoD approach the paradox that "the systems that enable success with today's model reinforce behaviors that are inconsistent with discovering tomorrow's model" (Anthony et al., 2019).



This Chart Summarizes the Attributes. The Arrows Demonstrate the Close Ties Between These Particular Attributes.

Figure 1. The Bureaucratic Environment Attributes

Independence

Independence is the degree to which the organization is responsible for its budget, human resources, procurement, acquisition, and overhead.

- Measurement tool : Observational
- Scale: High to low

Independent organizations would have their own budget authority, contracting processes, human resources processes. A highly independent organization would be responsible for implementing these processes themselves rather than leverage a Shared Service (e.g., Washington Headquarter Services provides these elements for all organizations within the Office of the Secretary of Defense and a number of other Washington-based organizations). A high degree of independence may accompany a lack of clear external champion and would require any organization to advocate for itself and prove its value in the budget process (Former Senior Defense Official, personal communication, April 30, 2021).

Autonomy

Autonomy, as distinct from independence, is the degree to which the organization has freedom of action, "to be able to translate one's own preferences into authoritative actions, without external constraints," (Nordlinger, 1982) to include oversight considerations.

- Measurement tool: Observational
- Scale: High to low

Autonomy allows organizations to prioritize their own actions and drive their own agenda. When autonomy is high, external organizations are collaborators, but not drivers of the actions. This is modeled by the Strategic Capabilities Office close collaboration with Combatant Commands. When autonomy is low, external organizations have more say over priorities and actions. This autonomy serves the requirements of innovation organizations, but it can never be wholly autonomous.

However, developing appropriate oversight to help manage the autonomy is a challenge for the DoD. There is a conflict between understanding stabile processes, activities, and programs, and understanding those in active reform. Those performance measures that work for the steady state of the organization are inadequate for understanding performance in innovation organizations. Time, schedule, and budget may not apply.

Proximity to Customers

Proximity to customers includes customers' reliance on the organization, ability to understand the customers' problems, the value added provided to serve the needs of the CCMD, Services, and/or OSD. Integration of end user from the beginning.

- Measurement tool: Judgement
- Scale: Preference for increased ability to engage customers

Some DoD innovation organizations like the SCO and SOFWERX have direct ties into the end users, by close liaison or co-location. Others, such as DARPA have less direct interaction, intentionally so as not to be driven by a requirement so much as to be driven by exploring the boundaries of science. Proximity to "customer" is a way to think through how relevant is the work of the organization to the people who will use it most directly? Do you have a direct value-add to the Services? A Combatant Command? Perhaps the Secretary of Defense? Do they find value in the service provided? Can the organization bring those "customer" challenges together with others to provide insight to solutions?

Time to Stand Up (e.g., Full Operational Capability)

Estimate on length of time to fully establish all processes and support functions for a new, merged, or re-configured organization; to include Congressional action or policy changes.

- Measurement tool: Observational
- Scale: Length of time

This attribute looks towards how quickly a new organization (if required) could be brought on line. For example, a full agency takes up to two years to get organized. A smaller office, might be able to be rapidly stood up and integrated into the system on a much quicker level. However, that smaller organization would likely need a champion or sponsor to give it the time to grow into its mission.

Deliver Capabilities

Encompasses the mechanics of contracting authority, shorter timeframes, and process knowledge to bring capabilities on line. The ability to advocate for new authorities and funding, as required.

- Measurement tool: Judgement
- Scale: Preference for increased ability to deliver capabilities

If independence is the need to have your own contracting capabilities, deliver capabilities reflects the mechanics of how that is implemented. If the organization is not highly independent and running its own, do they have access to adequate resources elsewhere? Does the organization have access to a dedicated contracting team that knows how to engage the different parts of the bureaucracy? Is there sufficient institutional knowledge that allows them to fulfill missions? Are Other Transactions a regular requirement, or an anomaly? When gaps are identified who knows what triggers to pull in order to close them? Are there adequate resources to manage the system?

Personnel

Encompasses the mechanics of managing personnel to include authorities to bring on staff to the organization, to include manpower cap considerations.

- Measurement tool: Judgement
- Scale: Preference for access to personnel authorities that ease hiring and maintain performance based compensation

If independence drives the need to have your own personnel system in place, this attribute gets into the adequacy of available hiring authorities, duration of recruitments, pay scale, and clearance concerns. Personnel might also appear as unique hiring policies. DARPA demonstrates this aspect by their term limitations.

Can we bring the people we need onboard in a timely manner? The DoD has been granted hiring authorities, such as Acquisition Demonstration Authority (AcqDemo), that can be helpful to the innovation organizations. How are these organizations supported in their use? AcqDemo allows for pay for performance through a different rating structure, outside of the general schedule (i.e., the traditional government system), as long as there are:

> a) At least one-third of their civilian workforce occupying positions coded as meeting the requirements of the Defense Acquisition Workforce Improvement Act (DAWIA); and
>
> b) At least two-thirds of the civilian workforce consisting of members of the AWF and supporting personnel assigned to work directly with the AWF. (DoD, 2019)

These authorities are available to organizations that qualify on their own or as part of a larger organization, such as the Office of the Secretary of Defense Acquisition and Sustainment.

The traditional hiring process is notoriously cumbersome and slow—double that of the private sector (Hamilton, 2020). In recognition of the DoD's competition with industry, direct hire authority has allowed the DoD to streamline the process (DoD, Defense Civilian Personnel Advisory Service, n.d.). A number of other potential authorities exist to assist in recruiting the types of characteristics, described below in People and Intellectual Capital.

The Innovation Environment Attribute

Removal of Boundaries

Flexible organizational structures within the organization allow for information and ideas to flow agilely, with speed and responsiveness. Potential for rotational opportunities between organizations.

- Measurement tool: Judgement (i.e., attaches a preference to the observation)
- Scale: Preference for increased ability to move information and ideas through the system, facilitate rotational opportunities

Innovation in part comes from connections made between new thoughts and ideas. Innovation organizations need to actively remove boundaries and stovepipes both within the organization and between others in order to facilitate these connections (Audretscha et al, 2021).

A recent MG Harold Greene Awards for Acquisition paper spoke of the lack of networks for innovators at the DoD, an investment that is worth making. “Today, the DoD lacks a department-wide network mechanism for DoD innovators to connect, engage, share learnings, and problem solve. While the DoD has many innovation champions, most operate in minor and often unrelated networks due to the lack of an innovation scaling framework at the Joint Force level” (Theodotou, 2021).

Are rotational opportunities integrated into the organization? Does it work to remove information barricades, or does information need to flow up to move out? What level is empowered to act? To get off the ground, it is possible an initiative will be insulated, but what then is the plan to follow that with integration to the larger whole—how will the initiative’s outcome be integrated? What are the means by which the siloes are networked?

Leadership

Leadership of the organization should have adequate seniority (at or above SES-3); reflect “Intrepreneur” qualities, such as knowing the DoD well enough to draw new connections, willing to try new approaches, run with new ideas. Leader who know the larger organization well enough to use the authorities granted. Provides tools to accomplish the mission, vice rules to be followed. Needs the right team, but sets the cultural tone of creativity.

- Measurement tool: Judgement
- Scale: Preference for seniority in leadership, ability to recruit for “intreprenurial” qualities, and ability to align disparate innovation organizations

Any organization aimed at innovation is a product of the personality of the leader. Innovation is a human behavior, dependent on personality, and there is no change without change agents. Bureaucracy’s repeatable processes are designed so that any properly trained individual can do them. Leadership for innovation organizations is a task that only a few may be capable of doing well. Instead of getting away from the personality-driven aspect, solve for it (Former Defense Official, personal communication, June 9, 2021). Invest in early identification and support to those who show the traits and characteristics that will support innovation without removing them from the DoD processes and systems they will need to learn to be effective.

Ability to Disrupt

Finding ways to use new technologies to rethink old patterns and processes.

- Measurement tool: Judgement

- Scale: Preference for influence over directed

Is the organization able to leverage the aforementioned proximity to customer in order to implement an innovation, or is it just as likely to have the contributions ignored? Proximity also builds community and buy-in, as innovations are more readily adopted if they come from within the community (*Van Maanen & Barley, 1982)*. It helps to prevent the tendency to question new approaches before they get off the ground. This helps align permeability of the organizations, and move ideas quickly, with the hopes of preventing:

> Innovations which are interpreted as potentially deskilling or which might disrupt the social structure and prestige of the community as it is currently organized will be resisted and, if possible, sabotaged. For example, artillerymen in the Israeli army pride themselves on their ability to quickly calculate and pinpoint targets using sharply honed trigonometric skills. In fact, such prestige attends the artilleryman's ability that mere privates often possess recognition and prestige that go well beyond their military rank. Consequently, when computerized range finders were installed in Israeli batteries many artillerymen gutted or otherwise disengaged the electronic equipment and continued to make the necessary calculations in their heads. Of course, the housings were discreetly left mounted and intact in case officers happened to inspect the operation (Kunda, personal communication). (Van Maanen & Barley, 1982)

Access to Technology

Information flow freely between the organization and industry; right technology get to the right implementing organization.

- Measurement tool: Judgement
- Scale: Preference for clear signaling to external stakeholders

Outside partners need an understanding of which innovation organizations within the DoD they should present technology or promising research that should be integrated into a design.

People and Intellectual Capital

Attract talent with entrepreneurial cognition and the ability to recognize opportunity and act on it; extensive networking and relationship building that facilitates connecting new potentially unrelated ideas; and general creativity.

- Metric: Judgement
- Scale: Preference for ability to identify and recruit those able to connect disparate thoughts and ideas and act on them

Innovation requires personnel with characteristics that can draw new connections between what is known and what is unknown, “dot connectors and pattern recognizers,” and growth mindsets.

What's Omitted?

It is worth explicitly stating that there are two attributes that do not appear on their own in this framework, which may seem counter-intuitive. The first is the bureaucratic tendency for longevity. The second is speed. Longevity and speed for the sake of longevity and speed do not support the objectives of the Department—whether bureaucratically or in the innovation environment. The framework instead emphasizes nearness to end user, disruption, and rapidity of fielding. Former Deputy Secretary of Defense Robert Work asserts that speed matters in the context of its alignment to decisions that need to be made alongside priorities (Work, n.d.). We can extrapolate that to longevity as well. Match speed to the requirement. Match longevity to the mission.

Concluding Thoughts

This framework was developed to support effective innovation organizations recognizing many of the realities of the Department of Defense modus operandi. Such a framework may be useful in considering any potential innovation strategy for the Department which would align missions, personnel, and budgets to greater effect. The Innovation Steering Group has already honed their map of the core DoD innovation ecosystem down to 20 organizations. As they continue to map the future of innovation at the DoD, the attributes described here can serve their thinking about the alignment of the organizations within the enterprise. Should the DoD decide to approach innovation in such a manner, this kind of framework can help ensure consideration of attributes that make innovation organizations effective in a bureaucratic environment.

Mixing this cultures and ways of doing business is incredibly difficult. The framework is intended as a starting point for discussion about what matters on both sides to resolve any tensions that limit integration of innovation and innovation organizations within the DoD. In applying the framework, it may help to prioritize certain attributes for decision making around alignment in innovation—because considerations yield different results depending on the most important attributes. There are ways to accommodate the necessary changes within the bureaucracy.

This framework can assist in indicating what pieces should be centralized to allow more freedom for innovation at the Department of Defense—like hiring, budgeting, administration, acquisition management—that benefit from consistency. This framework may assist to build a case to measure innovation differently from the rest of the Department, but do so in a way that ensures oversight is still occurring. Define and agree on performance metrics appropriate to innovation—such as positive disruption to programs. Work to identify and build a cadre of professionals who speak both languages to minimize the frustrations of culture clash.

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References

Anthony, Scott D., Paul Cobban, Rahul Nair, and Natalie Painchaud. "Breaking Down the Barriers to Innovation." Harvard Business Review, November-December 2019. https://hbr.org/2019/11/breaking-down-the-barriers-to-innovation.

Audretsch, David B., Erik E. Lehmann, Matthias Menter, and Katharine Wirsching. “Intrapreneurship and Absorptive Capacities: The Dynamic Effect of Labor Mobility.” Technovation 99 (January 2021). https://www.sciencedirect.com/ science/article/pii/S0166497218307922.

Bauer, Ted. “Process Improvement: End ‘Process for the Sake of Process.’” The Context of Things, April 13, 2016. https://thecontextofthings.com/2016/04/13/process- improvement/.

Department of Defense, DOD Civilian Acquisition Workforce Personnel Demonstration Project. Operating Guide. n.p., September 13, 2019. https://acqdemo.hci.mil/ docs/AcqDemo_OpsGuideSep2019_final.pdf.

Department of Defense, Defense Civilian Personnel Advisory Service. Direct Hire Authorities. Alexandria, VA: DCPAS, n.d. https://indd.adobe.com/view/0eb55b03- bbfc-40e4-b945-58d6c02577d2.

Department of Defense. Quadrennial Defense Review Report. Arlington, VA: Office of the Secretary of Defense. September 30, 2001. https://history.defense.gov/Portals/ 70/Documents/quadrennial/QDR2001.pdf?ver=AFts7axkH2zWUHncRd8yUg%3d

Flagg, Melissa and Jack Corrigan. “Ending Innovation Tourism Rethinking the U.S. Military’s Approach to Emerging Technology Adoption.” Washington, DC: Center for Security and Emerging Technology, July 2021. https://cset.georgetown.edu/wp- content/uploads/CSET-Ending-Innovation-Tourism.pdf.

Hamilton, Jillian. “5 Reasons the Federal Government Struggles to Attract Top Talent.” ClearanceJobs.com, August 31, 2020. https://news.clearancejobs.com/ 2020/08/31/5-reasons-the-federal-government-struggles-to-attract-top-talent/.

Laurent, Anne. “So Many Innovation Hubs, So Hard to Find Them: It’s Still too Hard for Emerging Companies and the Agencies Looking for Them to Find Each Other.” Government Executive, September 11, 2019. https://www.govexec.com/technology/ 2019/09/so-many-innovation-hubs-so-hard-find-them/159798/.

Lofgren, Eric. “OTAs and Beyond: Scaling Innovation in Defense Contracting.” Federal News Network, March 14, 2022, https://federalnewsnetwork.com/commentary/ 2022/03/otas-and-beyond-scaling-innovation-in-defense-contracting/.

Myers, Meghann. “Pentagon Tech Boss Used Unauthorized App for Official Communications: Watchdog.” Military Times, June 25, 2021. https://www.militarytimes.com/news/your-military/2021/06/25/pentagon-tech-boss- used-unauthorized-app-for-official-communications-watchdog/.

MITRE Website. “Tap the Innovation Ecosystem.” Accessed March, 2022. https://aida.mitre.org/demystifying-dod/innovation-ecosystem/.

Nordlinger, Eric A. On the Autonomy of the Democratic State. Cambridge, MA: Harvard University Press, 1982.

Picucci, P.M., Robert Angevine, Max Roberts, and Dave Sparrow. “Categorizing Defense Innovation.” Defense Acquisition Magazine, March 9, 2021. https://www.dau.edu/library/defense-atl/blog/Categorizing-Defense-Innovation.

Pisano, Gary P. “The Hard Truth about Innovative Cultures: Creativity can be Messy. It needs Discipline and Management.” Harvard Business Review, January-February, 2019. https://hbr.org/2019/01/the-hard-truth-about-innovative- cultures?autocomplete=true.

Pellerin, Cheryl. “DoD Strategic Capabilities Office Gives Deployed Military Systems New Tricks.” U.S. Department of Defense News, April 4, 2016. https://www.defense.gov/News/News-Stories/Article/Article/712938/dod-strategic- capabilities-office-gives-deployed-military-systems-new-tricks/.

Theodotou, Dr. Marina. “Scaling Innovation at the Department of Defense: An Actionable Framework and Practical Steps for the Joint Force.” 2021 Major General Harold J. “Harry” Greene Awards for Acquisition Writing, 2021: 22-26. https://asc.army.mil/web/wp-content/uploads/2022/03/ 2021_ACQ_writing_awards_FINAL.pdf.

Maanen, John Van and Stephen R. Barley. ‘‘Occupational Communities: Culture and Control in Organizations.’’ Technical Report. MIT Sloan School of Management, November 1982. https://apps.dtic.mil/sti/pdfs/ADA122826.pdf.

Work, 32nd Deputy of Defense Robert. “IDA Symposium on Defense Management Reform.” Presentation to Institute for Defense Analyses. https://dmr-symposium.ida.org/pages/videos.html.

Gamification in Defense Acquisition Training and Education

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Abstract

Leveraging research conducted as part of an Acquisition Research Program sponsored thesis, this paper expands upon an essay written by our research team (submitted to *USNI*), in which we argue that gamified learning (building games to promote learning of traditional material) presents a unique opportunity for enhancing education and training within the defense workforce.[2] We provide an in-depth explanation of what gamification is and why it might be particularly useful for enhancing learning in non-traditional defense contexts, using defense acquisition as a test case. We present initial evidence from our empirical research to highlight the opportunities and challenges for advancing military education into the present age through gamified learning methods. Finally, we outline future directions for research in gamification for defense applications,

[2] Portions of this article were derived from Finkenstadt and Helzer (2022).

bringing attention to the need for collaboration across the defense-focused entities exploring the potential for gaming in future defense education and training.

Introduction

“One of the lessons we’ve learned is that we’re going to have to be flexible enough that different subjects and different kinds of training are going to require different kinds of technology.”

- Major General Andrea D. Tullos, Commander, 2nd Air Force (Hudson, 2021)

The Department of Defense (DoD) is looking for new and better ways to educate and train its increasingly tech-savvy workforce. Research indicates that traditional military schoolhouse models, which rely on rote memorization of task-relevant knowledge, are ill-suited for learning, particularly among a target population of 18–24-year-olds who have been raised entirely in the digital age. In this paper, we argue that gamified learning may be a huge part of the answer to this force readiness issue. We present initial evidence from our empirical research to highlight the opportunities and challenges for advancing military education into the present age through gamified learning methods.

Defining Gamification

In the context of learning, gamification occurs when the means of acquiring new skills or knowledge are infused and enhanced with game-like elements, including fantasy or simulated game environments; competition; points, leaderboards, and badges; and other features (see Table 1). In academia and industry, gamified methods have been applied to a range of subjects and industries with the intent to enhance learning through increased engagement and motivation with content. Relative to conventional modalities for learning new information, gamified learning can engross the learner in the material, offering the potential and motivation for deeper processing and retention.[3]

To date, the military and the DoD have leveraged games and simulations in traditional areas including wargaming, flight training, and weapons skills training (Smith, 2009). Recently, the Navy announced a plan to bolster recruiting efforts through the development of an Esports team, Goats and Glory. The application of gamification to less traditional skills acquisition and refinement, however, is only a recent innovation.

Through the course of our research, we have discovered disparate cells across the DoD ecosystem that are bringing innovative minds together to explore the potential for using gamification to enhance learning in foreign language, program management, and –our focus– defense acquisition (DA).

Should Gamified Learning Work for Defense Acquisition?

DA specialists operate in a high-risk, tightly regulated, zero-defect environment with acute public scrutiny. Decades of research in organizational science caution that such

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[3] For a critical review, see Dichev, C., & Dicheva, D. (2017). Gamifying education: What is known, what is believed and what remains uncertain: A critical review. *International Journal of Educational Technology in Higher Education*, *14*. https://doi.org/10.1186/s41239-017-0042-5

environments, which offer little room for experimentation and put a high price on failure, instill a *performance orientation* and stifle learning. This presents a paradox: How do organizations promote effective and deep learning in professional fields where the conditions most supportive of learning are perceived as a risk to ultimate mission?

The paradox is resolved if we decouple the operational environment from the learning environment. Yes, DA specialists must operate in a performance oriented, zero-defect environment, but that does not mean they need to learn in that same environment. Indeed, in fields for which requisite knowledge is detail-focused, highly manualized, and, frankly, dry, gamified learning might spark engagement with material that does not inherently engross the learner.

Games have a typical set of core features that can be highly useful for overcoming challenges in translating operational, performance-oriented environments to learning-oriented education and training environments. Larsson et al. (2021) use the term “feature” to describe the underlying design components of games, including inter-game mechanics. Games created for the primary purpose of learning may employ different features than games focused on entertainment; however, there are many features that span all types of games. Primarily, games seek to be *fun*. This ability to evoke a sense of fun separates games from many other activities. Malone (1980) has described three features through which good games evoke fun: challenge, fantasy, and curiosity. Wilson et al. (2008) contend that fantasy, representation, sensory stimuli, challenge, mystery, assessment, and control are among the most important distinguishing features of games. McGonigal (2012) puts forth four defining features of games: a goal, rules, a feedback system, and voluntary participation. We draw a common set of game features from these three sources.

Fantasy involves creating make-believe environments, scenarios, or characters (Wilson et al., 2008). It allows players and learners to escape the real world and take on a variety of traits or identities previously inaccessible. Examples of fantasy include mythical creatures like the minotaur, far-off lands such as the Moon or Mars, or imaginary moments in the future. *Challenge* requires a balancing game difficulty to promote player motivation and desire to achieve a goal. Players that are motivated want to reach the goal and win the game. McGonigal (2012) states, “the goal provides players with a sense of purpose” (p. 31). However, if the level of challenge does not match the player’s skills, by being too easy or too hard, it can result in players becoming disengaged or frustrated (Wilson et al., 2008). *Representation* is the complement of fantasy. It is the physical and psychological similarity between a game and the environment it represents (Wilson et al., 2008). It is important when applying games to training or education that they mimic the real world since trainees would not experience fully fantastical situations in any other facet of life, such as with war and combat tactics, techniques, and procedures related to defense applications.

Curiosity and *mystery* affect motivation, similar to challenge. Malone (1980) claims that “game environments should be neither too complicated nor too simple” (p. 165); they should be novel, but not incomprehensible. Mystery paints a broader stroke but arouses curiosity in “two forms— sensory curiosity and cognitive curiosity” (Wilson et al., 2008, p. 233). *Feedback* can work in sync with curiosity and mystery features. Sensory curiosity attracts the attention of players through sensory feedback, such as light or sound (Malone, 1980). This can be experienced in games through offering players audible cues such as dings or buzzes when reaching a new level or getting a response incorrect. Cognitive curiosity is provoked by paradoxical information (Wilson et al., 2008). In a game, learners want to complete their information by filling in any information gaps. The feedback system informs players of their performance or how close they are to reaching the goal (McGonigal, 2012). Feedback is important for learners, and it is a concept taught throughout military training and education systems.

McGonigal (2012) separates *rules* from *goals* and clearly defines rules. “Rules place limitations on how players can achieve the goal” (McGonigal, 2012, p. 32). Without rules, the path to a goal becomes unclear, as the player can navigate through objectives free of any restriction. Rules motivate players to explore uncharted possibilities in games (McGonigal, 2012). Rules foster increased creativity and strategic thinking (McGonigal, 2012), furthering levels of fun and participation. Wilson et al. (2008) agree that well-established rules are necessary components of effective education games. There are three types of rules: system rules, procedural rules, and imported rules (Wilson et al., 2008). System rules are those functional parameters inherent to the game itself (Wilson et al., 2008). Procedural rules are in-game actions that control behavior (Wilson et al., 2008). Lastly, imported rules are those that originate from the real world (Wilson et al., 2008), such as physical limits of human beings. Without rules, games do not exist, as the greater goals of the game become too easy to reach (Suits, 1978/2005).

Voluntary participation is a critical feature of games. Wilson et al. (2008) call this feature “safety.” It is a safe way to experience reality through the disassociation of actions and consequences (Wilson et al., 2008). This feature means that players willingly accept the parameters of the game. The goal, the rules, and the feedback are known by all, and that establishes the common ground from which all players start (McGonigal, 2012). This makes games transferrable between all players, meaning no player has an unfair advantage as a participant. Also, the ability to come and go in a game “ensures that stressful and challenging work is experienced as a safe and pleasurable activity” (McGonigal, 2012, p. 32). Voluntary participation can be critical to the success of games that are focused on training and education. We know that DA is characterized by a high-risk, tightly regulated, zero-defect environment overseen with acute public scrutiny. Lowering or removing the consequences in a training environment allows learners to experiment in ways that may not be comfortable in traditional training delivery methods and may encourage greater student learning orientation over performance orientation. Finally, *mulligans* refer to the ability for games to allow trainees and players a “do-over.” This interacts with the features of curiosity and feedback, allowing the student to take risks based on intellectual curiosity, receive feedback, and learn the greater lesson without fear of irreparable harm to themselves or their missions.

Table 1 provides a side-by-side depiction of the alignment between the typical features of games with those of the DA operational environment. The interaction column indicates how features of the game environment interact with features of the DA operational environment to promote greater learning by either reducing features of the DA operating environment that are detrimental to learning or reinforcing those features that promote critical learning objectives. For example, the threat of real-world legal consequences in the DA operational environment limits students’ exploratory behaviors; however, the *fantasy* aspects of the gamified learning environment can encourage students to explore, try, and fail. *Voluntary participation and mulligans* allow players to experience various roles within the DA process and redo experiences within the DA process to improve outcomes or simply explore alternative results without fear of consequence. Of course, unbounded fantasy is unlikely to promote transferrable knowledge to the DA operational environment, so counterbalancing this with *representation*, which increases exposure to actual complexities in these markets, and *game rules*, which reinforce the limits of highly regulated environments, can potentially optimize the balance between operational realism and game-enhanced learning. Other game features, such as *challenges/goals*, *curiosity/mystery*, and *feedback*, not only mimic features of the DA environment but may enhance motivation and engagement with the material to be learned. In short, games allow learners to enter a world of low consequence and strong feedback with variable degrees of operational realism—one in which the decisions and challenges are entered into voluntarily and allow for freedom of exploration.

Table 1. Alignment of Gamified Learning Environment With Features of DA Operating Environment (Finkenstadt & Helzer, 2022)

Features of Gamified Learning Environment	Interaction	Features of DA Operating Environment
Fantasy	Reduces	Objective realities with real consequences in litigious environments.
Challenges/Goals	Reinforces	Complex problems, levels of professional achievement, varied levels of problem difficulties
Representation	Reinforces	Evolving problems in highly variable environments.
Curiosity/Mystery	Reinforces	Heterogeneous requirements that require customer discovery and market research and intelligence gathering.
Feedback	Reinforces	Communications across networks. Interactions with public and private entities. Adverse consequences for poor performance or conflicts of interest.
Rules	Reinforces	Strong regulatory environment tha, in many cases, is based on procedural rules.
Voluntary Participation and Mulligans	Reduces	All decisions have consequences for one or more DA parties (costs, schedule, performance, reputation etc.). DA member roles are constrained by regulatory authorities and agency rules (only the contracting officer may obligate fiscal funds, etc.)

Gamified Education and Training Research Lines of Effort

Our research has shown us that the design and development effort for gamification studies is highly involved, including three concurrent lines of effort. First, teams must design game content. They must focus on the curriculum and subjects of interest and specify learning objectives. This can include designing material to be learned in a variety of manners, from simple rote memorization to complex derivative means such as procedural rhetoric. Second, teams must design the game itself. It involves skilled development teams with proficiencies in a variety of skills from coding, commercial game development software functionality, graphic design, visual narratives, etc. Finally, research teams must design the study to explore efficacy and other research questions. This may include survey design, pre- and post-tests, timing, internal review board approvals, etc. Synthesizing these three lines of effort is a complicated undertaking that requires sound program management skills to pull off successfully.

Game Types

Our research and experiences in exploring gamification for defense training and education have revealed three primary game modalities that can be used for learning: (1) serious/simulation gaming, (2) exposure gaming, and (3) engagement gaming.

Serious games are realistic games that put the player through the motions of performing real world tasks in a simulated operating environment with the intent to sharpen skills. These games closely recreate physical and relational environments, as in the case of the widely popular “Apex Officer” VR game or Walmart’s Spark City game, in which players are required to manage the day-to-day operations (keeping shelves adequately stocked, keeping customers satisfied) of a fictional Spark City store.

In exposure games, players also practice the skills and abilities of their real-world roles but do so through proxy or by way of carry-over effects. For example, financial managers or logisticians in the military playing games such as “7 Days to Die” or “Green Hell” must rely on resource management skills and planning over long horizons of time in order to successfully survive the game, even though the game environment bears little resemblance to players' real world operating environments.

Finally, in engagement games, very few elements of the game environment or activities within the game match the players' real world operating environments; it is more about introducing curriculum subject matter to the player in an alternate universe/setting to evoke a sense of increased interest and engagement. In our research to date, we have worked from the modality of engagement gaming to allow players to learn and rehearse otherwise "dry" material in a learning environment that leverages game-enhanced motivation and cognitive engrossment.

Gamification of Training and Education in Industry

Gamification is being used by many commercial firms. With over 500,000 downloads on the Google app store as of March 2022, Walmart's Spark City game stands out as a clear example of simulated work that has gained popularity (Grill-Goodman, 2019). In the game, players are required to manage the day-to-day operations of a fictional Spark City store. This includes keeping shelves adequately stocked and keeping customers satisfied. The intent is to help managers improve skills and to encourage non-managerial associates to learn more about each department.

Deloitte is a well-known consulting firm that has been named one of the best 100 firms to work for by *Fortune* magazine. Deloitte also does a substantial amount of work with the federal government, with over 4,000 contracts and subcontracts in the last seven years. Deloitte chose to gamify its executive leadership training when they observed that the standard delivery model was being underattended or not completed. They developed a serious game related to leadership interactions. They introduced gamification elements such as badges, leader boards and status indicators. Deloitte has reported that players interacting with the game achieve greater intrinsic reward, enter a sense of flow, want more experience with the game as difficultly progresses, and enjoy instant feedback on their performance. Employees reported the game becoming almost addictive, and participation in the training nearly doubled. Performance on cognitive ability tests were 10–20% higher among game players than those that did not play the game or those who played a game that did not increase game difficulty progressively (Bradt, 2013).

Gamification of Training and Education in the Military

Gamification in the military has been previously utilized and is becoming more common as the digital world becomes more ubiquitous to professional military communities. As the next generation of warfighters (i.e., those born on or before 2004) enters the military, they bring their tendencies and preferences for learning. For many, this includes video games and simulations. Since 2002, the Army has used "America's Army" as a recruiting tool and means of improving strategic communications with citizens. The military has used simulators for years for training pilots, missileers, or simulating troop carrier rollovers in Iraq and Afghanistan. More recently, this has expanded into other areas, including VR simulation games that train security personnel in the U.S. Air Force with the game "Street Smarts." However, not all training has to be directly attributed to technical or tactical skills. Other, less kinetic areas of military training are moving into VR space. In 2021, the Air Force began training for sexual assault and prevention using VR from the firm Moth+Flame. Games that cross into simulation and engagement are being built. For instance, the Defense Acquisition University is building a game called "MindShift" that teaches players how to run a software development acquisition team and an organic software factory within the military. MindShift allows players to trade real world decision criteria in a resource-constrained environment while playing in a space that feels more like Minecraft or Roblox than a military office.

We see engagement gaming increasing in the military as well. Our “Sandbox Contracting” game, discussed in detail below, was launched at the 344th Training Squadron in San Antonio, Texas, in 2021 and tested on four waves of contracting students and a wave of Naval Postgraduate School (NPS) graduate students during the summer and fall of 2021. The Defense Language School is building a linguistics game entitled “Mage Duel” that allows players to earn magical powers and energy to fight off enemies by successfully translating phrases in various languages associated with their area of study. Our teams at NPS are working with NC State University to build short pinball and pachinko games for teaching contract protest areas of risk for junior acquisition personnel and more robust games such as market intelligence-based virtual escape rooms and tower defense games for learning operational contracting support skills. And there are any number of opportunities to build and test technical and communication skills development using exposure gaming with products like “Keep Talking and Nobody Explodes” or “Satisfactory.” The military services have all invested in building up their own E-sports teams, and military education organizations like the Air University (AU) are posting open calls for schools and firms to propose ideas about how to build leadership skills through gamified learning. AU has recently launched “Project DAWG (Developing Airmen with Games)” in collaboration with Innovatrium at the University of Michigan as an open innovation tournament for training and education game development.

Engagement Gaming for Defense Acquisition: An Initial Investigation Through Curriculum Modality Evaluations

In initial work, our MBA students at NPS programmed a first-person shooter game involving gun battles and bomb diffusion, in which success depended on players’ ability to correctly answer questions about federal acquisition rules and regulations (Larsson et al., 2021). We were fortunate enough to be able to team with the 344th Training Squadron at Lackland AFB, Texas, for the testing phase. Our partners at the 344th provided our MBA students with approved curriculum and assisted in developing pre- and post-tests for assessing short-term, immediate knowledge retention. A wave of data was also collected from NPS students in the DA field.

As the game begins, an on-screen manager provides players with an overview of relevant curriculum content and information needed to answer future game questions correctly. At the end of the instruction period, the player learns that the office is under siege. Upon entering the main game area, players must fight off waves of attackers in each level. At each critical juncture, players are presented with a bomb to diffuse by cutting one of four wires, corresponding with four possible answers (one correct and three foils) to a federal acquisition related question. As shown in Figure 1, if the correct wire is cut, the bomb is diffused, and the player earns points to put towards upgraded equipment. If the player fails to answer the question correctly, the bomb explodes, and the player takes damage. At the end of the game, each player receives an after-action report detailing their performance on attacker engagement and bomb diffusion (i.e., correct answers).

Learning outcomes for our “gamer” participants were compared to outcomes for control groups who received the very same material delivered in standard instructional format (Power Point guided lecture). Along with post-training knowledge tests, we compared learners’ satisfaction and engagement to understand the opportunities and challenges of gamified learning in military education.

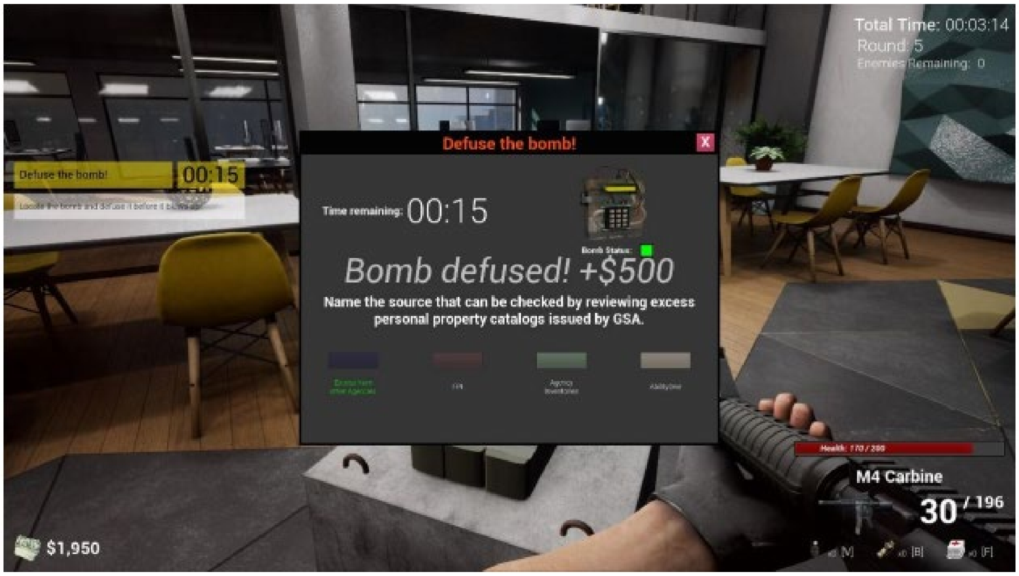

Figure 1. Screenshot of Sandbox Contracting Player Feedback
(Larsson et al., 2021)

Findings

We find that gamified DA training shows mixed results in short-term material retention (Larsson et al., 2021). All results indicate a positive increase in material retention; however, variation exists across study waves when comparing the retention of students exposed to gaming versus those exposed to conventional methods. Figure 2 presents the pre- and post-scores on lesson quizzes related to FAR Part 8 for waves 1–4 and category management for wave 5. Figure 3 represents the same results for the students exposed to gamified versus conventional lessons. Table 2 provides a summary of overall findings from the Larsson et al. 2021 study. In three of the five waves, the traditional (control) method outperformed gamified (treatment) method by a median improvement of 5–10%. In one wave, the gamified and traditional methods performed equally well. In a final wave, with environmental and curriculum variation, the gamified method outperformed the traditional method by more than 15 percentage points. We attribute much of the variation in results to three primary factors: 1) students' prior preferences for gaming, 2) the gaming environment versus control environment, and 3) curriculum learning objective design.

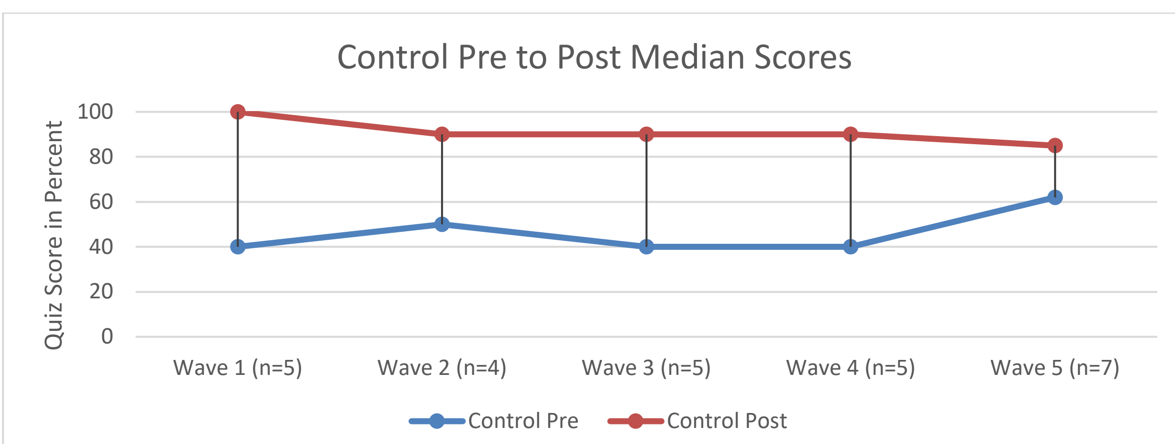

Figure 2. Control Pre to Post Quiz Score Comparison Across Waves

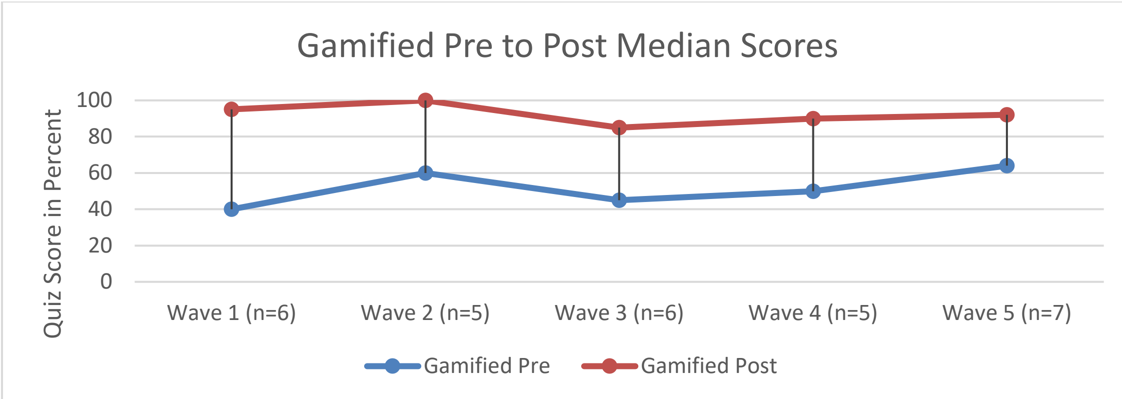

Figure 3. Gamified Pre to Post Quiz Score Comparison Across Waves

Table 2. Summary Results From Larsson et al. (2021)

Wave	Curriculum	Treatment Median Pre-Post Change	Control Median Pre-Post Change	Question Type
344-A	FAR Part 8, Mandatory Sources of Supply	55%	60%	1-for-1
344-B	FAR Part 8, Mandatory Sources of Supply	40%	40%	1-for-1
344-C	FAR Part 8, Mandatory Sources of Supply	40%	50%	1-for-1
344-D	FAR Part 8, Mandatory Sources of Supply	40%	50%	1-for-1
NPS	OMB Category Management	30%	23%	Derivative
Wave	**Game Version**	**Game Hardware**	**Treatment Environment**	**Control Modality**
344-A	1.0	Chromebook	Individual play in instructor observed lab	In-person PowerPoint (PPT) and discussion
344-B	2.0	Chromebook	Individual play in instructor observed lab	In-person PPT and discussion
344-C	2.0	Chromebook	Individual play in instructor observed lab	In-person PPT and discussion
344-D	2.0	Chromebook	Individual play in instructor observed lab	In-person PPT and discussion
NPS	2.0	Gaming CPUs	Competitive play in SILAS gaming lab	Zoom PPT and discussion

Our research found that students come to the education and training experience with a range of preferences for learning modalities. Some students prefer any form of game over traditional instruction, others prefer only specific types of games over traditional instruction, and still others find gamified learning undesirable before ever experiencing it. This latter group should receive special attention as agencies determine whether to gamify education and training, especially if gamified methods are being considered as a full replacement for traditional methods. Voluntary participation is a key tenet in the concept of play. Researchers have found that mandatory play may remove the benefits from gamified learning (Furdu et al., 2017). Our findings suggest that gamified learning as augmentation may be the best approach for most situations and curricula. Our research utilized randomized assignment of students to gamified versus traditional methods. This may have negatively impacted the performance of those learners who are not predisposed to playing video games. Future studies should consider allowing for self-selection. Though this is contrary to most clinical between-groups study design recommendations, it may be the best way to capture the benefits of gamified learning for those who would self-select into the method. Agencies should be open to the idea of offering a variety of learning modalities to meet heterogenous student preferences.

We attribute the next important source of variation in outcomes to varied gamified and conventional learning environments. The four waves of research conducted at the 344th were limited in computational capabilities. We ran our games on Chromebooks versus gaming computers, which provide better graphics capabilities and smoother running performance. Based on comments from learners in the gamified environment at the 344th, this seemed to impact their experience with the game. Notably, students in our fifth wave of research at NPS utilized gaming computers. They reported enjoying the experience and had fewer complaints about game performance impacting their learning. Using appropriate technology to support gamified learning is a critical element to successfully deploying these instruction modalities. Additionally, players at the 344th were instructed to play individually with instructor observation, whereas NPS players were allowed to openly interact and engage in competitive practices with the MBA study team standing by for technical assistance. Taken together, these environmental variations could have meaningfully impacted students' performance.

Finally, we would point out that our waves show variation in short-term lesson retention across varied curricula. The curriculum for NPS covered federal category management principles using derivative learning (questions in the game were not exactly what was on the pre- and post-test but could help the player answer the post-test questions by deriving the information from questions within the game). The waves at the 344th used 1-for-1 questions: questions in the game exactly matched what players saw prior to and following the game. All versions of the game randomized the sequence of questions within the game such that the player could not simply memorize a pattern of answers to beat the game; however, the one wave in which gamification outperformed conventional methods relied on higher level of critical thought. This should be further studied, as it suggests that gamification can lead to greater improvements in higher-order learning when compared to conventional methods, perhaps by leveraging cognitive curiosity. Simple recall objectives may be more sensitive to other areas of variation, such as player predispositions toward games and environmental heterogeneity.

Player Experiences

In our study, we explored a variety of measures of efficacy, player engagement, and player sentiment. The evaluation instrument contained multiple choice questions related to pre and post evaluation of student knowledge, five-point Likert scale–type agreement questions, and open-ended questions related to experience and satisfaction. Likert-based questions were used to assess favorability and quality of the training, confidence in participants' answers, and experience with video games. The open-ended questions asked about military experience, the player's most often played games, and open feedback on each type of training. A recommendation-based question was inserted to assess the Net Promoter Score (NetPS) for each participant. This score was based on how likely the respondent was to recommend these learning methods to a friend or colleague. We decided to use NetPS to directly compare favorability between the groups as it is a commonly used technique for product evaluation in industry. NetPS is a metric used in customer experience programs and measures the loyalty of customers to a company (Qualtrics, 2021). NetPS can give an instant indication of customer satisfaction, informing overall favorability (Jain, 2020). This data was collected in five waves (four at the 344th and one at NPS) during the second half of 2021 to align to active course schedules at both locations.

Table 3 shows the categories that were created to identify trends in the responses by learning groups. Treatment groups tended to attribute their NetPS to game design factors, while control groups overwhelmingly attributed their NetPS to method/modality preference. Interestingly, when it comes to Net Promoter Scores, for all 344th waves in which the control group outperformed the treatment group on test improvement medians, control groups also assigned a higher NetPS score than did treatment groups. This suggests that learners' satisfaction with the learning modality was partly a function of how well they learned the material.

A representative quote from 344-C (wave 3) demonstrates the importance of game design in conducting these studies and employing gamified education and training methods:

> If the idea of gamifying the learning environment is to take off, a larger investment needs to be put in the development and hardware aspects of the games. The game ran choppily, glitches occurred to many of my fellow students, and overall, the quality of the game itself played fairly poorly compared to what one would expect from a new experiment designed for learning.

Similarly, 344-B (wave 2) and the NPS wave 5, which had equal or greater improvement scores by treatment versus control groups, showed higher promotion for the game method versus the traditional method.

A representative quote from 344-B (wave 2) demonstrates a preference for gamified learning in the treatment group:

> I believe that gamification takes the mundane feeling out of learning. Death by PowerPoint is never a fun time for anyone, and it can make learning (and teaching) an arduous experience and task. Being able to break up that monotony with interactive games which utilize repetition and recall, I believe, would drastically improve test performance and overall opinion on the classroom environment. If you make individuals have a desire to come to class and be engaged (i.e., playing games, having fun, etc.) then they will be more eager to learn and have an overall more positive attitude towards the subject. I believe gamifying military education is a wonderful step in the right direction.

This may indicate that these samples were predisposed to the benefits of the gaming modality, which could have contributed to their post-testing improvement. Additionally, we found that many participants stated that they would use gaming to learn outside of class and that they felt that using game training methods would increase their job satisfaction. Finally, we would point out that the gaming literature discourages the idea of mandatory play (i.e., forcing subjects to play a game they do not opt into). Our prototype testing utilized random assignment of learners to treatment versus control groups. Although this is a "gold standard" practice in randomized control trials, in this case it may have negatively impacted the performance of those subjects who were not predisposed to playing video games. Future studies should consider allowing for self-selection. and agencies should be open to the idea of offering various learning modalities to meet heterogenous student preferences.

Table 3. Stated Reasons for Player Net Promoter Score Rating (Larsson et al., 2021)

Theme	Definition
Active Learning	Mentions of different concepts of active learning (see Chapter III literature review) – Treatment group
Ease	Participant rated the experience based on ease of learning/information delivery – Treatment group
Game Design	Includes game genre, various gameplay mechanics, difficulty of gameplay, gameplay issues (bugs/glitches) – Treatment group
Instructor Delivery	Mentions of instructor delivering material effectively – Control group
Neutral	Comments did not provide significant insight to the reason for rating – Both groups
Opportunity for Feedback	Learning environment presents opportunity for immediate feedback. Respondent appreciates the opportunity for feedback and interaction with instructor – Control group
Perceived High Level of Learning	Respondent perceived their level of learning to be high – Control Group
Preference	Mentions of a preferred method/modality of learning i.e., visual learning, auditory learning, active learning, gamified learning etc. – Both groups

Gamer Types

One of the most important lessons we have learned throughout our research is the role that gamer types may play in player perceptions of games and gamified learning experiences. Anytime a game is developed, it is important to consider a variety of player types. Most games do not entice every type of player. In 1996, Bartle created a taxonomy of player types based on a debate about what people wanted out of a multi-user dungeon (MUD) game (Bartle, 1996). Bartle summarized months of discussion on the topic into four sub-groupings of player types and their desires. Bartle (1996) found that people typically enjoyed four things about MUDs: achievement within game context, exploration of the game, socializing with other players, and imposition of one's will upon others. These four aspects were graphed using the source of players' interest as axes (see Figure 4).

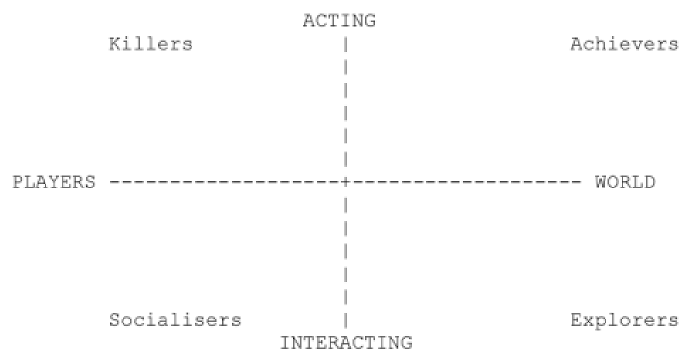

Figure 4. Bartle's Taxonomy of Player Types
(Bartle, 1996)

This 2×2 taxonomy results in four types of players: killers (those with an interest in acting on other players), achievers (those with an interest in acting on the game world), socializers (those with an interest in interacting with other players), and explorers (those with an interest in interacting with the game world). The x-axis stems from an interest in *players* to an interest in the *gaming world*; the y-axis ranges from an interest in *interacting with other players* to an interest in *acting on other players* (Bartle, 1996). This typology can serve as a foundation for developing gamified contracting training, informing future game design and studies following our work. There are additional typologies that have emerged since Bartle's work in the 1990s. Our research points to a need to conduct a wide-ranging assessment of overarching player archetypes within DA to maximize the effectiveness of gamified education and training design.

In a short in-class test of DA gamer types, we found evidence that DA players were most likely to fall into the category of *achievers*, followed by a mix of *explorers*/*killers*, and were least likely to be *socializers* (see Figure 5). This is only based on a small sample of active-duty U.S. Air Force Contracting personnel at NPS, and given the low number of respondents, the types are essentially evenly split across an average DA player. But this is an early indication that each of Bartle's (1996) gamer types should be considered in DA game design efforts in the future. The students are officers competitively selected for higher education. They are more than likely pre-disposed to achievement orientation as well as a tendency to want to act on others versus with others. They may not represent the wider swath of DA personnel but may represent a prototypical officer within DA. Further research is needed to explore the various levels of heterogeneity in player types (officer/enlisted/civilian, active/reserve/guard, gender, experience levels, etc.) before a generalized finding can be reported.

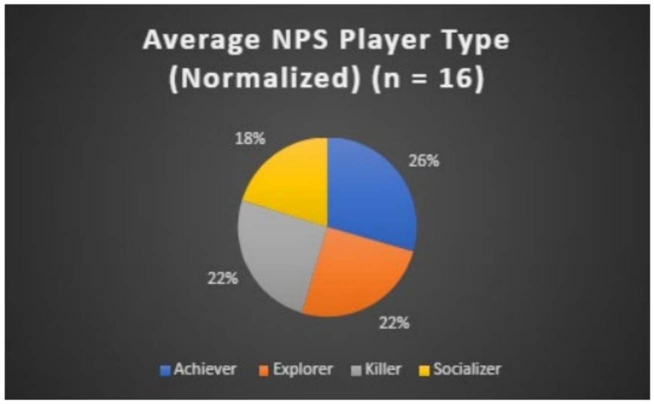

Figure 5: Normalized Prototypical Player Type, NPS DA Student
(Larsson et al., 2021)

Future Studies

We have found that gamified learning is a ripe area for future development, research, and investment in military education. Currently our team at NPS is working in the SILAS lab to build games related to acquisition sciences. We believe that these and other military specialty focused gamified learning opportunities should be explored. One avenue for future research is to explore how different types of games (e.g., first-person shooter, role playing games) can promote enhanced learning by appealing more closely to the preferences of the individual player. We anticipate a future in which a range of curricula are offered to students via a suite of gaming options, like the app store within Oculus. Table 4 provides a representative matrix concept. Matrix cells marked with an "x" currently have a game design effort complete or underway within our network of DA game developers.

Table 4. Notional Application Matrix for Defense Acquisition Subjects and Game Types

	Game Types					
Subject	**First Person Shooter**	**Escape Rooms**	**Arcade-style**	**Role-playing**	**Puzzles**	**Tycoon**
Requirements Development						
Systems Engineering						
Mandatory Sources	x					
Market Research/Intelligence		x				
Category Management	x					
Acquisition Plans						
Solicitation Development						
Contractor Evaluations						
Negotiations						
Intellectual Property						
Contract Protests			x			
Contract Quality Management						
Contract Changes and Mods						
Closing Contracts						
Contingency Contracting/OCS						
DevSecOps / Software Acq						x
Subject	**Game Types**					
	Action-adventure	**Sandbox**	**Real-time Strategy**	**Tower Defense**	**Base build**	**Simulation**
Requirements Development						
Systems Engineering						
Mandatory Sources						
Market Research/Intelligence						
Category Management						
Acquisition Plans						
Solicitation Development						
Contractor Evaluations						x
Negotiations						
Intellectual Property						
Contract Protests						
Contract Quality Management						
Contract Changes and Mods						
Closing Contracts						
Contingency Contracting/OCS				x	x	
DevSecOps / Software Acq		x				

As our research and thinking has developed, we have discovered various cells within and outside of the DoD all working on developing games for promoting learning in military education. Currently this space is primarily filled by NPS, North Carolina State University, Defense Acquisition University, Defense Language Institute, and a small band of organic developers within the Air Force Installation Contract Center, each working independently with very little crosstalk. We are currently working with support from the Acquisition Research Program and Acquisition Innovation Research Center to explore further areas of research in DA gamified learning. Most notably, we plan to explore gamer types in DA communities, the potential dark side of gamified training and education, the use of virtual escape rooms for DA training and education, and the development of a tower defense game to meet DoD operational contracting support (OCS) learning objectives. The opportunity for collaboration on these and other gamification-related research is at our fingertips, enhancing the potential of game-based learning to become a reality for 21st century military education.

References

Bartle, R. (1996). *Hearts, clubs, diamonds, spades: Players who suit MUDs*. Players who suit MUDs. https://mud.co.uk/richard/hcds.htm

Bradt, G. (2013). How Salesforce and Deloitte tackle employee engagement with gamification. *Forbes*. https://www.forbes.com/sites/georgebradt/2013/07/03/howsalesforce-and-deloitte-tackle-employee-engagement-with-gamification/

Finkenstadt, D. & Helzer, E. (2022). *Expanding gamified learning for defense applications* [USNI Essay Working Paper].

Furdu, I., Tomozei, C., & Köse, U. (2017). Pros and cons gamification and gaming in classroom. *Broad Research in Artificial Intelligence and Neuroscience*, *8*, 56–62. https://doi:10.5281/zenodo. 1045364.

Grill-Goodman, J. (2019). *Walmart adds gamification to its next-gen workforce training toolkit*. RIS News. https://risnews.com/walmart-adds-gamification-its-next-genworkforce-training-toolkit

Hudson, A. (2021). Air Education and Training Command embraces virtual and augmented reality. *Air Force Magazine*. https://www.airforcemag.com/article/the-classroom-on-your-head/

Jain, A. (2020). *Why you should measure net promoter score (NPS)*. ReadWrite. https://readwrite.com/2020/07/03/why-you-should-measure-net-promoter-scorenps/

Larsson, I, Marshall, M., & Whitworth, L. (2021). *Sandbox contracting: An evaluation of gamified vs. traditional contracting training methods at the USAF enlisted contracting technical school* (Acquisition Research Program Report No. NPS-CM-22-014). https://dair.nps.edu/bitstream/123456789/4533/1/NPS-CM-22-014.pdf

Malone, T. (1980). What makes things fun to learn? Heuristics for designing instructional computer games. *Proceedings of the 3rd ACM SIGSMALL Symposium and the First SIGPC Symposium on Small Systems*, 162–169. https://doi.org/10.1145/800088.802839

McGonigal, J. (2012). *Reality is broken: Why games make us better and how they can change the world*. Vintage.

Qualtrics (2021). *The ultimate guide to net promoter score (NPS)*. https://www.qualtrics.com/experience-management/customer/net-promoter-score/

Smith, R. (2009). The long history of gaming in military training. *Simulation & Gaming*, *41*, 6–19. https://doi.org/10.1177/1046878109334330

Suits, B. (1978/2005). *The grasshopper: Games, life and utopia*. Broadview Press.

Wilson, K. A., Bedwell, W. L., Lazzara, E. H., Salas, E., Burke, C. S., Estock, J. L., &. Conkey, C. (2008). Relationships between game features and learning outcomes. *Simulation & Gaming*, *40*(2), 217–266. https://doi.org/10.1177/104687810832186

Harnessing the Power of Digital Platforms to Accelerate Adoption Rates of Emerging Technologies and Innovations

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Abstract

The recent Overmatch championed Artificial Intelligence and Networks (AINet) Advanced Naval Technology Exercise (ANTX) demonstrated an alternative all-digital ANTX format enabled by integrated Rapid Innovation Labs (iRILs). This resulted in shortened ANTX planning and execution timelines, increased focus on technologies of interest, earlier integration into naval architectures, sharing of relevant operational data with participants, and meaningful feedback to developers throughout integration phases, informing research and development (R&D) and program acquisitions. An iRIL is a digital environment and an acquisition tool used to address priority Fleet needs, evaluate technologies and prototypes, and inform and influence external partner R&D investments. An all-digital iRIL can facilitate faster, smaller cycles of iterative

experimentation of component technologies of interest within representative Fleet architectures and simulated operational environments. Future applications of iRILs could fundamentally change the way we acquire systems. The use of open competitive events such as an ANTX Prize Challenge could yield component level, containerized technologies of interest that are matured throughout the event process and can be assessed as well-behaved. Such well-behaved software containers or component technologies may enter the Overmatch Software Armory (OSA) or Live, Virtual, and Constructive (LVC) pipelines, achieving rapid authorities to operate (ATO), cycling to a ship within days.

Key Words: DEVSECOPS, LVC, ATO, iRIL, MOSA, Accelerated Acquisition

Introduction

Advanced Naval Technology Exercise (ANTX) events are a venue for warfighters, technologists, engineers, acquisition professionals, and sponsors to demonstrate and assess the potential of novel tactics, emerging technologies, and prototypes aligned to priority Fleet needs. ANTX events are typically hosted by Naval Warfare Centers (NWC), occasionally endorsed by a warfighting sponsor, with technologies provided by participants across the Naval Research and Development Enterprise (NR&DE), industry, and academia. The traditional approach to planning, executing, and transitioning ANTX findings has resulted in acquisition program transitions and fieldings on the order of 12–18 months or more post ANTX event. This time is typically devoted to modifications necessary for Fleet adoption (e.g., communications packages upgrades, engine modifications, ruggedization, tactics development, etc.; UAS Vision, 2018).

While ANTX's have been heralded as venues with rapid feedback loops that have resulted in some system-level procurements and have tremendously helped the U.S. Marine Corps in particular re-imagine their force structure, the pace of warfare in this century has been said to be accelerating evermore. At ANTX West 2019, Rear Admiral Donald Gabrielson, then Commander of San Diego-based Carrier Strike Group 11, spoke of the rapid change in the battle space, saying that "change is accelerating, and so we have to accelerate in order to maintain our competitive advantage" (Fuentes, 2019).

Between May 2021 and December 2021, the Artificial Intelligence and Networks (AINet) ANTX team was challenged with the audacious objective to identify and field emerging technologies at the blistering pace that maintaining overmatch over a high-tech adversary demands. The team pioneered the pairing of multiple novel concepts including leveraging innovative prize challenge acquisition authority with ANTX events, and executing technical and operational assessments in fully digital, integrated rapid innovation laboratory (iRIL) environments. These iRILs adhered to the *free, perfect, and instant* (McAffee & Brynjolfsson, 2017) key tenets of the power of the platform and were crucial to the success of the Navy's first-ever all-digital ANTX event.

An iRIL is a digital platform typically constructed of hybrid live, virtual, and constructive (LVC) environments within which emerging technologies can be easily integrated, developed, and continuously assessed. When an iRIL is developed in alignment with priority Fleet needs, and is shared widely with developers from across the NR&DE, industry, and academia, the outcome is a *shared consciousness* (McChrystal et al., 2015) and influence of internal research and development (IR&D) investments across the defense industrial base (DIB).

This shared consciousness is a state of "emergent, adaptive organizational intelligence," which fuses "generalized awareness with specialized expertise" (McChrystal et al., 2015). Noting the complex problem space and the requisite flattened knowledge dissemination required to find a solution from a systems approach, General (Ret.) Stanley McChrystal

(McChrystal et al., 2015) wrote that “harnessing the capability of the entire geographically dispersed organization meant information sharing had to achieve levels of transparency” that were “entirely new” to parties involved. He was describing the basis for his *team of teams* construct in the Joint Special Operations Task Force in Iraq in the early 2000s. This is the agile construct that Overmatch strived to achieve with the DIB via the all-digital ANTX.

In doing so, these methods improved the focus and quality of engagements with industry, non-traditional providers, and the academic community; and has driven scientific and technological investments toward technological areas of priority importance to Overmatch objectives. The application of these novel concepts was essential in enabling the speed and efficacy of technical and operational assessments for almost fifty emerging technologies submitted to AINet ANTX by industry, academic, and Navy teams.

The scope and scale of the impacts exceeded expectations. Lowering the barrier of entry into Overmatch digital platforms and providing insight into representative Fleet architectures and relevant operational environments allowed participants to quickly gain meaningful insights and near-real time detailed and quantitative assessments and feedback.

The AINet ANTX team harnessed the power of the digital platform and it became particularly profound in the context of Overmatch objectives and constraints. This audacious vision has laid the foundation and has the potential to have an even more profound impact on acquisition strategies that would strive to establish open, competitive, iRIL-powered, digitally-enabled industry engagement events on a more periodic basis.

Overmatch

Overmatch is a high priority Department of the Navy (DoN) initiative aimed at connecting platforms, weapons, and sensors together in a robust Naval Operational Architecture (NOA) that integrates with Joint All-Domain Command and Control (JADC2) for enhanced Distributed Maritime Operations. Overmatch was initiated late in 2020 with advanced capabilities already being fielded to four aircraft carriers (Katz, 2022). Additionally, the Overmatch Software Armory (OSA) and integrated LVC environments were established for the continuous integration of emerging technologies that will advance the reach, capacity, and resiliency of maritime tactical network of networks.

Yet, Overmatch is as much about delivering the NOA as it is about transforming the way that capability is delivered. The Chief of Naval Operations (CNO) Admiral Michael Gilday wrote:

> We will effectively apply modern digital and information technology to allow us to make better and faster decisions in combat and ashore, improve our readiness and sustainability, and drive affordability... Digital technologies, coupled with process improvement and an innovative mindset of continual learning, are critical to winning a future fight. (Gilday, 2021)

The end-state is not an architecture that we can specify today to meet tomorrow’s needs. The end-state is about the “how” and transforming how we deliver capability. In 2020, the Secretary of the Navy (SECNAV), Kenneth Braithwaite, wrote of concerns regarding the quickly eroding advantages the United States has enjoyed as a maritime nation and provided key guidance on the path forward to retaining overmatch:

> America’s creativity and innovative spirit are an enduring advantage over our rivals. Integrated investments must reinvigorate and restore an agile, modern U.S. maritime industrial and innovation base. Our efforts will draw upon traditional defense suppliers, commercial companies, and institutions at the leading edge of emerging technologies, including next generation

communications, artificial intelligence, and quantum computing. (Braithwaite, 2020)

Thus, the speed and efficacy of industry engagements and science and technology (S&T) transitions are paramount to maintaining overmatch over advancing threats which are very, very real.

The AINet ANTX and associated iRILs were designed to build upon the Overmatch infrastructure and to provide the mechanism to explore emerging technologies from across the technical community. The prize challenge solicitation was open to participants from traditional defense industry and government laboratories, but also non-traditional participants from commercial industry, small business, and academia. The objective was to very quickly identify operationally relevant innovations and emerging technologies that can be easily integrated and fielded into Fleet architectures with upgrades that do not require major hull, machinery, engineering (HME) modifications or significant "hot-work" (Katz, 2022).

Approach

In creating an agile team of teams structure with the DIB, the use of a digital platform, the iRIL, was essential to accelerating the creation of a shared consciousness while capitalizing on key strengths of a digital information technology. The iRIL is a generic term for a sandbox that is sufficiently representative of the target platform that can be provided to developers to quickly develop and then confidently assess emerging technologies prior to fielding decisions.

The general advantages of an online, digital platform are its economics—that it is free, perfect, and instant and thus, begets the benefits of "near-zero marginal cost of access, reproduction, and distribution" (McAffee & Brynjolfsson, 2017). The use of digital platforms ensures an inherent modularity which can be capitalized upon to aggregate and disaggregate data, capabilities, applications, and processes at will. Further, the ability to bundle and unbundle any set of digital resources provides practical utility when the data, applications, and/or processes need to be isolated or integrated in response to sensitivity or desired scope. These "modular sets of digital resources" could be "combined and recombined" (McAffee & Brynjolfsson, 2017) and made instantly accessible, agnostic to geographical constraints, thus allowing dissemination to a much greater audience, at speeds that could not be previously achieved.

As a result, these resources could reach and be used by a singular developer or grassroots groups. This is in contrast to previous approaches, where chiefly only established entities could support the requirements of entry and subsequent development for the government. With a network delivery cost of virtually zero, this drastically reduces the barrier to contribution, providing an open hearth while maintaining necessary segregated boundaries for anyone with internet access to collaborate and contribute to the development of a solution for a dedicated problem set.

Thus, novel innovations can result, not necessarily from the direct innovation of something novel, but from the combination of materials already existing in a manner that is novel. This is the underlying theory of a process called *combinatorial innovation* (McAffee & Brynjolfsson, 2017). As stated by McAffee and Brynjolfsson (2017), "Combinatorial innovation can be fast and cheap, and when it's leveraged by the power of the free, perfect, and instant characteristics of platforms, the results are often transformative."

An advantage in the use of a digital platform is the inherent alignment to the DoD's framework for use of modular open systems architecture (MOSA) in defense acquisition programs (Deputy Director for Engineering, 2020). It is an integrated business and technical strategy which aims to achieve the incremental acquisition of "warfighting capabilities, including systems, subsystems, software components, and services, with more flexibility, competition, and innovation" (Directorate of Defense Research and Engineering for Advanced Capabilities, 2017). The bundling and unbundling feature is directly in line with MOSA in that digital platforms present forums for "highly cohesive, loosely coupled, and severable modules that can be competed separately and acquired from independent vendors" while maximizing re-use of assets alongside reducing ownership costs and risk between both parties further left of acquisition (Directorate of Defense Research and Engineering for Advanced Capabilities, 2017).

The AINet ANTX harnessed the power of the digital platform, effectively providing free, perfect, and instant (McAffee & Brynjolfsson, 2017) virtual environments to confidently assess technologies of priority interest via the AINet iRILs. These iRILs were defined by the overarching principles of digital platforms and combinatorial innovation. They were rapidly established by leveraging existing laboratory infrastructure and resources from across the NR&DE, in effect, "free." Within this greatly accelerated timeline, they were "perfect" enough, as environments were adapted to be representative within acceptable constraints of naval systems and architectures to allow for component development, with the fidelity dependent on the classification level. Lastly, they adhered to the principle of being "instant" in that iRILs were architected to be readily deployable and easy to use by third-party developers (e.g., industry, academia, non-traditional performers, etc.) with mechanisms to provide automated and instantaneous feedback. The deliberate use of an all-digital iRIL capitalized on the advantages of being able to facilitate faster, smaller cycles of iterative experimentation of component-level technologies of priority interest within representative Fleet architectures and simulated operationally relevant environments.

iRiL Foundational Technologies

Partnering with the Defense Advanced Research and Projects Agency (DARPA) and the DoN M&S Office (NMSO) was key to establishing the iRILs with minimal additional investments. Within these iRILs the AINet ANTX hosted and executed two prize challenges over a six-month period. Relevant quantitative metrics were determined within selected mission vignettes and performance was assessed automatically via the iRIL.

For the purposes of providing an in-depth case study on the use of the iRILs in conjunction with the Prize Challenge authority, the remainder of this paper will focus on the Networks iRIL. The Networks iRIL consisted of a virtual machine (VM) which was distributed virtually to participants. Participants remotely developed, deployed, and iterated their containerized algorithms within this VM and could watch how the network routing protocols within their container performed in real time in an unclassified mission vignette. Six technologies were assessed utilizing the Networks iRIL within two weeks, yielding quantitative data for comparison and assessment both at the unclassified and classified level. The unclassified results were shared with Prize Challenge participants, which can be used to guide future improvements and developments to their component technologies. This was all executed in a completely digital, distributed environment. Additional components and assessment capabilities can be added to the iRIL, an artifact that can be reused and adapted to future needs, including additional mission vignettes, adjusted for different metrics across different classification thresholds.

Naval Integrated Live, Virtual, Constructive (LVC) Environment (NILE)

LVC events are a venue for warfighters, technologists, engineers, and sponsors to demonstrate mature technologies within an operational setting with live, synthetic, or simulated systems. Live, synthetic, or simulated systems are employed to represent either red or blue forces and scenarios are typically played to mature emerging concepts of operation, assess the impact of emerging technologies, identify integration issues, etc. The naval-integrated LVC environment (NILE) is distributed across almost 20 NWCs and ranges. The various NWCs and ranges frequently run local events, but they can also connect through a distributed R&D network, which enables a distributed configuration to run scenarios as if the systems were integrated onto a single ship, e.g. communications, computers, command and control (C4I) and electronic warfare (EW) physical systems from the Naval Information Warfare Center (NIWC) based in San Diego, CA (a C4I center of excellence), and the Naval Surface Warfare Center (NSWC) based in Crane, IN (an EW center of excellence). These entities can be integrated through the NILE to run scenarios as if the systems were integrated onto a specific ship.

In March 2019, four ANTX West technologies were integrated into the NILE virtually as either hardware or software-in-the-loop, and 24 technologies were constructively simulated. Considering most of these participants did not already have Navy contracts for their technologies, this was an extremely unique opportunity for traditional and non-traditional partners to be invited into the Naval lab infrastructure. While there were many positive outcomes from this first-of experience, most of the constructive simulations were not of high enough fidelity to make immediate fielding decisions, and less than five participants were able to meet stringent information assurance (IA) requirements to connect virtually into the NILE environment (Marine Corps Warfighting Laboratory; Naval Information Warfare Center Pacific, 2019). This experience was a tremendous success, but the approach still resulted in transition timelines of 12–18 months (or more) as a best-case scenario.

Multifunctional Information Distribution System (MIDS) Reference Implementation Lab (RIL)

In January 2019, NIWC Pacific piloted an innovative method to respond to an emergent need for Multifunctional Information Distribution System (MIDS) acquisition program office outside of traditional acquisition pathways by establishing a government-industry partnership to rapidly develop and integrate advanced waveforms.

Enabled via a Cooperative R&D Agreement (CRADA) between an industry partner and NIWC Pacific, this government-industry team prototyped a proof of concept that demonstrated successful integration of advanced waveform on a MIDS Joint Tactical Radio System (JTRS) in a Reference Implementation Laboratory (RIL). In December 2019, within 10 months, the government-industry team published a classified white paper informing of opportunities and trade-offs to integrated advanced waveform capabilities on MIDS JTRS radio. The paper also informed a classified report to Congress, released to U.S. Air Force (USAF) staff (Classified Congressional Report on LPX Capabilities, 2020).

In August 2020, the government-industry team demonstrated advanced capability of integrated waveforms and informed of the effort to several flag officers and Senior Executive Service (SES) members in the Washington D.C. area. As a result, the MIDS program office submitted a Program Objective Memorandum (POM) request to resource the capability on MIDS JTRS radio hosted on Navy tactical aircrafts (FY19 Navy Programs: Multi-Functional Information Distribution System (MIDS) Joint Tactical Radio System (JTRS), 2020). Learning about the opportunities provided by advanced waveform, in Fiscal Year (FY) 2021, the Precision Strike Weapons Program Office also initiated the formal acquisition process to onboard on their weapons platforms.

As a result of this effort the industry partners, government stakeholders, and program office were able to significantly reduce risks and shape the opportunity to meet an emergent need. This team is credited with refining the concept of establishing reference models to engage with industry and academia to mature, assess, integrate, and prototype innovations prior to formal acquisition decisions being made. If the reference models are representative enough, this approach has the potential to significantly shorten integration and Fleet transition timelines from 12 to 18 months to less than 6 months post-R&D (Amin, 2020).

Distributed Experimentation Environment (DE2)

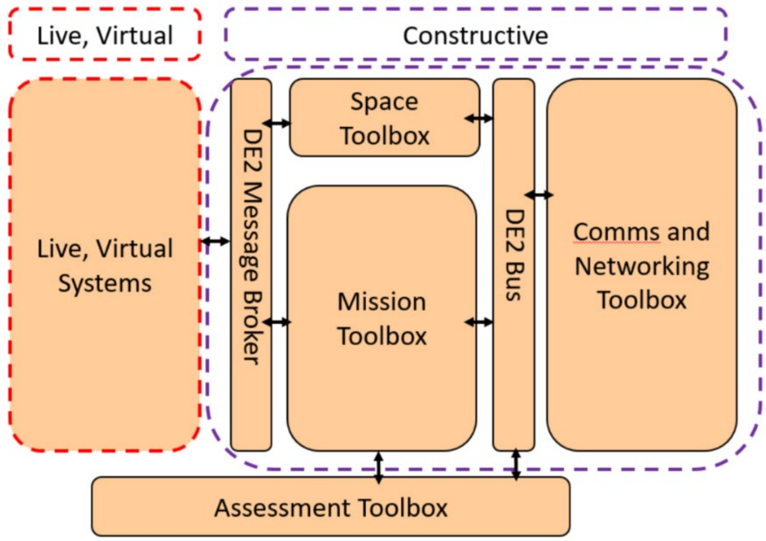

Figure 1. DARPA's Distributed Experimentation Environment (DE2)

The Distributed Experimentation Environment (DE2) is used for the testing and continuous integration and development of complex joint System of Systems (SoS) and Advanced Warfighting Architectures (AWA). The primary intent of DE2 experimentation is the development and demonstration of capabilities and technologies through the integration of constructive, virtual, and live (CVL) environments that more effectively integrate the component pieces of these constructs. The DE2 testbed provides the ability to test new concepts and technologies, provide data to assess capability and technical feasibility, and identify technical and capability gaps. The DE2 provides an avenue for continuous integration and experimentation to evolve concepts and capabilities, which delivers a risk reduction through CVL experimentation.

The DE2 architecture, as seen in Figure 1, can be broken down into two broad categories for ease of understanding. First, the DE2 contains a federation of toolboxes that integrate CVL elements to allow for broad variation in the levels of human participation and system simulation. The DE2 toolboxes are the Mission Toolbox, the Space Toolbox, the Communication & Networking Toolbox, and the Assessment Toolbox. Second, the DE2 also contains a DE2 Message Broker which allows for the integration of outside applications and other external data sources (e.g., live systems, remote sites, software-in-the-loop, human-in-the-loop) with the DE2. Figure 1 depicts the current DE2 architecture schema.

Through modular architecture, these toolboxes can be utilized either individually or federated to evaluate SoS architecture solutions. The Networks ANTX Prize challenge leveraged the Mission Toolbox (MTB) and the Communications & Networking Toolbox (CNTB).

The Mission Toolbox is an essential component to the constructive and virtual environment of the DE2. The core component is the Next Generation Threat System (NGTS). The toolbox uses threat and friendly non-deterministic behavior, weapon, system, and subsystem models for air, ground, surface, and sub-surface platforms to provide the constructive "World" state to the DE2. The toolbox provides varying levels of SoS control within the simulation, which supports the Reference Model. Non-deterministic platform behavior models are dynamic and configurable in accordance with the architecture requirements defined during experimentation planning. This was important for setting mission context in the evaluation of the solutions developed for this prize challenge.

DE2 Sigma

Sigma is a network simulator that is the backbone of the DE2 CNTB. It provides libraries of models to evaluate the effects of network technologies, algorithms, and protocols on network topologies and architectures. Unlike traditional network simulators, which requires the scenario to be defined at the start, Sigma is designed for live experimentation and platforms are added to the simulation as they are created in NGTS, without a prior knowledge. This enables support for non-deterministic behaviors that may happen during the run of a scenario in NGTS. Sigma also has the ability to connect live and virtual platforms via ethernet interface, so that those platforms can take advantage of the constructive environment being simulated in Sigma, depicted in Figure 2. This feature was heavily used for the Networks prize challenge, where the routing solutions were run in separate containers that were connected over constructive networks that were simulated in Sigma.

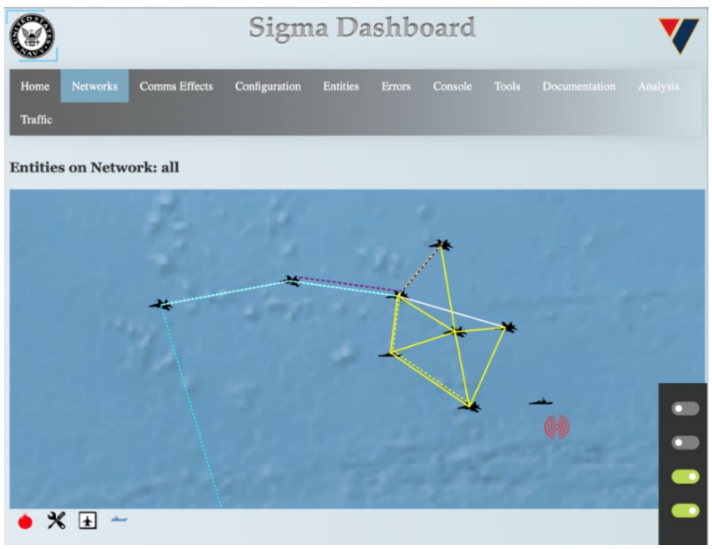

Figure 2. Sigma provides constructive networks over which live traffic is routed, giving an approximation of what would be seen in a live instantiation of the scenario being tested.

iRiL Overview and Instantiation

Given Overmatch's charter and the pace at which our high-tech adversaries are fielding new systems, we needed to reimagine our approaches to produce timelines at relevant speeds. By drawing from the lessons learned through the NILE and MIDS RIL, the concept of the iRIL was formed.

In order to be effective, the iRIL must be crafted to direct problem focus and apply boundaries to the solution space. It also must be representative enough of the target transition platform (i.e., OSA and LVC), but abstracted sufficiently as to not overshare sensitive system details, interfaces, or other sensitive or classified information. Figure 3 depicts the particular instantiation of the Networks iRIL, which took a "slice" of LVC capabilities, packaged and shared with developers within a secure Simulation Based Environment (SBE) with automated feedback. In turn, the products derived from this exchange could be plugged back into the entirety of the LVC grid and evaluated within a larger SoS context.

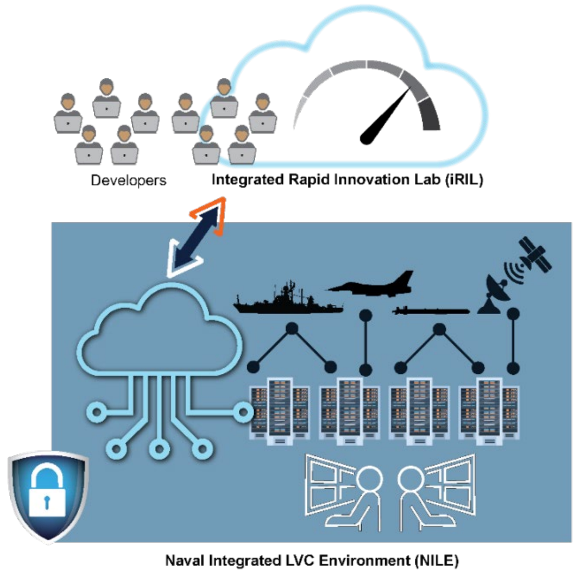

Figure 3. Graphical Representation of the iRIL

The design and use of a developer deployable iRIL offers several advantages over the traditional approach where the product is designed and developed in isolation of the target platform and integrated later, including:

(1) The iRIL allows the specification of the problem statement and defines the boundaries in which the solution must operate, more concretely than an abstract description. This allows industry to focus on primarily solving the issue at hand, without adding extra features which may or may not be of interest.

(2) The iRIL should provide a reasonable approximation for the target platform, and this leads to quicker and easier transitions.

(3) The fact that it is deployable to developers makes it easier for our industry partners to develop and test in their own space and at their own rate, rather than relying on government resources for integration and testing events.

(4) Lastly, the inclusion of integrated performance analysis into the sandbox increases the pace of the development cycle and allows for rapid tuning of the system being developed, within the problem scope.

To achieve the accelerated timelines, it is important to leverage existing technologies to build the desired sandbox. As previously mentioned, the AINet ANTX iRILs leveraged more than 5 years of DARPA's investments that have expanded the NILE framework into DE2. Leveraging the communications and networks toolbox enabled the rapid timeline from solicitation to prize award.

The Networks iRiL

Leveraging the DE2, the Networks iRIL was created as an SBE that employed tactically-relevant scenarios in operationally-relevant conditions. This iRIL was designed with a very narrow focus: to evaluate routing protocols. It was constructed in such a way that the ANTX participants only needed to install their routing solution in a given container, and then they could run the experiments and look at the performance results based on post-process analysis. It is critical that the iRIL be easy to operate given the short timeline for development and integration.

With the Networks iRIL, the process was greatly automated, the routing solution could be evaluated with only a few clicks, and without necessarily understanding the components of the iRILs or how they interoperated.

Execution and Outcomes

The 2021 all-digital AINet ANTX, powered by digital platforms (i.e., iRILs), offered an alternative ANTX approach that resulted in:

- Shortened ANTX planning and execution timelines
- Increased focus on specific components of interest within digital representations of naval systems and architectures with well-defined metrics and automated assessments
- Earlier integration of technologies into relevant naval architectures
- Sharing of relevant operational data with developers
- More meaningful feedback to developers throughout integration phases to inform R&D and drive program acquisitions
- Ease of evaluating technologies in operationally relevant scenarios
- Mission relevant assessments upfront

Shortened ANTX Planning and Execution Timelines

The Project Overmatch established LVC environments and DEVSECOPS powered software development pipelines were essential to enabling the rapid and iterative integrate, test, field, *and* learning cycles. The OSA and our implementation of DEVSECOPS is key to rapidly delivering new capability. The iRILs were built directly upon the key infrastructure pieces and demonstrated the ability to deploy next-generation networking and ML/AI tools at speed. Figure 4 shows the marked difference in execution and planning cycles for traditional ANTX compared to digital ANTX, and the requisite level of effort measured in manpower in order to execute.

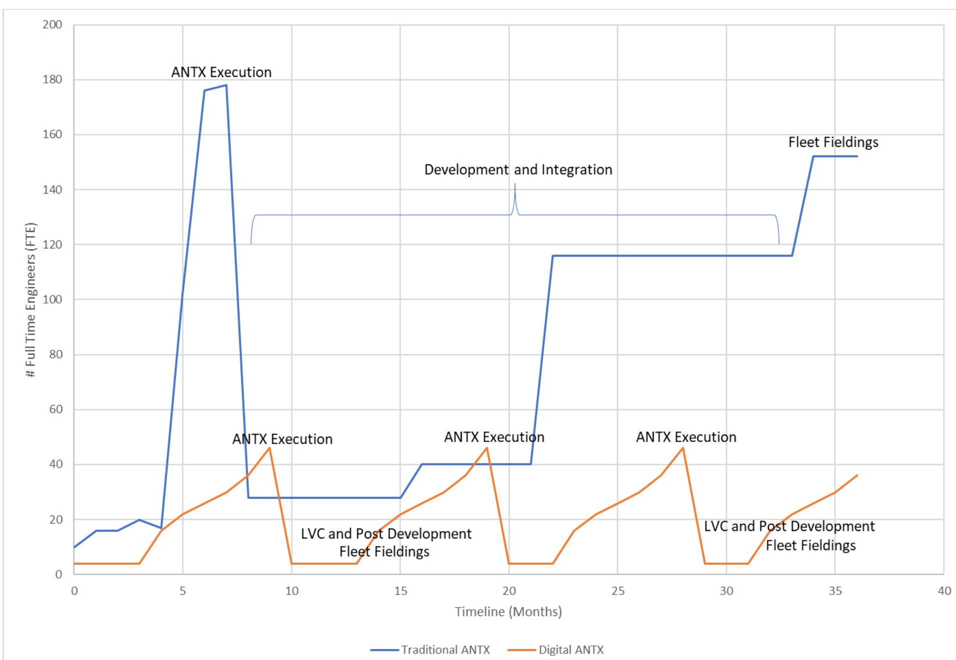

Figure 4. ANTX Approaches—Timeline Comparison

Increased Focus on Specific Components of Interest With Well-Defined Metrics and Automated Assessments

The goal of the Networks prize challenge was to find efficient routing protocols that can operate in dynamic, low-capacity networks. The iRIL and assessment criteria focused on technologies that contribute specifically to the Open Systems Interconnection model (OSI model) network or application layer. The OSI model defines the functionality of the network layer as structuring and managing multi-node network, including addressing, routing, and traffic engineering (X.220, 2008). Solutions were required to run in a Linux (Centos8) container, with potentially multiple Ethernet interfaces. Solutions were expected to control how application packets were forwarded, queued, or dropped on a per-packet or per-flow basis. Technologies that operated above layer 3 (e.g., application layer routing protocols), but manipulated the routing tables or captured and redirected traffic to interfaces, were considered within scope. Solutions that leveraged Software Defined Networking (SDN) technologies or Mobile Ad-hoc Networking (MANET) solutions were encouraged.

The Networks iRIL and assessment criteria for this challenge focused specifically on improvements to network routing protocols for highly-distributed, highly-contested, low-bandwidth, and low-latency networks. The novel prize challenge approach, sophistication of the iRIL, and speed of execution, provided the Overmatch team unmatched insight into commercially developed technologies and innovations that improved the performance of extremely limited Maritime network conditions characterized by sparsely connected nodes, multi-hops, and low bandwidth links with dynamic and unpredictable connectivity.

Solutions solicited were required to provide efficient, low-overhead routing of application packets. As Figure 5 shows, the metrics looked at packets delivered, overhead, latency, and mission impact. The definition of these metrics and the post-run analysis which quantified the performance of the routing protocol with regards to these metrics, focused our industry partners on the problem via optimization of the resulting performance evaluation. The post-run analysis in the Networks iRIL gave insight at multiple levels an overall assessment to flow-level to packet-level metrics.

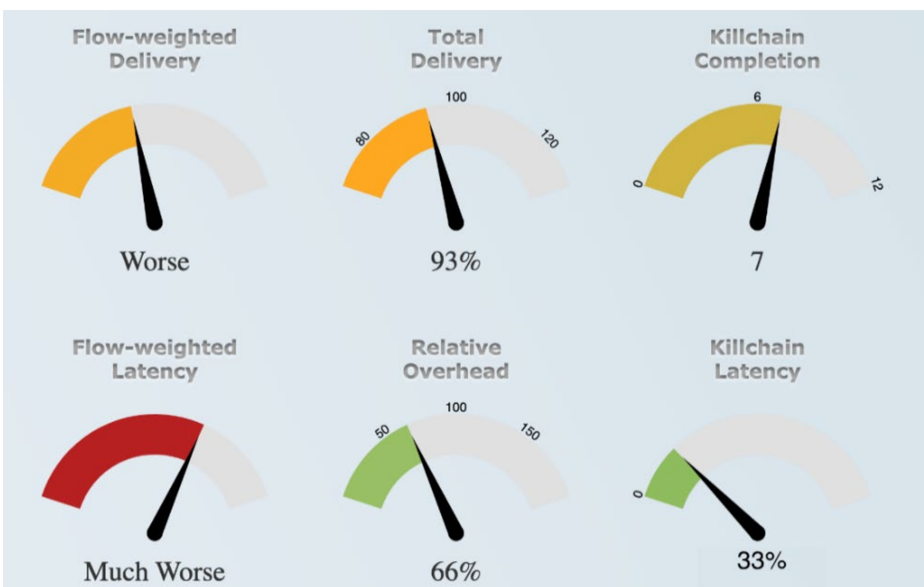

Figure 5. Sample Output From the Post Analysis in the Networks iRIL Showing the Performance Relative to the Baseline

Even though there are many text artifacts available to speak to this challenge area (i.e., Information Warfare (IW) Science and Technology Objectives (STOs), PEO C4I S&T Gaps, AINet ANTX Prize Challenge announcement, etc.), the participants admitted they did not fully grasp the complexity or difficulty of the technical challenge that the Maritime networks scenario presents until they tried to get their routing protocol working in the Networks iRIL.

Earlier Integration of Technologies Into Relevant Naval Architectures

In the end, the winner extracted their routing protocol from a commercial hardware specific implementation and was successful in demonstrating performance improvements through innovations. This was a great result, as the resulting solution, the extracted routing protocol, is something that is more useable than the hardware/software integrated product the vendor would usually try to market. The use of the iRIL provided well defined boundaries of the solution space: it had to run on a standard Linux installation, and had to route application packets using the Linux routing table. This excluded full-stack or custom hardware solutions that would be much more difficult to integrate, evaluate, and eventually field. Instead, the participants needed to deliver a containerized, workable solution which greatly eases the transition pathway.

Sharing of Relevant Operational Data With Developers

The AINet ANTX lowered the barrier of entry to access relevant Fleet architectures and data sets. Operationally relevant and training-quality data sets were made available to industry and academic participants across both prize challenges within the ANTX.

While the Networks prize challenge has been largely the focus within this paper, the authors would like to note how the AI prize challenge in particular lowered the barrier of entry into the OSA. Participants were given access to a secure government-owned cloud environment, datasets for training AI models, and drove the development of the very first version of the Overmatch AIOps development pipeline. Prior to the AINet ANTX, access to these tools and datasets was limited to current contractors with Common Access Cards (CACs), and in many cases required active contracts and security clearances. The development of the AI iRIL significantly lowered the barrier of entry and granted access to a wider variety of participants who were still all U.S. citizens for the purposes of competing in the prize challenge. The AIOps development pipeline was conceived, developed, and provisioned to participants in less than 2 months' time. Without this innovation, more than 70% of the invited participants would have been precluded from participating in the AINet ANTX event. During assessments, the operational impact of the innovative approaches and solutions were of particular interest and the Fleet assessors provided valuable insights to the technical assessors and participants alike.

More Meaningful Feedback to Developers Throughout Integration Phases to Inform R&D and Drive Program Acquisitions

This experience inspired this non-traditional industry provider to continue to invest their discretionary or internal R&D (IR&D) investments and to explore software-focused business models. The team of government experts responsible for the development of the Networks iRIL and overall AINet ANTX orchestration also inspired other industry participants to recognize the DoN's interest in this specific technical area and shift IR&D investments into an area which had been dormant for over 10 years, at least in the case of one of our more traditional industry partners. Further, the technical focus and difficulty of the challenge continues to be highly motivating to all participants. All AINet ANTX participants, and many others who have since heard about the novel Networks iRIL approach, have expressed interest in participating in future experiments where this iRIL can be made available to assess improvements to network routing protocols.

Mission Relevant Assessment Upfront

New technologies are only relevant if they enable the mission objectives sought by the Navy. Yet, this gap is particularly difficult to fill by both academia and industry as they lack adequate insight into what the Navy is trying to achieve, due to the sensitive nature of the matter. Traditional acquisitions methods would outline the desired capabilities, but leaves much room for interpretation. With AINet ANTX, the mission relevance was built into the iRIL by capturing it in the problem formulation and in the metrics used for evaluation. For example, the Networks Challenge sought an efficient routing protocol, and there are many ways to achieve routing packets in the system. However, to be relevant in the intended system, the routing must be done by updating the Linux routing table. Furthermore, NGTS was used to model the mission, and its inclusion ensured evaluation in the context of Navy missions. To handle the sensitivity of the mission relevance, there were two classes of scenarios—classified and unclassified. The unclassified scenario gave a "fuzzy" view of how the technology would be used in the broader system, in a sample mission that does not reveal sensitive information. The classified scenario, however, leveraged DARPA mission scenarios, which allowed better evaluation of the mission impact while following the same principles as the unclassified scenario in terms of execution and evaluation. This approach allowed the evaluation of the technologies in the context of missions, ensuring the result would have a positive impact on Navy missions.

Conclusions

In demonstrating the power of the platform at the blistering pace of Overmatch, the AINet ANTX team's approach and findings have challenged the defense acquisition community and our defense industry primes to think bigger and beyond the constraints of today's approaches, architectures, and acquisition strategies.

Overmatch is the DoN's priority initiative to connect naval assets (e.g., ships, aircraft, weapons systems, sensors) into a coherent NOA. The AINet ANTX proved successful in rapidly identifying cutting-edge technologies and innovations from non-traditional partners that could be immediately integrated into the NOA. The AINet ANTX team's efforts resulted in the award of four prize challenges, which were recognized as exemplar and critical to the success of the first-ever all-digital, Overmatch-championed ANTX event. The team embraced this initiative with objectivity and a sense of commitment that will have a lasting effect on the quality, feasibility, and transition probabilities of these, and future, technologies and innovations by:

(1) Demonstrating the power of the digital platform

(2) Establishing mechanisms for more effective collaborations between technology providers, resource sponsors, and program offices much earlier in the acquisition process

The team's success is leading Overmatch to pursue additional iRILs and ANTX events to address other priority S&T needs. Additionally, the AINet ANTX team is responsible for shifting industry internal R&D (IRAD) investments in areas of key interest to Navy priority programs.

The benefits and results of iRILs are not limited to theory; the AINet ANTX event is proving out and testing iRIL potential and promises. Rapid identification, maturation, continuous assessment, transition, and ultimately **fielding to the warfighter** are the promises upon which iRILs must deliver. There are multiple ongoing efforts to:

(1) Continue development of technologies demonstrated within the prize challenge

(2) Advance the capability and scope of the Networks iRIL itself

(3) Leverage the Networks iRIL for other LVC events and continuous testing

(4) Develop additional iRILs in other areas of priority interest

ANTX Follow-On Technology Development

The ANTX event was executed under the Prize Challenge Authority (15 U.S. Code § 3719) with cash awards going to first place and second place winners. The prize incentivized industry and the broader NR&DE to participate and integrate into iRIL environment, and was structured in a way to enable follow-on sole-source award under a variety of authorities. Upon completion of assessments, announcement of winners, and distribution of final participant reports, the team reviewed each participant's technology and demonstrated capability to identify ideal next steps. Due to the compressed timeline, many technologies did not demonstrate a level of maturity that supported immediate government investment. As a result, CRADAs were being pursued at the time of writing this report. CRADAs will allow industry to continue development within the government-furnished iRIL, providing industry access to the relevant naval data, architectures, and vignettes. After the technologies reach maturity, prototype OTAs will be directly awarded to the technologies that demonstrate best value to the Navy. Currently the team is discussing possible prototype OTA award in FY2023. The team is unsatisfied with this timeline. Based on lessons learned and organizational relationships being established, future technologies developed and demonstrated within iRILs should be able to transition into prototype OTAs almost immediately after the conclusion of an iRIL-hosted ANTX event. The AINet ANTX team demonstrated that these timelines are possible and that there are no technical limitations in achieving this bold vision.

iRIL Development

A tangible outcome from the AINet ANTX was the strong desire to further develop the iRILs themselves. Multiple stakeholders and organizations have gained a strong appreciation for the iRIL concept, each with their own equities and expertise in identifying and assessing emerging technologies. Each stakeholder group may establish new and different tools and features within the iRIL itself. In the future, iRILs may be developed as part of acquisition programs with direct support from prime contractors to engage wildly with the broader DIB as systems are developed.

Future prize challenges will focus on the other OSI layers (application through physical layers) and/or technology areas which include—but are not limited to—communications, networking, unmanned systems, weapons systems, modern software development pipelines and infrastructure, underlying data architectures, and rapid deployment of automation, machine learning (ML), and artificial intelligence (AI) into tactical applications both afloat and ashore.

Acquisition Impacts of Digital ANTXs Enabled by iRILs

The Networks and AI iRILs built directly upon key infrastructure pieces and demonstrated the ability to deploy next-generation networking and AI/ML tools at speed. This has the potential to set a new standard not only for ANTX events, but for acquisition programs as well.

As more and more of the DoN acquisition programs adopt Overmatch key tenets of modern containerized architectures and MOSA approaches, the engineering development models and fielded systems become the iRILs. In this manner, the resultant technologies could be considered *well-behaved*, i.e., developed and containerized in Navy-approved DEVSECOPS software pipelines and can satisfy Risk Management Framework (RMF) Rapid Assess and Incorporate Software Engineering (RAISE) application integration requirements. Acquisition programs can utilize this mechanism to directly drive effective and recurring series of industry engagements to field technologies at a blistering pace.

This speaks to the demand-side economies of scale, also known as a *network effect* (McAffee & Brynjolfsson, 2017), where certain commodities increase in value as usage increases. The economics of the network effect are “central to understanding business success in the digital world” and “were worked out in a series of papers in the 1980s” (McAffee & Brynjolfsson, 2017). Fundamentally, acquisition professionals will need to consider network effects on the acquisition processes, cultural behaviors, and desired outcomes across the information and technical domains. Use of the construct of iRILs can lead to successful implementation of MOSA. The MOSA Reference Frameworks in Defense Acquisition Programs noted:

> Acquisition programs using MOSA as a foundational practice have achieved a degree of modernization (e.g., technology refresh, inclusion of innovative technology); cost savings (e.g., cost avoidance, savings realized from increased competition); and interoperability. If programs are organized to incorporate MOSA, then MOSA reference frameworks can enable DoD engineering and business communities to structure technology investments, upgrades, and innovation opportunities for insertion into programs during design and at regular refresh cycles. (Deputy Director for Engineering, 2020)

The use of open competitive events such as an ANTX Prize Challenge could yield component level, containerized technologies of interest that are matured throughout the event process and can be assessed to be well-behaved within representative Fleet architectures and relevant to operational environments. Such well-behaved software containers or component technologies may enter the OSA or LVC pipelines, rapidly achieve authority to operate (ATO), and cycle to an operational unit within days (not months or years).

Next Steps and recommendations

While the overall execution of the inaugural Overmatch AINet ANTX was a success, much remains to be done in order to further the goals of Overmatch S&T efforts as a whole, as well as accelerate Fleet adoption of S&T (FAST). To that end, the team recommends the following:

ANTX timeline recommendations. The protocols demonstrated in the Networks iRIL and the algorithms deployed to the AI iRIL were just the start. Many of the technologies remain TRL 4 or 5. We believe a period, of not less than 6 additional months, should be allowed for each of the participants to further mature their technologies with continued guidance and technical direction from Overmatch S&T entities. This could be done leveraging IRAD, SBIR, CRADA, and other mechanisms to be codified in the FAST framework.

Further iRIL development. The demonstrated iRIL capabilities proved to be an effective tool for quick assessments of technology readiness and applicability to operational scenarios of relevance, particularly with the Networks Prize Challenge. Even with the AI Prize Challenge, the AI iRIL, though in its infancy, proved to be quick to set up within the overall 6-month time constraint. Both iRIL’s demonstrated value in getting a protected, controlled, and unclassified level digital sandbox environment which attracted non-traditional partners’ interest in experimentation with and for Overmatch priorities. Advancing current iRIL capabilities could include expansion of the Networks iRIL to include dynamic scenarios which can walk through an operational scenario and be modularized and integrated into existing Navy LVC infrastructure and DoN M&S. Further iRIL development should be aligned to Overmatch priority needs but also responsive to areas of significant DIB, commercial, or other R&D investment, where the available technologies options are identified to be dense and diverse (Jackson et al., 2018).

Drive Overmatch aligned acquisition programs to iRIL constructs to identify emerging technologies. The event itself proved to be a useful gatekeeping function for the Overmatch team, as many prospective DIB partners are still proposing innovations at the system-level, as opposed to component or container-level innovations. Use of iRIL's in Overmatch hosted events provides a publicized venue for Overmatch to engage with prospective external partners, and rapidly assesses technologies aligned to Overmatch needs that could be fielded very quickly.

Accelerate the Fleet Adoption of S&T. The Overmatch S&T acquisition approach began as a theory, but the event execution proved useful to accelerate the FAST. However, much of the approach post-S&T event remains to be fully defined and demonstrated. The first of its kind event proved out certain key aspects, including focusing iRIL development and ANTX solicitation to priority Overmatch needs, and collaborating with transition sponsors early in the development process. The team recommends further refinement with input from Overmatch internal and external stakeholders to codify a FAST framework and establish deliberate pathways with the requisite funding and requirements flexibility to field emerging technologies into future fielded baselines.

References

Amin, K. (2020, September). Advanced Tactical Data Link (ATDL) Reference Implementation Lab. Naval Information Warfare Center Pacific.

Braithwaite, K. J. (2020). *Advantage at sea.* Office of the Secretary of the Navy.

Classified Congressional Report on LPX Capabilities. (2020, May).

Deputy Director for Engineering. (2020, May). Modular Open Systems Approach reference frameworks in defense acquisition programs. Office of the Under Secretary of Defense for Research and Engineering.

Directorate of Defense Research and Engineering for Advanced Capabilities. (2017). Modular Open Systems Approach. Undersecretary of Defense for Research and Engineering. https://ac.cto.mil/mosa/

Fuentes, G. (2019, April 14). *Navy, Marines exercising how to use information warfare in future conflicts*. (USNI News). https://news.usni.org/2019/04/12/navy-marines-exercising-how-to-use-information-warfare-in-future-conflicts

FY19 Navy Programs: Multi-Functional Information Distribution System (MIDS) Joint Tactical Radio System. (2020, January). *2020 Annual Report*. Office of the Director, Operational Test and Evaluation.

Gilday, M. M. (2021). *NAVPLAN 2021.* Office of the Chief of Naval Operations.

Jackson, C., Sansone, A., Mercer, C., & King, D. (2018, May 9–10). Application of set-based decision methods to accelerate acquisition through tactics and technology exploration and experimentation (TnTE2). *Proceedings of the 15th Annual Acquisition Research Symposium.*

Katz, J. (2022, January 25). Four carriers being prepped for Navy's Project Overmatch. *Breaking Defense.* https://breakingdefense.com/2022/01/four-carriers-being-prepped-for-navys-project-overmatch/

Marine Corps Warfighting Laboratory & Naval Information Warfare Center Pacific. (2019, April 9). Advanced Naval Technology Exercise (ANTX)—West Fight the Naval Force Forward (FNFF) FINEX. DoN.

McAffee, A., & Brynjolfsson, E. (2017). *Machine platform crowd.* W. W. Norton.

McChrystal, S., Collins, T., Silverman, D., & Fussell, C. (2015). *Team of Teams.* Penguin.

UAS Vision. (2018, July 31). *Martin UAV—Naval Air Systems Command Sign Contract*. https://www.uasvision.com/2018/07/31/martin-uav-naval-air-systems-command-sign-contract/

X.220. (2008, December 10). *Use of X.200-Series protocols in CCITT Applications*. International Telecommunications Union. https://www.itu.int/rec/T-REC-X.220-198811-S/en

Exploring the Potential for 3D Printing in Medical Logistics for Medical Supplies in Operational Environments

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Abstract

Medical supply shortages occur in mass casualty events in operational military environments. These challenge environments both lead to and exacerbate medical supply shortages. This study answers the research questions: Does 3D printing have the potential to positively affect medical logistics operations in these challenging environments, and if so, which Class VIII(a) consumable medical supplies show high potential? A qualitative case analysis investigates the challenges of medical logistics in austere, deployed environments, particularly in mass-casualty scenarios, and the implications of additive manufacturing to medical logistics operations in these environments. The analysis and findings suggest that some Class VIII(a) medical supplies are not good candidates for 3D printing, but others meet characteristic requirements to be 3D printed in operational environments. The study results in initial insights, propositions, and recommendations on how to proceed with 3D printing to support medical logistics operations in operational environments.

Introduction

Mass casualty events in operational military environments consume medical supplies very quickly, leading to or exacerbating life-threatening supply shortages in an environment where refilling those supplies can be difficult or impossible. Our study explores this problem and assesses the potential for 3D printing to help medical logisticians address this challenge.

Medical logistics in operational military environments must deal with challenges very different from those facing so-called garrison military treatment facilities that operate in more stable, non-combat locations, and typical civilian hospitals, even those specializing in trauma care. Some challenges are obvious, such as the risks of adversaries attacking either the operational locations themselves, the resupply deliveries, or both. Less dramatically, locations can be difficult to reach, both in terms of distance and the supporting infrastructure (e.g., roads) that might not support normal delivery vehicles, requiring delivery by aircraft. Unlike large civilian trauma centers, medical facilities in operational environments can experience no trauma cases for weeks at a time; conversely, given the unpredictable nature of war zones, multiple mass casualties can occur in a very short time, rapidly depleting critical supplies for which resupply is difficult or impossible. Compounding the effects of mass casualty events, even modestly prolonged patient stays can drastically exacerbate shortages of Class VIII(a) consumables. Accordingly, military facilities in operational environments must expect to operate without resupply for an indeterminate time (Eyer & McJessy, 2019).

Manufacturing healthcare products on-site to treat battlefield injuries and medical conditions presents a possible solution—or at least a partial mitigation—for this challenge. Our study explores this problem and assesses the potential for 3D printing to help medical logisticians address this challenge, by printing necessary medical supplies on-site to mitigate critical supply shortages. While other studies have explored the utility of 3D printing in humanitarian assistance environments (Corsini et al., 2020; Savonen et al., 2018), the literature on 3D printing in combat zones is "scant" (Yu & Khan, 2015). Our study investigates the challenges of medical logistics in austere, deployed environments and the potential of 3D printing to address those challenges. We seek to answer the question, "Can 3D printing positively affect medical logistics operations for existing austere operational environments?" Specifically, we focus on what the U.S. military calls Class VIII(a) medical supplies, which have both a high risk for short-notice depletion and a high potential for 3D printing.

We focus our study specifically on what the Navy refers to as Class VIII(a) consumable items, or simply medical supplies, which are medical materiel—equipment and consumables—used in military medical communities, including repair parts peculiar to medical equipment. We focus on these items, because they are critical to survivability and quality-of-life outcomes but can rapidly deplete in a single mass casualty event, leading medical professionals (e.g., doctors, nurses) to resort to nonstandard workarounds to care for patients in operational medical facilities. To further scope our exploratory study, we restricted our focus to medical resupply for Naval medical units at operational medical facilities.

Our findings are exploratory, based on a single setting, and are not generalizable to all settings. However, our study's focus on 3D printing for specific (Class VIII(a)) consumable supplies in one DMO environment provides initial insights, propositions, and recommendations on how to proceed. Our findings suggest that, while some Class VIII(a) medical supplies are not good candidates for 3D printing, other potential Class VIII(a) consumables do appear to be candidates to be 3D printed in operational environments.

Background

Medical Logistics

The United States military, and particularly the United States Navy, manages medical supplies through a network of organizations. The Defense Logistics Agency (DLA), Naval Supply Systems Command (NAVSUP), and Naval Medical Logistics Command (NMLC) provide total logistics support to military facilities (Defense Logistics Agency, 2020). Within this broad network of organizations, however, thee resupply process for Class VIII(a) material differs from the other classes of material because Navy Medicine acquires medical materials from a designated Prime Vendor under a ten-year contract (Cardinal Health, 2020; Defense Logistics Agency, 2020). This so-called prime vendor is a single distributor of brand-specific medical supplies and provides next-day delivery to military medical facilities in the continental United States (CONUS). The designated prime vendor fills all orders for its material; if the primary prime vendor cannot fill the order timely, the customer can place the order with a secondary prime vendor (Cardinal Health, 2020). Class VIII(a) medical supplies are purchased based on recurring demand using a continuous review ordering system (http://www.navybmr.com/study%20material/NAVEDTRA%2014295B.pdf))

Medical Logistics In Operational Environments

The U.S. military calls its hospitals Military Treatment Facilities (MTF). Operational MTFs are typically situated in combat areas or hostile environments. The MTFs place orders with the prime vendors, which are located within the United States. The Defense Logistics Agency, located in the CONUS, receives classes of supply from manufacturers and prime vendors, and ships the supplies through a series of overseas distribution centers to the end-user MTFs (Resnick et al., 2014). One of those MTFs is NATO's Role 3 Military Medical Unit (MMU) in Kandahar, Afghanistan. NATO Role 3 MMU is far removed from prime vendors in the United States and relies heavily on two intermediate distribution centers in its region to restock Class VIII(a) medical supplies.

Applying standard logistics processes for all medical supplies in an operational environment creates gaps due to remote locations separated by time and distance. Unpredictable demand makes it difficult to identify recurring orders to manage inventory levels, set reorder points, or stock the right products in the right quantity. Inconsistent demand can lead to MTFs failing to designate otherwise critically-needed items as recurring orders; a critical item may be used one month and not used again for several months or used four times in three days. Storing large amounts of inventory as an inventory buffer is challenging due to the varying shelf lives of Class VIII(a) medical supplies, limited storage capacity, and the erratic nature of demand. Varying shelf lives of items creates issues. because an item can arrive expired or can expire before being used. Patient influx can vary greatly, based on the erratic operational environment, resulting in prolonged patient care that rapidly depletes inventory; also, buffers can be exhausted during a single event.

Research Approach

As we noted previously, we focus our study specifically on what the Navy refers to as Class VIII(a) consumable items, or simply medical supplies, which are medical materiel—equipment and consumables—used in military medical communities, including repair parts peculiar to medical equipment. We focus on these items, because they are critical to survivability and quality-of-life outcomes but can rapidly deplete in a single mass casualty event, leading medical professionals (e.g., doctors, nurses) to resort to nonstandard workarounds to care for patients in operational medical facilities. To further scope our exploratory study, we restricted our focus to medical resupply for Naval medical units at operational medical facilities. Additionally, because Class VIII(a) consumables must be resupplied through contracts awarded to so-called prime vendors and located in the United States, fulfillment lead-times can extend significantly; this leads to loss of patient life or patient quality of life, further emphasizing the importance of these supplies.

This study explores the potential of 3D printing to positively affect medical logistics operations for Class VIII(a) consumables in operational environments through a case analysis (Baxter & Jack, 2008; Eisenhardt, 1989; Gibbert & Ruigrok, 2010; Yin, 2018). Our study focuses on cases that are extreme, and thus the processes that influenced events and outcomes are likely to be transparently observable (Flyvbjerg, 2006; Pettigrew, 1990). Because of the nature of combat situations, however, the cases represent similar extreme situations. Our approach is appropriate because 3D printing is an emerging technology and extant research is largely focused on non-medical repair parts, with medical, and especially surgical, supplies being under-researched (Yu & Khan, 2015). We focus on three mass casualty events that occurred between October 2018 and April 2019; within those events, we analyze shortages of six critical Class VIII(a) consumable medical supplies during the mass casualty events: syringes, IV tubing, central lines, cranial kits, suction valves, and canisters.

This qualitative, exploratory research focuses on how logistics processes for Class VIII(a) consumables differ from the processes for other classes of materials, and how 3D printing might help mitigate challenges in resupplying those materials. MTFs in operational environments must use prime vendor contracts to resupply Class VIII(a) consumables (Cardinal Health, 2020). This study's focus on Class VIII(a) medical supplies is derived from one author's field experience, where constraints with resupply strained the medical care system. Class VIII(a) supplies are important because these consumables have a unique purpose: to save lives.

Interviews were the principal data source for each phase of analysis. We also collected operational documentation from the NATO MMU and reports of research on 3D printing of medical supplies. To understand how a shortage of medical supplies affects a Role 3 MMU during a mass casualty event, as well as the resupply process for Class VIII(a) consumables, we conducted semi-structured initial interviews with intensive care unit (ICU) nurses who served at the Kandahar NATO Role 3 MMU. Our initial interviews lasted one to three hours and follow-up interviews lasted 30 minutes to two hours. We asked medical professionals to describe their experience during October 2018 to April 2019, including how shortages of medical supplies affected the Role 3 MMU during mass casualty events which occurred in this timespan. Interviewees described the patient medical conditions, the number of patients, and the effects the mass casualty events had on Class VIII(a) medical supplies. They described insufficiencies in the resupply chain of Class VIII(a) and improvised actions taken to supplement shortages during long order fulfillment lead-times between acquisition and receipt.

These medical professionals identified Class VIII(a) items that were rapidly depleted during mass casualties. We used these items as inputs to subsequent interviews of 3D subject matter experts. To gather information on the potential of 3D printing for Class VIII(a) consumable items and to identify high potential consumables, we reviewed documents and conducted interviews with experts from Uniformed Services University (USU) and Walter Reed National Military Medical Center (WRNMMC) who have successfully researched and tested 3D printing medical supplies.

The medical professional interviewees identified Class VIII(a) consumables that were rapidly depleted during mass casualties. We shared this information with the 3D printing subject matter experts to solicit their expertise on the potential of 3D printing Class VIII(a) medical supplies and to get their recommendations on which Class VIII(a) medical supplies show the highest potential. Interviewees described the characteristics of 3D printing materials and types of printers with potential to print Class VIII(a) medical supplies in an operational environment and shared their thoughts on the feasibility of 3D printing Class VIII(a) medical supplies in an operational environment. Interviewees also shared their knowledge of field tests of specific medical supplies.

The so-called seven rights of logistics framework (Swamidass, 2000) provided an overall framework to guide our analysis. These so-called rights are "to deliver the right product, in the right quantity and the right condition, to the right place at the right time for the right customer at the right price" (Swamidass, 2000). Our analysis emphasized four of the rights: product, place, time, and quantity. These four rights reveal constraints most relevant to this study's research findings within the operational environment. The other rights, while important to the framework, do not provide value-added contributions to this study. For example, while logistics and 3D printing experts would argue generally that it is more cost effective (the right cost or price) to ship in bulk, this study places more emphasis on having the right product at the right time for unpredictable demand environments.

We analyzed the data in phases. First, we analyzed the case data to develop an understanding of the challenges of medical logistics in operational environments. Next, we drew on initial findings and the seven rights of logistics framework and analyzed the 3D printing data to develop an understanding of the current state of the art in 3D printing related to medical supplies. Finally, we integrated these analyses to answer the study's research questions.

Case Context

Since 2010, NATO Role 3 MMU, a 70,000 square foot trauma care facility, has been the primary trauma care facility for all combat casualties and inpatient care in Southern Afghanistan. It is a rocket proof structure staffed by military and contract support personnel from NATO nations.

The MMU experienced unpredictable demand during the mass casualty events of our case study (October 2018 to April 2019). The unpredictability of demand, number of patients, and unknown patient lengths of stay complicated demand calibration, made identification of recurring ordered items challenging, and setting reorder points more challenging. It was challenging to identify items as recurring or non-recurring because of limited storage space, obsolete consumables, previously stockpiled supplies, the needs of the local populace, and the varying shelf lives of Class VIII(a) medical supplies. Time and distance compounded by rotational deployments further complicated projecting logistics requirements.

To mitigate the long delivery times and distance from prime vendor, NATO Role 3 MMU relied on partnerships with other hospitals within the same geographical area to meet unexpected demand. These partnerships included Kandahar Regional Medical Center and Craig Joint Theater Hospital (CJTH) at Bagram Airfield, and Landstuhl Regional Medical Center in Germany, which provided longer-term care to NATO patients once stabilized. Kandahar Regional Medical Center had limited capacity, which caused NATO Role 3 MMU to face unanticipated patient demand and longer patient stays for stabilized patients. CJTH experienced similar long lead time constraints and mass casualties as NATO Role 3 MMU which made resource sharing difficult. Finally, while NATO Role 3 MMU cared for trauma victims among local Afghan partnered forces, these personnel were required to stay in country rather than being transported to Germany for longer-term care or rehabilitation as is the case with NATO forces, which, when combined with Kandahar Regional Medical Center's limited capacity, exacerbated demand for medical supplies at NATO Role 3 MMU.

Increased hostilities during this time resulted in compounded mass casualties that strained medical equipment. Long patient stays require excessive use of Class VIII(a) medical supplies such as syringes to deliver medicine, IV tubing, IV fluids, needles, bandages, and any surgical interventions that are used to treat battle injuries, adding to the strain on Class VIII(a) stocked medical supplies and medical equipment. Increased hostilities and attacks led to increased base threat conditions, grounding all incoming flights. This delayed the resupply of items depleted during the mass casualty event. Mass casualty patients required multiple surgeries and then admission to the Intensive Care Unit (ICU). Finally, NATO Role 3 MMU had limited storage capacity. There was not enough space for the right product because the warehouse was filled with obsolete products The facility therefore had little room for building buffers of critical items identified by a new rotation.

Case Findings

The medical professionals we interviewed described critical events they experienced, which provide insight into the burn rate during mass casualties and that caused shortages in Class VIII(a) medical supplies commonly used and rapidly depleted. Table 1 describes how these critical events influenced logistics. The critical event the MMU experienced was a shortage of medical supplies, which led in turn to subsequent deviation from standard medical practice. This had the potential to have negative effects on patient care. The same interviews identified items most likely to be depleted during mass casualty events (see Table 2).

Four major constraints causing shortages emerged from this analysis: time, distance, mass casualties, and facility space. These constraints resulted in long patient stays, delays, reuse, and stock/storage. The process for ordering supplies is constrained by unpredictable demand while the delivery process is constrained by time and distance.

Time

Our analysis suggests both long patient stays and resupply delays depleted resources and strained the inventory of medical supplies. Resupply for items stored at nearby distribution centers could arrive in seven to ten days; however, non-recurring items took two to four weeks to transit from the prime vendor in the continental United States just to the first distribution center in Europe, much less to the end user in the NATO Role 3 MMU.

Distance

NATO Role 3 MMU is far from the mandated sources of supply in the CONUS. As with time, prime vendor items ship from CONUS to a first stop distribution center. There is no direct delivery to NATO Role 3 MMU (Resnick et al., 2014), which is within a landlocked operational environment. Prime vendor items must first stop at a distribution center in Europe, adding to the distance it takes to resupply. The distance from prime vendors to intermediate distribution centers to NATO Role 3 MMU caused shortages and impacted availability of Class VIII(a) medical supplies. This led to limited resources and improvised actions not practiced in civilian or stateside hospitals.

Mass Casualties

Mass casualties are uncertain within operational environments and can occur rapidly or not at all. Mass casualties compounded with shortages, patient influx, and length of stay rapidly depleted resources impacting the availability of the right product, in the right quantity, at the right time (Swamidass, 2000). Mass casualties create unpredictable demand that makes it difficult to identify the right products in the right quantity to maintain in inventory. Stocked items in MEDLOG rapidly depleted during a single event. Unpredictable demand with uncertain types of medical conditions and number of patients caused significant challenges in identifying items that should be recurring to establish an order history. Recurring items were rapidly depleted because of long patient stays because of surgical interventions and intensive care requirements. The facility is only set up for 72-hour trauma care support. Afghan partnered forces remained in NATO Role 3 MMU the longest. Critical items required to treat a medical condition from a mass casualty event were often non-recurring items. Non-recurring items were the ones typically exhausted during extensive surgeries. When mass casualties occurred, it was often from an attack which then increased threat conditions for the base. Communication during high threat levels is challenging within a landlocked operational environment. Kandahar has one airfield that experiences limited inbound flights during high threat levels which delay receiving resupply shipments.

Facility Space

NATO Role 3 MMU was constrained by limited storage space. Supply catalogs had duplicate items, items that would never be used and inconsistencies from rotation to rotation in recurring ordered items and levels of inventory. Some items ordered incorrectly, cases instead of boxes, took up storage capacity. Unfortunately, the MMU also stocked too many supplies that would never be used and carried too many of the wrong items and not enough of the right items.

Table 1: Critical Events, Drivers, and Outcomes

Critical Event	Driver	Outcome	Sample quotation
Critical Event 1: Placement of tracheostomy in Afghan patient. Tracheostomy is not expected care in an operational trauma facility.	Providing intensive care beyond 72 hours. More time and intensive care than facility was intended to provide. Local facilities were not capable to care for patient.	Caused personnel to go through supply of suction valves incredibly quickly.	“The suction valves are a one-time-use item; however, due to the necessity of their use for the patient, and our rapidly dwindling supply of the valves in our stock and inability to get replacements quickly, we had to reuse the valves repeatedly.”
Critical Event 2: U.S. patient with abnormal heart rhythm, a medical condition not expected in an operational environment.	More time and intensive care than facility was intended to provide.	Medical condition required more rapid use of flushes, which depleted supply of flushes. Personnel was required to improvise flushes.	“We had a patient with an abnormal heart rhythm and no flushes. I had to send a nurse to run and make flushes.”
Critical Event 3: Patient with extreme and highly contagious infection came in along with mass casualties.	Facility and supplies are not designed for highly contagious patients, with an open ward and limited PPE.	Personnel were forced to break infection control protocol because of rapid depletion of PPE and secondary resources (e.g., linen, pillows, and cleaning supplies that had to be destroyed).	“Forced to break infection control protocol to take care of him. This is significant because our infection protocols are followed as strictly as possible to keep both the patients and staff safe, but in this case, we were forced to put them aside to ensure keeping the patient alive.”
Critical Event 4: Surgery on Afghan patient with ruptured brain malformation, a procedure not typically conducted in a deployed environment.	Supplies not adequate for this type of procedure. More time and intensive care than facility was intended to provide. Local facilities were not capable to care for patient.	Items available were not the right size and thus personnel improvised use of surgical clips during trauma care.	“We treated one medical condition, a ruptured brain malformation. The clips the surgeons had to use in surgery to stop the bleeding were bigger than what neurosurgeons would have used if in the United States.”
Critical Event 5: Multiple patients with GSW to the head over short period of time. This number of similar cranial injuries in this short period of time was unprecedented.	Not stocked with the number of cranial kits needed to treat the specific injury, because event was not anticipated. Condition necessitated prolonged care.	Facility ran out of cranial kits and was forced to request kits from other facilities. These limitations delayed patients going into surgery. Also, facility was not stocked with sufficient items needed to treat the patients over the necessary length of stay.	“During our 5 days receiving GSWs to the head we ran out of cranial kits.”

Table 2: Rapidly Depleted Class VIII(a) Items

Rapidly Depleted	Depleted in Critical Events	Depleted in Critical Events
10 cc Syringes	Cranial Kits	Cranial Kits
Suction Tubing	Central Lines	Central Lines
Flushes	Surgical Clips	Surgical Clips
Suction Canister	Craniotomy Flaps	Craniotomy Flaps
Primary Tubing	Central Lines	Central Lines
Secondary Tubing	Surgical Clips Scalpel	Surgical Clips Scalpel
Alaris Tubing		
Trac Holder		
Arterial Line Set Up		

Case Observations

Our findings revealed problems with product, place, and time specific to the operational environment's unique characteristics and challenges. The three rights that were most problematic shape the subsequent sections: problems with product, problems with place, and problems with time.

Problems with Product

This section discusses problems with products identified within the embedded case. Shortages led to limited resources and improvised actions not practiced in civilian hospitals. For example, there was a shortage of IV tubing and secondary IV tubing for medical equipment pumps. The driver for problems with product was the influx of patients resulting in high burn rates of certain Class VIII(a) medical supplies. The consequence was extending the life of the item and reusing tubing that would not be done stateside. If this were practiced in stateside U.S. hospitals, medical professionals would lose their license.

Medical equipment is a challenge and strains the delivery of patient care. Medical equipment was broken, required replacement, or needed repair parts. The glide scope in the ICU was old, outdated and even recalled. Components needed to operate the scope were missing. The ICU and ER had a few of the components required and between the two units the parts could be compiled to create one good working glide scope, but it was not standardized. The ultrasound machines were past life expectancy and had to be kept plugged in or they would shut down. If the machine was not near a transformer (converter), patient care was more challenging. IV pumps were past life expectancy, and new pumps were acquisitioned. The pumps were delayed due to a software updates and contract modifications. When they arrived, the IV tubing was not compatible further delaying the use of the new pumps.

One issue with medical equipment was the need for transformers. Transformers are required to run all medical equipment delivering patient care. Medical equipment is procured from United States manufacturing companies that require 140-watt voltage. NATO Role 3 MMU was built with European outlets at 240-watt voltage. All medical equipment to deliver patient care had to be plugged into a transformer that was plugged into the wall. Transformers only had two outlets compatible for U.S. voltage. Outlets were in short supply and could easily be all occupied on a single patient. The transformers were unsafe and would be turned off to prevent overheating. However, if the units did not keep the medical equipment plugged in, the equipment would shut off during patient care. The medical equipment and transformers required unscheduled preventive maintenance and experienced significant delays in receiving replacement parts.

Problems with Place

This section discusses problems with place identified within both cases which described the operating environment. The situations provide an understanding to why the operational environment must be viewed differently. Normal medical logistics practices are constrained within the operational environment. The operational environment causes anxiety, and supply shortages lead to more anxiety of the medical professionals, resulting in improvised actions and rationing supplies. Certain types of medical conditions can deplete resources rapidly due to patient demographics shaped by the increase in Afghan partnered relationships, unpredictable demand, and erratic mass casualties. The medical professionals interviewed stated that medical conditions arriving would not typically stay in a trauma care facility set up for only 72 hours of care. NATO Role 3 MMU did not just treat U.S. military and coalition forces. All interventions done within the NATO Role 3 MMU for Afghan police, army, or CG patients would guarantee they stay longer than 72 hours, because of the capacity constraints at the local Kandahar hospital.

Problems with Time

Problems with time were also identified within the embedded case. The extended time to receive supplies and the extended time patients stayed within NATO Role 3 MMU are just a few of the differences from a similarly classified civilian or stateside military treatment facility. There are long lead times affiliated with prime vendor within the United States, which delays the arrival of resupply to operational environments. An item can stock out within while new inventory is being shipped. Such long lead times required medical professionals in the operational environment to take actions, whether improvised or not. They were required to adapt and reuse medical supplies in ways not practiced by stateside hospitals. If an item is necessary to save a patient’s life, measures beyond the typical scope of practice, whether improvised or reactionary, are taken. This is an understanding of medical professionals within operational environments. The problem with time is long lead times, intermediate stops, unpredictable demand, and prolonged patient stays.

3D Printing Analysis and Findings

3D printing involves building a “three-dimensional object using a computer-aided design” (Saptarshi & Zhou, 2019). Medical devices can be produced “using a range of media, including metals, plastics, hydrogels, or vein biological materials” (Manchanda, 2020). Medical companies have embraced 3D printing to create “personalized devices for patients or provider specific tools” (Kondor et al., 2013). The nature of the raw materials melted and restructured into a plastic or metal object, however, limits some medical supplies from being safe for patient care.

All medical supplies are “highly regulated by the U.S. Food and Drug Administration” because they encounter humans (Resnick et al., 2014). Medical supplies come in direct contact with patients making the nature of the structural integrity of specific items important to understand. Medical supplies have specific characteristics such as a plastic material that delivers medication. That material must be intact and must not introduce any other material into the patient. Our initial findings showed the following Class VIII(a) medical supplies were rapidly depleted: syringes, IV tubing, central lines, cranial kits, suction valves, and cannisters. This section describes the analysis of interviews with experts in 3D printing and identifies potential limits and constraints to 3D print the six items in an operational environment.

Our interviews identified five characteristics key to 3D printing the rapidly depletable items. Table 3 summarizes those characteristics. These characteristics influence the potential for printing the six items.

Table 3: Key characteristics to 3D print critical items

Internal/External	"An implant is printed with materials sustainable within a patient, approved by the FDA." (Interview 5).
Material and Use	"It's not just being in the patient, it's the material of the object that matters." (Interview 4)
Watertight	Syringes or IV tubing . . . require being "watertight."
Flexibility	"Material/objects that are rigid (like scalpel handles) are easier to print than flexible materials (like IV tubing). From an engineering perspective, 3D printing flexible materials is not impossible but more difficult, and R&D required." (Interview 4)
Technology Requirements	"3D printing 'watertight' objects requires specific printing technologies, which are bulky and take longer to print . . . therefore, they are not practical in operational environment." (Interview 5) "Some polymers can leach harmful compounds over time." (Interview 5) Testing to determine if this occurs with 3D printed plastics delivering liquids through IVs to patients' blood stream likely will not happen soon. "Printing implants on-site in operational environment would require a larger foot-print. Million-dollar printer to print implants, very costly." (Interview 5)

Syringes

Syringes are vital to administering medicine, blood, nutrition, and other fluids. In trauma care syringes are vital to gain access to internal blood streams through IV flushes and ensuring patency. Syringes are a critical item. As shown in the case analysis, when syringes are not available, medical professionals deviated from standard practice to treat patients. Syringes are used outside of the body and thus are not subject to regulation for internal use. The syringe does not have to be flexible. However, the seal must be watertight. Interviewees suggested that it may be possible to 3D print syringes, but there are some challenges. Syringes include a rubber stopper and there is currently there is no material to print rubber. One interview participant said:

> Some biomaterials available could aid in printing the plastic of a syringe but there remains the concern about leaching. A syringe has a rubber stopper and SME's do not know any material that could print the rubber stopper. (Interview 5)

Overall syringes exhibit moderate potential for 3D printing in an operational environment.

IV Tubing

IV tubing provides the continued flow of fluids whether blood, normal saline, or medicine to keep patients alive during trauma and prolonged care. There is concern regarding the potential to 3D print IV tubing. One interview participant recommends it is better currently being manufactured by companies because it is a thin plastic. Thin plastic materials holding a substance are a concern to 3D printing experts because there is no feasibility testing on the potential to leach 3D printed material into the solution. More biocompatible research is required to determine if the printed material will leach undesirable materials from the plastic into the liquid and thus into the patient. Specific characteristics are not compatible with 3D printing. Interview participants said:

> IV tubing may not be feasible due to the construction of the plastic tubing being fine and thin. However, it is possible to print medical equipment replacement parts. (Interview 4)
>
> One must consider what is being printed. Consider that face shields printed by FormLabs for COVID are thin and take two hours to print. A thicker material will take longer; therefore, in a mass casualty it may not be a logical expectation that one can print an item rapidly. (Interview 5)

Overall, IV tubing exhibits low (to none) potential for 3D printing in an operational environment.

Implants

As mentioned previously, the production and reconstruction of implants are currently better served within WRNMMC. One interview participant made this point:

> Printing implants on-site in operational environment would require a larger footprint. This would be a million-dollar printer to print implants, very costly. Overhead and the materials alone would be expensive plus the printer and power requirements. WRNMMC handles all DoD implant requests and is suitable to maintain all requests. (Interview 5)

Overall implants exhibit high potential for 3D printing in an operational environment; however, better to 3D printed within WRNMMC.

Suction Canisters, Valves, and Instruments

One interview participant noted that suction canisters, valves, and surgical instruments, which are used during both trauma care and prolonged patient care, could be a candidate for 3D printing, though not without some possible constraints. They said,

> Suction canisters could be printed; however, there would be concerns about water tightness. Some materials printed can absorb or leach materials. This is a complication with 3D printing IV tubing because of the thinness of the tubing, potential for leaching and the lumen within the tubing. (Interview 5)

Overall, and given these constraints, suction canisters appear to exhibit moderate potential for 3D printing in an operational environment.

Antibiotic Bandage

Although the medical professionals did not mention antibiotic bandages, one interview participant did note they had potential to be 3D printed in an operational environment. As another interviewee noted:

> The USU research teams are looking at leaching antibiotics and antifungals from the bandage. The leaching time of the compounds within the bandage allows the bandage to administer antibiotics over days to weeks. (Interview #4)

The ability to 3D print an antibiotic bandage, which could deliver antibiotics for days or weeks, is significant; it could—at the risk of dramatization—mean life or death to a warfighter, in bridging the gap from point of injury to care at a military trauma center.

Discussion, Limitations, Conclusions, and Recommendations

Our study sought to explore whether 3D printing has the potential to impact medical logistics in operational environments. Our findings, limited and exploratory as they are, suggest it does.

Analysis of the interviews identified the size of the printer, safety concerns (explosion from materials), and the types of materials required limit the potential to 3D print in an operational environment. Larger capacity printers are not suitable for operational environments. Printing metal in an operational environment may be challenging because those printer types have a larger throughput but in turn have a large footprint and may not be ideal for operational environments. Some plastics will be challenging because there is not enough research and testing done currently regarding whether the 3D printed plastic object is watertight. If the 3D printed material holds a liquid, there is concern with delivering the liquid through a plastic object directly to a patient. There may be leaching from the plastic materials into the liquid, however, at this time, no feasibility testing has been conducted.

An effective 3D printer within an operational environment would be a small plastic printer that can do multiple small items including repair parts and non-critical parts. Generally, the materials for small printers are stable and could be successful in Kandahar. There is also the added benefit of little concern in the personnel running it and the maintenance requirements. There is little training and operation skills required in advance.

This research found that while 3D printing can do many things, some things are logistically better served by manufacturers in bulk, such as IV tubing. Not a lot of Class VIII(a) medical supplies have been researched or tested using a 3D printer at this time, but some medical supplies are being tested in studies and field cases. While this study focused on two specific cases with shortages of Class VIII(a) relevant to that deployment, the analysis and findings have provided additional medical supplies that have the potential to be 3D printed in operational environments. More testing in the field should be done in the future to discover the benefits and potential of Class VIII(a) medical supplies rapidly depleted during mass casualties, but not enough data is currently available on those specific Class VIII(a) medical supplies. The analysis and findings from both cases did identify medical equipment repair parts with significant problems in receiving them due to backorder.

References

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report*, *13*(4), 544–559. http://nsuworks.nova.edu/tqr/vol13/iss4/2/?utm_source=nsuworks.nova.edu%2Ftqr%2Fvol13%2Fiss4%2F2&utm_medium=PDF&utm_campaign=PDFCoverPages

Cardinal Health. (2020). *DoD prime vendor program.* https://www.cardinalhealth.com/en/product-solutions/medical/laboratory-products/resources-for-laboratory-products/government-laboratories/dod-prime-vendor-program.html

Defense Logistics Agency. (2020). *The nation's combat logistics support agency*. Electronic Catalog (ECAT). https://www.dla.mil/

Eisenhardt, K. M. (1989). Building theories from case study research. *The Academy of Management Review*, *14*(4), 532–550. http://doi.org/10.2307/258557

Eyer, K., & McJessy, S. (2019, March 5). *Operationalizing distributed maritime operations*. Center for International Maritime Security. http://cimsec.org/operationalizing-distributed-maritime-operations/39831

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, *12*(2), 219–245. http://doi.org/10.1177/1077800405284363

Manchanda, G. (2020). *3D printing applications and workflows: Insights from the top ranked U.S. hospital* [Webinar]. Radiology Today. https://3d.formlabs.com/medical-3d-printing-insights-from-the-mayo-clinic-recording

Gibbert, M., & Ruigrok, W. (2010). The "what" and "how" of case study rigor: Three strategies based on published work. *Organizational Research Methods*, *13*(4), 710–737. http://doi.org/10.1177/1094428109351319

Pettigrew, A. M. (1990). Longitudinal field research on change: Theory and practice. *Organization Science, 1*(3), 267−292.

Resnick, A. C., Wesler, W., & Yoho, K. D. (2014). *Sourcing and global distribution of medical supplies* (Document No. RR-125-A). RAND Corporation. https://www.rand.org/pubs/research_reports/RR125.html

Savonen, B. L., Mahan, T. J., Curtis, M. W., Schreier, J. W., Gershenson, J. K., & Pearce, J. M. (2018). Development of a resilient 3-D printer for humanitarian crisis response. *Technologies, 6*(1), 30. http://dx.doi.org/10.3390/technologies6010030

Swamidass, P. M. (Ed.). (2000). Seven "rights" of logistics. In *Encyclopedia of production and manufacturing management.* SpringerLink.

Yin, R. K. (2018). *Case study research and application: Design and methods*. Sage Publications, Inc.

Yu, A. W., & Khan, M. (2015). On-demand three-dimensional printing of surgical supplies in conflict zones. *The journal of trauma and acute care surgery*, *78*(1), 201–203. https://doi.org/10.1097/TA.0000000000000481

PANEL 3. UNDERSTANDING TODAY'S DEFENSE INDUSTRIAL BASE

Wednesday, May 11, 2022	
9:40 a.m. – 10:55 a.m.	**Chair: Larry Jackson,** Director, Center for Joint & Strategic Logistics ***Improving Economy and Efficiency in Federal Contracting Presidential Use of the Federal Property and Administrative Services to Direct Procurement Policy*** Emily Murphy, George Mason University ***Defense Industrial Base Analysis: Body Armor*** Robert Mortlock, Naval Postgraduate School ***The Slow Destruction of the Defense Industrial Base*** Moshe Schwartz, Etherton & Associates Michelle Johnson, Naval Postgraduate School ***Analyzing the Composition of the Department of Defense Small Business Industrial Base*** Amanda Bresler, PW Communications Alex Bresler, PW Communications

Larry Jackson—is the Director, Center for Joint & Strategic Logistics, where he supports the Assistant Secretary of Defense for Sustainment and the Joint Staff Director for Logistics to develop strategies for the improvement of Department of Defense logistics & sustainment. He retired in October 2018 from the United States Navy as a Rear Admiral (upper) with over 33 years of commissioned service. His flag assignments included Director of Strategy, Plans and Logistics (J5/J4) at US Transportation Command, Deputy Director for Strategic Initiatives (J5-SI) on The Joint Staff, Deputy Commander of Military Sealift Command, and Reserve Deputy Director for Warfare Integration on the OPNAV staff at the Pentagon.

Larry is a graduate of the University of Virginia, the Naval War College, the Joint Forces Staff College, and the University of Maryland University College. Upon completion of Surface Warfare School, he reported to the USS Conyngham (DDG-17) where he served in a variety of engineering billets, culminating as main propulsion assistant. When Conyngham aided USS Stark (FFG-31) after it had been hit by two air-to-surface missiles, Jackson led fire-fighting and damage control teams, for which he was awarded the Navy Commendation Medal.

He later served as Combat Information Center (CIC) and Assistant Operations officer aboard the USS Ticonderoga (CG-47). His reserve assignments included Area Air Defense Command, Atlantic aboard USS Mount Whitney (LCC 20); Naval Amphibious Group 2; and the Navy Command Center. Jackson's command experience includes reserve units with Submarine Group 10 (Force Protection), Navy Expeditionary Combat Command, Military Sealift Command Norfolk and Navy Installations Command.

Jackson's deployed experience includes a 2008 assignment to the Multi-National Security Transition Command in Iraq where he served as an advisor and as chief of staff for the Ministry of Defense Advisory Team. In 2010, Jackson served as the Destroyer Squadron (DESRON) 40 deputy commodore and deployed to Haiti in USNS Comfort (TAH-20) in support of Operation Unified Response.

Immediately prior to his current duties, he served is an adjunct member of the Institute for Defense Analysis, where he specialized in projects involving logistics, strategy, planning, and defense institution building.

Improving Economy and Efficiency in Federal Contracting Presidential Use of the Federal Property and Administrative Services to Direct Procurement Policy

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Abstract

This paper focuses on how presidents have issued Executive Orders relying on the Federal Property and Administrative Services Act of 1949 (FPASA) over the past thirty years to shape the Federal acquisition system. Pursuant to FPASA, the President has the authority to issue policies and directives that promote economy and efficiency in the procurement functions of the government. Research found a sharp increase in the use of FPASA to issue Executive Orders, and an increase in the scope of Executive Orders relying on the FPASA authority. It also found that while Federal courts have traditionally given broad latitude to the President's FPASA authority, that deference is limited. Likewise, it found that Congress is rarely moved to intervene in support of or contravention of the FPASA authority. Yet the policies enacted using this FPASA authority have created uncertainty and burdens in Federal contracting, effecting the workforce and the industrial base. The author provides recommendations for legislative and administrative changes to promote the use of FPASA to strengthen the industrial base rather than to create confusion and increase compliance costs.

Research Question

This paper will analyze the use of FPASA authorities in Executive Orders across administrations from both an historical and substantive perspective to examine the effect of these policies on the health of the procurement system. While it will neither denounce or endorse any particular order, it will examine the legal parameters applicable to FPASA orders as derived from judicial challenges to these orders. Next, it will survey the modern use of FPASA under Presidents William Clinton, George W. Bush, Barack Obama, Donald Trump, and Joseph Biden to explore the frequency and the subjects of FPASA orders, and the interplay between orders issued during these administrations, and how Congress has responded to FPASA orders. Finally, it will explore the effects on the industrial base and acquisition workforce.

FPASA Authority

The Supreme Court has long held that "the Government enjoys the unrestricted power … to determine those with whom it will deal, and to fix the terms and conditions upon which it will make needed purchases" (Perkins v. Lukens Steel Co., 1940, 127). This finding has led to the conclusion that "[t]hose wishing to do business with the Government must meet the Government's terms; others need not"(AFL-CIO v. Kahn, 1979, 794). When those terms are set by a statute, the operative question is if the statute itself is constitutional. However, when those terms are set by Executive Order, the analysis becomes more difficult. While numerous other statutes provide the President with authority to promulgate regulations and guidance on Federal contracting, none provide as broad an authority at the Federal Property and Administrative Services Act of 1949 (FPASA).

FPASA, as codified throughout title 40 and title 41 of the U.S. Code, expresses Congress's intent to "provide for the Government an economical and efficient system for (a) the procurement and supply of personal property and nonpersonal services, . . .; (b) the utilization of available property; (c) the disposal of surplus property; and (d) records management" (40. U.S.C. § 471). In Section 205(a), the Act provides that the "President may prescribe such policies and directives, not inconsistent with the provisions of this Act, as he shall deem necessary to effectuate the provisions of this Act" which "shall govern the . . . executive agencies in carrying out their respective functions hereunder." This gives the President enormous authority to enact policies to deliver that "economical and efficient system."

Judicial Review of FPASA Authority

Traditionally, this authority has been interpreted very broadly. In the 1960s and 1970s, the case law reflected great confidence in the authority of the President, allowing for some of the first Federal nondiscrimination provisions in Federal contracts (Farmer v. Philadelphia Electric Company, 1964, 7).[4] Indeed, in the 1979 case of AFL-CIO v. Kahn, the majority opinion for the Court of Appeals for the DC Circuit noted that almost all uses of FPASA in Executive Orders up until that time had been to insert anti-discrimination provisions into Federal contracts (AFL-CIO v. Kahn, 1979, 790–791). While the following is not an exhaustive review of the FPASA case law, it provides a brief overview of the decisions most frequently cited in current FPASA cases.

AFL-CIO v. Kahn (Kahn)

In Kahn, the court provides a substantive discussion of what FPASA means in terms of presidential authority. After revisiting FPASA's origins in the reports of the Commission on Organization of the Executive Branch of the Government, the Kahn court concludes that Congress, "by emphasizing the leadership role of the President in setting Government-wide procurement policy on matters common to all agencies," intended for "the President play a direct and active part in supervising the Government's management functions" to the extent they promote economy and efficiency in the procurement system (AFL-CIO v. Kahn, 1979, 790–791). Kahn then expounds that "'[e]conomy' and 'efficiency' are not narrow terms; they encompass those factors like price, quality, suitability, and availability of goods or services that are involved in all acquisition decisions" and are intended to further the goals of FPASA that awards be made to the offeror whose bid "will be most advantageous to the Government" (AFL-CIO v. Kahn, 1979, 789, 792). While recognizing that the "the terms and legislative record of the FPASA are not unambiguous" and that FPASA includes an "imprecise definition of presidential authority," the Kahn court showed great deference to the Administration's reasoning and upheld the underlying EO on price controls ruling by finding that the EO would, "likely have the **direct and immediate effect** of holding down the Government's procurement costs." (AFL-CIO v. Kahn, 1979, 793, emphasis added).

Chamber of Commerce of the United States v. Reich (Reich)

In the 1996 Reich case, the same court cautioned that the Kahn decision did not "write a blank check for the President to fill in at his will" but required that the authority "must be exercised consistently with the structure and purposes of the statute that delegates that

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[4] For example, President Kennedy's Executive Order (EO) 10925 of 1961, Establishing the President's Committee on Equal Employment, was found by later courts to rely on FPASA (Farkas v. Texas Instrument, Inc., 1967, n.1)

power" (Chamber of Commerce of the United States v. Reich, 1996, 1,331). This case challenged to President Clinton's E.O. 12,954, which required that, "to ensure the economical and efficient administration and completion of Federal Government contracts, contracting agencies shall not contract with employers that permanently replace lawfully striking employees." The Reich court ultimately concluded that the Order was "regulatory in nature and is pre-empted by the [National Labor Relations Act (NLRA)] which guarantees the right to hire permanent replacements" (Chamber of Commerce of the United States v. Reich, 1996, 1,336).

In dicta, the Reich court revisited the economy and efficiency requirements from Kahn, stressing "stressed the importance of the nexus between [an EO] and likely savings to the government" (Chamber of Commerce of the United States v. Reich, 1996, 1,331). While the court declined to find whether the economic justification provided in the Order was insufficient, it acknowledged that the appellant's argument that "use of permanent replacements is a good deal more efficient than temporary replacements" was also persuasive (Chamber of Commerce of the United States v. Reich, 1996, 1,336). Therefore, the Reich court found that "it [is] untenable to conclude that there are no judicially enforceable limitations on presidential actions, besides actions that run afoul of the Constitution or which contravene direct statutory prohibitions, so long as the President claims that he is acting pursuant to [FPASA]," thereby signaling a willingness to consider whether future orders exceeded the authority of FPASA even if they did not contradict a specific statute (Chamber of Commerce of the United States v. Reich, 1996, 1,331).

Building and Construction Trades Department v. Allbaugh (Allbaugh)

Six years later, the Court of Appeals for the DC Circuit attempted to explain the Reich ruling when considering a challenge was to President George W. Bush's Order 13,202, which directed that recipients of Federal funds could not allow or disallow a contractor's use of a Project Labor Agreement. In distinguishing Reich, the Court stated that the Reich Order had "the effect of forcing corporations wishing to do business with the Federal government not to hire permanent replacements even if the strikers are not the employees who provide the goods or services to the government" (Building and Construction Trades Department v. Allbaugh, 2002, 36). Thus in Allbaugh, the court upheld the Order because it applied only "to work on projects funded by the government" and "does not address the use of PLAs on projects unrelated to those in which the Government has a proprietary interest" (Building and Construction Trades Department v. Allbaugh, 2002, 36).

UAW-Labor Employment & Training Corp. v. Chao (Chao)

In the Reich decision, the court expounded that Executive Order 12,800, which required government contractors to post notices informing their employees that they could not be required to join or remain a member of a union, was legal" (Chamber of Commerce of the United States v. Reich, 1996, fn 10). As the order was repealed by President Clinton with Order 12,836, it was only when President George W. Bush issued a materially similar order, Executive Order No. 13,201, that any challenge to the FPASA policy was heard. Ultimately, the Chao court upheld Executive Order No. 13,201, finding that the Kahn economy and efficiency test was met because, "[w] hen workers are better informed of their rights, including their rights under the Federal labor laws, their productivity is enhanced" and that the "availability of such a workforce from which the United States may draw facilitates the efficient and economical completion of its procurement contracts" (Exec. Order No. 13,201, 2001). The court conceded that the "link may seem attenuated (especially since unions already have a duty to inform employees of these rights), and indeed one can with a straight face advance an argument claiming opposite effects or no effects at all" (UAW-Labor Employee & Training Corp. v. Chao, 2003, 366–367). Yet, citing Kahn's "lenient standards" the court found that there was a sufficient nexus (UAW-Labor Employee & Training Corp. v. Chao, 2003, 367).

Challenges to Executive Order No. 14,042, Ensuring Adequate COVID Safety Protocols for Federal Contractors (Contractor Mandate)

The most recent series of cases diving into the FPASA justifications involve Executive Order No. 14,042, the Contractor Mandate, which used FPASA to require that Federal contractors provide adequate COVID-19 safeguards to workers performing on or in connection a Federal contract in order to "decrease worker absence, reduce labor costs, and improve the efficiency of contractors and subcontractors at sites where they are performing work for the Federal Government." To accomplish this goal, the Order required a task force provide guidance outlining the necessary safeguards, and that the OMB Director review those safeguards to determine if they would promote economy and efficiency in Federal contracting. Ultimately, the Contractor Mandate required the FAR Council to amend the FAR to comply with this guidance.

The COVID-19 Workplace Safety: Guidance for Federal Contractors and Subcontractors (Contract Guidance) required that contractors "working on or in connection with a covered contract or working at a covered contractor workplace" including contractors who were working entirely from home, be fully vaccinated within four months (Contractor Guidance, sections 3–5, 11). The OMB Director concurred with the Contractor Guidance and determined that the FPASA standard was met (Determination 1; Office of Management and Budget, 2021a). The FAR Council then issued the suggested contract clauses agencies were encouraged to adopt via deviation (FAR Council Guidance). At that time, 21 states sought injunctive relief in five separate case which were heard in Arizona, Georgia, Missouri, Kentucky, and Florida. Unlike the prior cases discussed, challenges to the Contractor Mandate all address injunctive relief at the district court level rather than the appellate level. While each court granted an injunction, each applied the existing caselaw differently.

During this litigation, the OMB Director issued a revised determination that included an extensive FPASA justification (Determination 2; Office of Management and Budget, 2021b). It cited to six external studies, providing data on the costs incurred by the Federal Government and contractors due to COVID, data explaining that vaccination reduces net new costs to the government and the contractor community, and information on how masking and distancing reduce contractor and agency costs before concluding that the Guidance would increase economy and efficiency (Office of Management and Budget, 2021b, 63,423).

To grant injunctive relief, each court decided that the plaintiffs had proven a substantial likelihood of ultimate success on the merits (Georgia v. Biden, 2021, 25).[5] They unanimously found that the nexus required by Kahn was lacking, and the practical

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[5] Additionally, the court had to find that the injunction was necessary to prevent irreparable harms, that the harm outweighs an injury to the Federal government, and that the injunction would not "be adverse to the public interest" (Georgia v. Biden, 25). Given the topic of this paper only the question of success on the merits will be addressed here, so as to focus on the five theories considered by the courts.

implication of upholding the Contractor Mandate would mean that almost any action could be justified by FPASA and "would grant the President a breathtaking amount of authority" (Arizona, 55). The Missouri court positing that under the authority claimed in the Order, "the President would be able to mandate virtually any public health measure that would result in a healthier contractor workforce." (Missouri v. Biden, 2021, 14). The Arizona and Kentucky courts speculated as to other absurd ways the Administration could use FPASA to reduce absenteeism and the spread of COVID, such as a ban on sugary drinks or a ban on hiring obese workers (Arizona, 56; Kentucky, 22). The Georgia court similarly found that the reasonably related nexus needed to be sufficiently narrower, otherwise it would give "the President the right to impose virtually any kind of requirement on businesses that wish to contract with the Government (and, thereby, on those businesses' employees) so long as he determines it could lead to a healthier and thus more efficient workforce" (Georgia v. Biden, 2021, 31). Finally, in Florida the Court notes that Determination 2 "fails . . . to identify any instance in which absenteeism attributable to COVID-19 among contractor employees resulted in delayed procurement or increased costs also attributable to COVID-19" so that the nexus test is not met (Florida v. Nelson, 2021, 37).

The Arizona, Georgia, and Kentucky cases also found that the actions of the Contractor Mandate were of such "vast economic and political significance" that it required an explicit authorization from Congress (Arizona 57; Georgia v. Biden, 28). The Kentucky court stated that because FPASA is limited to promoting "economy and efficiency Federal contracting," that "even for a good cause, including a cause that is intended to slow the spread of Covid-19, Defendants cannot go beyond the authority authorized by Congress" (Kentucky, 22–23).

The courts in Arizona, Georgia, Kentucky, and Florida all criticize the use of FPASA to act in an area of public health traditionally reserved for the states. The Arizona Court finds that the Contractor Mandate is a public health mandate outside the contemplation of a statute intended to authorize "policies and directives related to procurement" (Arizona, 59). Likewise, the Kentucky court states that a "a vaccine mandate would be more appropriate in the context of an emergency standard promulgated by [the Occupational Safety and Health Administration (OSHA)]" given that OSHA "was created to ensure safe and healthful working conditions for workers by setting and enforcing standards and by providing training, outreach, education and assistance" (Kentucky, 27). However, given that the Fifth Circuit had recently struck down an OSHA-promulgated a vaccine mandate, the Kentucky court rejects the idea that a vaccine mandate could be outside the scope of a public health law but within that of a procurement law. The Georgia court agreed, stating that the Contractor Mandate "goes far beyond addressing administrative and management issues in order to promote efficiency and economy in procurement and contracting, and instead, in application, works as a regulation of public health, which is not clearly authorized under the [FPASA]" (Georgia, 29–30).

The interplay between FPASA and Congress's delegation authority was addressed by the Arizona and Kentucky courts. While Congress may statutorily delegate some policy making authority to the Executive branch, it must ensure that in doing so it "lay[s] down by legislative act an intelligible principle to which the person or body authorized to [exercise the delegated authority] is directed to conform"(Arizona, 60). Thus, the Arizona court suggests that any reading of FPASA broad enough to "permit the executive to issue the Contractor Mandate" would itself suggest that FPASA itself is unconstitutional (Arizona, 64). The Kentucky court agrees, noting that while it is rare to find a statute to violate Congress's delegation authority, the court "believes that today's holding is consistent with prior nondelegation doctrine precedent" (Kentucky, 29).

The Arizona and Kentucky courts found that the Contractor Mandate violated FPASA by "intrud[ing] into an area traditionally and principally reserved to the states" without an express grant of such authority from Congress (Arizona, 64). The Kentucky court reiterated that "a person receiv[ing] a vaccine or undergo testing falls squarely within the States' police power" (Kentucky, 30). The Arizona court explained that simply because police power grants vaccination authority to the states does not mean that the Federal government could not exercise concurrent power, but that such an exercise would require "clear and manifest purpose of Congress" (Arizona, 68).

Thus, in the Contractor Mandate series of cases, all of the Courts found that the Executive Order exceeded the President's FPASA authority. While the unifying theory of the decisions relies on Kahn, each court had a decidedly different approach to what authorities the President holds under FPASA, which will later be discussed in terms of recommendations.

Presidential Use of FPASA: 1993 to the Present

Given that many statutes provide more explicit and specific authority for presidential action related to procurement, historically FPASA justifications for Executive Orders have been used sparingly.

President Clinton

While President Clinton issued 364 Executive Orders addressing covering everything from child labor, electric vehicles, and IT procurement reform, the FPASA authority was used sparingly: only five Orders cite to FPASA itself or its codification. By topic category, they are:

- <u>Labor Unions and Collective Bargaining</u>.

Executive Order No. 12,836, Revocation of Certain Executive Orders Concerning Federal Contracting, revoked Executive Orders 12,800 and 12,818. Executive Order No. 12,800 required Federal contractors to inform workers of the right to not join unions or pay certain dues. Executive Order No. 12,818 prohibited requiring a Project Labor Agreement on Federal construction contracts.

Executive Order N. 12,954, Ensuring the Economical and Efficient Administration and Completion of Federal Government Contracts, barred Federal contractors from hiring permanent replacements for striking workers. However, as previously discussed, the Reich case held that the Order was preempted by the National Labor Relations Act.

- <u>Nondisplacement of Incumbent Contractor Labor</u>.

Executive Order No. 12,933, Nondisplacement of Qualified Workers Under Certain Contracts, established a requirement for contractors to retain the incumbent workforce of a predecessor services contract.

- <u>Undocumented Workers</u>.

Executive Order No. 12,989, Economy and Efficiency in Government Procurement Through Compliance with Certain Immigration and Naturalization Act Provisions, created a reporting system intended to prevent and detect the use of undocumented workers on Federal contracts.

- <u>Economic Development</u>.

Executive Order No. 13,005, directed the FAR Council to provide incentives on unrestricted contracts for businesses located in underutilized areas.

While the Courts invalidated Executive Order No. 12,933, and later Administrations would revisit Orders 12,836 and 12,933, the other orders remain applicable today. President George W. Bush expanded upon Executive Order No. 12,989 with the E-Verify program. Congress took modified portions of Order 13,005 to create what is now the Historically Underutilized Business Zone (HUBZone) contracting program in section six of the Small Business Reauthorization Act of 1997.

President Bush

President George W. Bush issued 70 fewer Executive Orders that President Clinton. Three of his first orders used FPASA to reverse policies set by the Clinton Administration, and ultimately President Bush relied upon FPASA authority for six orders covering four topics. The only new subject matter addressed was real property management.

- Labor Unions and Collective Bargaining:

Executive Order No. 13,201, Notification of Employee Rights Concerning Payment of Union Dues or Fees, revoked Executive Order No. 12,836, thereby once again requiring contractors to notify employees of the right not to join a union and to opt out of certain dues. This marked the third reversal of course in nine years.

Executive Order No. 13,202, Preservation of Open Competition and Government Neutrality Towards Government Contractors' Labor Relations on Federal and Federally Funded Construction Projects, reinstated the requirement of government neutrality on Project Labor Agreements that had been revoked by the Clinton Administration.

Executive Order No. 13,208, Amendment to Executive Order No. 13,202, Preservation of Open Competition and Government Neutrality Towards Government Contractors' Labor Relations on Federal and Federally Funded Construction Projects, again modified the government's stance on Project Labor Agreements, allowing Federal agencies the ability to allow for the use of these agreements on specific projects. This marked the fourth change to the policies and direction provided workforce and industrial base in nine years.

- Nondisplacement of Incumbent Contractor Labor.

Executive Order No. 13,204, Revocation of Executive Order on Nondisplacement of Qualified Workers Under Certain Contracts, repealed Executive Order No. 12,933. This allowed contractors the discretion to decide whether or not to extend offers to an incumbent contractor's workforce.

- Real Property Management.

Executive Order No. 13,327, Federal Real Property Asset Management, promoted better management of Federal buildings and lands. It established the Federal Real Property Council.

- Undocumented Workers.

Executive Order No. 13,465, Amending Executive Order No. 12,989, required that contractors use the E-Verify system to demonstrate that employees were legally able to work under immigration laws.

While later Administrations would revisit the FPASA orders on labor unions, collective bargaining, and the displacement of incumbent contractor workforces, the E-Verify and real property orders are still in effect today.

President Obama

Despite Saturday Night Live's parody suggesting that President Obama was overly reliant on Executive Orders, he issued fewer orders than either of his predecessors. However, the Federal contractor community complained that a disproportionate share of these were directed at them. In 2015, in a letter to the President, they complained that due to 13 executive orders affecting government contractors, the "rapid growth in compliance requirements is becoming untenable" (Wheeler, 2015). While not all of these orders were based on FPASA, the Obama presidency saw a significant increase in reliance on FPASA authority, with 12 enacted FPASA orders and one draft order that drew Congressional scrutiny.

- Labor Unions and Collective Bargaining.

Executive Order No. 13,494, Economy in Government Contracting, made Federal contractor costs relating to collective bargaining and the management of union relationships unallowable, and was amended by Executive Order No. 13,517.

Executive Order No. 13,496, Notification of Employee Rights Under Federal Labor Laws, revoked Executive Order No. 13,201 on union dues and additionally required affirmative worker education on labor rights.

Executive Order No. 13,502, Use of Project Labor Agreements for Federal Construction Projects, reinstated the preference for Project Labor Agreements. This marked the fifth revision to the policy in 10 years.

Executive Order No. 13,517, Amendments to Executive Orders 13,183 and 13,494, amended Executive Order No. 13,394 to clarify that contractor costs relating to labor relationship management were indeed allowable, but that cost related to influencing the workforce's decision to organize were not. It also addressed unrelated issues in Executive Order No. 13,183.

- Nondisplacement of Incumbent Contractor Labor.

Executive Order No. 13,495, Nondisplacement of Qualified Workers Under Service Contracts, was yet another volley in the debate about the treatment of incumbent service contractors, reverting to the requirement to retain these workers.

- Text Messaging.

Executive Order No. 13,513, Federal Leadership on Reducing Text Messaging While Driving, directed that agencies use contract clause to ban text messaging while driving.

- Human Trafficking.

Executive Order No. 13,627, Strengthening Protections Against Trafficking in Persons in Federal Contracts, marked a new use of FPASA with an order aimed at reducing human trafficking. While previous administrations had issued executive orders on this topic they had relied on other authorities. Specifically, the Order required the inclusion of new contract clauses and audit rights related to human trafficking, stating that these would promote economy and efficiency in contracting by "increas[ing] stability, productivity, and certainty in Federal contracting by avoiding the disruption and disarray caused by the use of trafficked labor and resulting investigative and enforcement actions."

- Equal Rights.

Executive Order No. 13,672, Further Amendments to Executive Order No. 11,478, Equal Employment Opportunity in the Federal Government, and Executive Order No.

11,246, Equal Employment Opportunity, reflected one of the most traditional uses of the FPASA authority, the expansion of equal rights protections. This bans contractors from discriminating based on gender identity or sexual orientation.

- Contractor Compensation.

Executive Order No. 13,658, Establishing a Minimum Wage for Contractors, also saw a new use of FPASA authorities. Finding that "[r]aising the pay of low-wage workers increases their morale and the productivity and quality of their work, lowers turnover and its accompanying costs, and reduces supervisory costs" would "lead to improved economy and efficiency in Government procurement," the Order established minimum rates of pay for contractor employees.

Executive Order No. 13,706, Establishing Paid Sick Leave for Federal Contractors, required that Federal contractors provide paid sick leave as part of the compensation offered.

- Contractor Responsibility.

Executive Order No. 13,673, Fair Pay and Safe Workplaces, was the most controversial of the FPASA orders signed by President Obama. Intended to increase efficiency and "cost savings in the work performed by parties who contract with the Federal Government," the order asserts that "[c]ontractors that consistently adhere to labor laws are more likely to have workplace practices that enhance productivity and increase the likelihood of timely, predictable, and satisfactory delivery of goods and services to the Federal Government" (Section 1). Because of the significance of this rule, a longer discussion is merited.

The Fair Pay and Safe Workplaces order provided FPASA-based Presidential direction in three areas. First, the Order addressed potential pre-and post-award violations of 14 labor laws and their state counterparts, requiring that prospective contractors self-report any "administrative merits determination, arbitral award or decision, or civil judgment" issued in the past three years as well as any violations by its proposed subcontractors (Sec. 2). Executive Order No. 13,738, amended this order to provide for direct subcontractor reporting to the government.

After allowing the contractor to explain any mitigating actions it has taken, the contracting officer is required to consult with a Labor Compliance Advisor (LCA) to determine whether the corrective measures are adequate or whether "appropriate remedial measures, compliance assistance [or] steps to resolve issues to avoid further violations" are necessary to allow for a responsibility determination (Section 2). Successful awardees would repeat these disclosures six months, at which time the contracting officer and LCA may require additional remedial measures, cancel the contract, and/or refer the contractor for suspension and debarment proceedings (Section 2). To ensure uniform application of these rules, the FAR Council is required to issued regulations and the Department of Labor is to provide guidance (Section 4).

In addition to the provisions governing a contractor's labor record, the order has two other provisions. For each pay period, it requires contractors provide their employees with a document stating "the individual's hours worked, overtime hours, pay, and any additions made to or deductions made from pay" (Section 5). Finally, the order requires contractors who normally have binding arbitration agreements with their employees to allow the employee to opt out of arbitration if the alleged violation is sexual harassment, a tort, or a violation of the Civil Rights Act of 1964 (Section 6).

The Order was immediately controversial. A contemporaneous article cites the director of Public Justice, a public interest law group, as saying that this is “one of the most important positive steps for civil rights in the last 20 years” (Bazelon, 2014). Others expressed concerns that “businesses will be penalized for pending claims against them before those claims have been adjudicated . . [or] that unions, knowing violations could put awards at risk, could threaten complaints as a pressure tactic” (Trottman, 2016). When the implementing regulations were issued in Federal Acquisition Circular 2005–90, contractor groups immediately filed suit as Associated Builders & Contrs. (ABC) of Southeast Tex. v. Rung. An injunctive order was granted on all but the paycheck transparency provisions, in part on the argument that FPASA could not regulate beyond the scope of the underlying laws (Associated Builders & Contractors of Southeast Texas v. Rung, 2016, 18–27). In early 2017, both the House and the Senate passed disapproval resolutions, which prohibited the rule from taking effect pursuant to the Congressional Review Act.

Twelve orders relying on FPASA authority were issued during the Obama presidency—more than the prior two presidencies combined. These covered seven different subjects, many of which had not previously cited to FPASA.

However, in addition to the aforementioned 12 FPASA orders issued by President Obama, a draft FPASA order was leaked in April 2011 (H. Rpt. 112–47). Titled “Disclosure of Political Spending by Government Contractors,” it would have required that Federal contractors disclose all contributions of directors, officers, subsidiaries and affiliates to candidates and to third party organizations. The Draft Order tasked the FAR Council with the collection and appropriate use of the data. The justification stated that this disclosure was necessary, lest companies decline to participate in Federal contracting out of a belief that the system was rigged to favor political contributors. Congress intervened, inserting a provision in the National Defense Authorization Act for Fiscal Year 2012 that blocked any attempt by contracting agencies to require the disclosure of campaign contributions.

President Trump

In only four years, President Trump issued 220 Executive Orders, a much faster pace than his predecessors. His FPASA orders broke with tradition in many ways: President Trump did not revoke the majority of the Obama FPASA orders, and he issued FPASA orders on novel topics.[6]

- Contractor Compensation.

Executive Order No. 13,838, Exemption from Executive Order No. 13,658 for Recreational Services on Federal Lands, modified the contractor minimum wage to exempt employees of concessionaires on public land found.

- Contractor Responsibility.

[6] Analyzing President Trump’s orders proves challenging because the authority is frequently vague. In many of his orders, President Trump cites only to his constitutional authority and unspecified laws of the United States.

Executive Order No. 13,782, Revocation of Federal Contracting Executive Orders, repealed the Fair Pay and Safe Workplaces Order concurrent with the Congressional Review Act vote, and directed a repeal of the FAR rule.

- Nondisplacement of Incumbent Contractor Labor.

Executive Order No. 13,897, Improving Federal Contractor Operations by Revoking Executive Order 13,495, again repealed requirements to extend offers to an incumbent workforce.

- Offshoring.

Executive Order No. 13,940, Aligning Federal Contracting and Hiring Practices with the Interests of American Workers, presents a novel use of the FPASA authority. It directs that the "head of each agency that enters into contracts shall assess any negative impact of contractors' and subcontractors' temporary foreign labor hiring practices or offshoring practices on the economy and efficiency of Federal procurement and on the national security" and then propose the appropriate responsive actions (Section 2).

- *Economic Development/Real Property*.

Executive Order No. 13,946, Targeting Opportunity Zones and Other Distressed Communities for Federal Site Locations, directs agencies to prioritize opportunity zones when seeking potential office.

- Equal Rights.

Executive Order No. 13,950, Combating Race and Sex Stereotyping, is the most controversial of the Trump FPASA orders. It finds that since the Federal government has, "long prohibited Federal contractors from engaging in race or sex discrimination," that it should also prohibit those companies from allowing employees to participate in training that "promotes race or sex stereotyping or scapegoating" since it "undermines efficiency in Federal contracting" (Section 2).[7] Therefore, the order directs agencies to include a clause banning such training in contracts.

While enforcement of the order was enjoined by the courts in the Santa Cruz case, the court did not examine whether FPASA was appropriately used here, instead finding that the prohibited conduct was so vague as to make the order unenforceable. Therefore, this novel use of FPASA has not been judicially vetted as to scope.

President Trump issued more FPASA orders in one term than either President Clinton or President Bush had in two terms. The six FPASA orders issued by President Trump covering six unique topics were promptly rejected by President Biden.

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[7] The order defines race or sex stereotyping as "ascribing character traits, values, moral and ethical codes, privileges, status, or beliefs to a race or sex, or to an individual because of his or her race or sex" and defines "race or sex scapegoating" as "assigning fault, blame, or bias to a race or sex, or to members of a race or sex because of their race or sex. It similarly encompasses any claim that, consciously or unconsciously, and by virtue of his or her race or sex, members of any race are inherently racist or are inherently inclined to oppress others, or that members of a sex are inherently sexist or inclined to oppress others."

President Biden

At the time of writing, President Biden had been in office for just over 14 months, during which time he issued 85 Executive Orders.

- Civil Rights.

Executive Order No. 13,985, Advancing Racial Equity and Support for Underserved Communities Through the Federal Government, revoked the Trump Executive Order No. 13,950 on Sex Stereotyping.

Nondisplacement of Incumbent Contractor Labor.

Executive Order No. 14,055, Nondisplacement of Qualified Workers Under Service Contracts, reasserts the FPASA rationale for retaining incumbent workforces, thus providing the fifth order on this topic in five administrations.

- Contractor Compensation.

Executive Order No. 14,026, Increasing the Minimum Wage for Federal Contractors, reinstated the prior application of the contractor minimum wage to concession workers and it raised the contractor minimum wage.

Executive Order No. 14,069, Advancing Economy, Efficiency, and Effectiveness in Federal Contracting by Promoting Pay Equity and Transparency, requires that contractors provide employees with detailed pay statements and limits or prohibits contractor inquiries into a candidate's compensation history.

- Labor Unions and Collective Bargaining.

Executive Order No. 14,063, Use of Project Labor Agreements for Federal Construction Projects, reasserts the preference Project Labor Agreements, even though President Trump had not repealed the Project Labor Agreement Order issued by President Obama

- Vaccine Mandates.

Executive Order No. 14,042, Ensuring Adequate COVID Safety Protocols for Federal Contractors, is perhaps the most controversial Biden FPASA order to date, addressing the vaccination of contractor employees. Because of the scrutiny it has brought to the Act itself, it is discussed in more depth in a prior section. At this time, several judicial injunctions have stopped enforcement of the Order.

With six orders deriving authority from FPASA in 14 months, President Biden has already equaled the volume President Trump's entire presidency. This volume has also surpassed that of two-term Presidents Clinton and Bush.

Effect on the Industrial Base and Acquisition Workforce

It is widely acknowledged that the industrial base is struggling, with the number of unique vendors for the Department of Defense falling from 80,000 firms in 2010 to just over 50,000 in 2019, despite a 286% increase the number of transactions during that period (Bresler & Bresler, 2020, p. 3). Even more precipitous was the decline of new entrants, falling from more than 15,000 entities per year to nearly 4,000 entities (Bresler & Bresler, 2020, p. 4).

While no studies can demonstrate that FPASA orders are directly or solely responsible for this decline, when the National Defense Industrial Association asked business what conditions limit a company's willingness engage in additional Federal contracting, more than 70% cited uncertain business conditions and nearly 63% cited administrative burdens (National Defense Industrial Association [NDIA], 2022, p. 7). Given that a substantial portion of FPASA orders are revoked and reinstated with each change in administration, and that new subjects are increasingly regulated using FPASA authorities, these orders are a factor contributing to and exacerbating the underlying problem.

Similarly, the pressures on the acquisition workforce are well documented, with a 2015 GAO report attributing the Department of Defense's shortfall in growing its contracting personnel to "high attrition rates and difficulty in hiring qualified personnel" (GAO, 2015, p. 15). The 2016–2021 DoD Acquisition Workforce Strategic Plan found that more than 25,000 civilian employees in the contracting career field would be eligible to retire in 2019 (DoD Acquisition, 2015, p. 76). Delayed appropriation cycles are placing increased pressure on contracting officers to fulfill requirements in a compressed timeframe. So while no analysis exists on the effect of FPASA orders on the acquisition workforce, it does raise the question of whether economy and efficiency are best met by the series of fire drills resulting from the rush conform contracts to each new order.

Trends

By looking at the FPASA based orders over the past 30 years, a few trends emerge. Primarily, FPASA is being used substantially more often. Since 2009, presidents have used FPASA 25 times, compared to only 10 uses between 1993 and 2008. This indicates an increased reliance by presidents on this authority, thereby emphasizing how important it is that there be additional clarity on depth and breadth of the scope Congress intended to delegate to the President under FPASA.

An analysis of the topics addressed in FPASA orders finds that some topics are perennial favorites, reliably revoked and reinstated based on the Administration. For example, in five administrations, there have been five orders on the nondisplacement of contractor workers, four orders on Project Labor Agreement, and three on contractor minimum wages and notices regarding union dues. While this predictable, it is not efficient, since each chain initiates a new series of FAR cases, contract clauses, modifications, training, and compliance audits.

When the courts defer to the President in cases such as those on Project Labor Agreements, they clearly signal that they are not persuaded by the FPASA justification since a justification of an apposite policy will also meet with approval under the statute. They are simply requiring a colorable argument that economy and efficiency will be served, and then they defer to the President. However, when considering FPASA orders covering novel grounds, judicial deference to FPASA orders also appears to be waning. In the recent spate of cases on Fair Pay and Safe Workplaces and the in cases the vaccine mandate, injunctive relief has been repeatedly granted. In the Contractor Mandate cases, all five courts made it abundantly clear that no amount of detail in a FPASA justification was provided, they did not believe that FPASA was intended to apply so broadly. Both judicial support and approbation have led to the devaluation of the underlying goal of promoting economy and efficiency.

Recommendations and Conclusion

In recent years, Congress has focused more on FPASA orders, holding multiple hearings in front of the Committee on Oversight and Government Reform, Committee on Education and Workforce, and Committee on Small Business. However, despite hearings and handwringing about FPASA orders, in 30 years Congress has only successfully invoked the Congressional Review Act once, for the Fair Pay and Safe Workplaces Order. Likewise, only the proposed order on campaign contributions was legislatively blocked. This suggests that while Congress is concerned about the use of FPASA authorities, the topics covered by those authorities in recent years are either unobjectionable or so divisive that Congress cannot reach an agreement.

The current FPASA scheme allows presidents of each party to increasingly use FPASA authority for political gain without any reasonable belief that these policies will endure under their successor. Rather than promoting economy and efficiency in Federal contract, FPASA is now more likely to tax the resilience of the acquisition workforce and the industrial base without any reasonable expectation of lasting change or benefits. Therefore, I offer the following suggestions to allow more meaningful improvements through FPASA orders.

1. Congress should require that any Executive Order relying on FPASA do so explicitly.

Such an action would require a clearer nexus to contracting and prevent situations where Presidents implicitly use their FPASA authority.

2. Congress should require that any new FPASA Executive Order provide explicit and measurable goals for increased economy and efficiency, and then task an entity such as the Office of Federal Procurement Policy with publicly reporting the results on an annual basis.

This recommendation would also promote a well-rationalized nexus to FPASA. It would force clarity around the outcomes being sought by the President. If such a test were applied to the numerous orders on labor notifications, Project Labor Agreements, and the retention of incumbent employees, it would ameliorate the issue identified in the Reich and Chao cases: the arguments for and against many FPASA policies can be so vaguely articulated under the Kahn standard that they are meaningless. It also will force administrations to answer questions such as how requiring Project Labor Agreements promoted economy and efficiency during the Clinton, Obama, and Biden presidencies but hindered economy and efficiency during the two Bush presidencies and the Trump presidency.

3. Congress should explicitly state if FPASA Executive Orders may regulate activities that are not expressly contemplated in FPASA.

While early FPASA orders focused on integrating the Federal workforce and prohibiting discrimination by Federal contractors, the trends of the past 30 years indicate that presidents are now willing to issue FPASA orders on an increasingly broad set of topics, ranging from pay and leave issues and offshoring of workers to permissible types of training and vaccine mandates. While the courts may act as a check on implementation in some cases, the expense and time consumed by the acquisition workforce and the industrial base preparing to implement these orders cannot be underestimated. Likewise, the latest cases on the Contractor Mandate suggest that some courts are open to FPASA itself to be so overly broad that it risks being ruled unconstitutional under a nondelegation theory. Therefore, Congress should provide greater specificity around those areas delegated to the President under FPASA.

Jointly or independently, these legislative changes would provide clarity and predictability, two qualities that will indeed improve economy and efficiency in Federal contracting.

References

AFL-CIO v. Kahn (Kahn), 618 F.2d 784 (DC Cir. 1979).

Associated Builders & Contractors of Southeast Texas v. Rung, 2016 U.S. Dist. LEXIS 155232 (E.D. Tex. 2016).
Bazelon, E. (2014, August 7). Obama is on a pro-labor roll. *Slate* (quoting Paul Bland). https://slate.com/news-and-politics/2014/08/obama-executive-order-on-mandatory-arbitration-huge-news-for-workers-rights.html.
Building & Construction Trades Department v. Allbaugh (Allbaugh), 295 F.3d 28 (DC Cir. 2002).
Bresler, A., & Bresler, A. (2020, April 27). *The effect of defense-sponsored innovation programs on the military's industrial base*. https://calhoun.nps.edu/bitstream/handle/10945/64763/SYM-AM-20-059.pdf?sequence=1&isAllowed=y
Brnovich v. Biden, 2022 U.S. Dist. LEXIS 15137Arizona District Court (D. Az. 2022).
Chamber of Commerce of the United States v. Reich (Reich), 74 F.3d 1322 (DC Cir. 1996).
Committee on Education and the Workforce. (2015, February 26). *The blacklisting executive order: rewriting federal labor policies through executive fiat* (Rpt. 114-3). https://www.govinfo.gov/content/pkg/CHRG-114hhrg93544/html/CHRG-114hhrg93544.htm
Committee on Labor and Human Relations. (1997, April 30). *Executive order on project labor agreements* (Rpt 105).
Committee on Oversight and Government Reform, Committee on Small Business. (2011, May 12). *Politicizing procurement: Will President Obama's proposal curb free speech and hurt small business?* (Rpt. 112-47). https://www.govinfo.gov/content/pkg/CHRG-112hhrg70516/html/CHRG-112hhrg70516.htm
Committee on Oversight and Government Reform. (2011, June 3). *H.R. 735 and project labor agreements, restoring competition and neutrality to government construction* (Rpt 112-60). https://www.govinfo.gov/content/pkg/CHRG-112hhrg70822/pdf/CHRG-112hhrg70822.pdf
Committee on Small Business (2015, September 29). *The blacklist: Are small businesses guilty until proven innocent?* (Rpt. 114-023). https://www.govinfo.gov/content/pkg/CHRG-114hhrg96853/html/CHRG-114hhrg96853.htm
Committee on Small Business. (2016, September 13). *The cumulative burden of President Obama's executive orders on small contractors* (Rpt. 114-071). https://www.govinfo.gov/content/pkg/CHRG-114hhrg23766/html/CHRG-114hhrg23766.htm
Commonwealth v. Biden, 2021 U.S. Dist. LEXIS 228316 (E.D. Ky.2021).
The Congressional Review Act, Pub. Law 104-121, 5 U.S.C. 801 et seq. (1996).
COVID-19 Workplace Safety: Guidance for Federal Contractors and Subcontractors. (2021). https://www.saferfederalworkforce.gov/downloads/Draft%20contractor%20guidance%20doc_20210922.pdf
Department of Defense Acquisition Workforce Strategic Plan for FY 2016 to FY 2021. (2015). https://www.hci.mil/docs/DoD_Acq_Workforce_Strat_Plan_FY16_FY21.pdf
Exec. Order12,800, *Notification of employee rights concerning payment of union dues or fees* (1992). https://www.presidency.ucsb.edu/documents/executive-order-12800-notification-employee-rights-concerning-payment-union-dues-or-fees
Exec. Order 12,836*, Revocation of certain executive orders concerning federal contracting* (1993). https://www.archives.gov/federal-register/executive-orders/pdf/12836.pdf
Exec. Order 12,933, *Nondisplacement of qualified workers under certain contracts* (1994). https://www.archives.gov/files/federal-register/executive-orders/pdf/12933.pdf
Exec. Order 12,954, *Ensuring the economical and efficient administration and completion of federal government contracts* (1995). http://www.gpo.gov/fdsys/pkg/FR-1995-03-10/pdf/95-6121.pdf
Exec. Order 12,989, *Economy and efficiency in government procurement through compliance with certain immigration and naturalization act provisions* (1996). https://www.govinfo.gov/content/pkg/FR-1996-02-15/pdf/96-3646.pdf
Exec. Order 13,005, *Empowerment contracting* (1996). https://www.govinfo.gov/link/cpd/executiveorder/13005
Exec. Order 13,201, *Notification of employee rights concerning payment of union dues or fees* (2001). https://www.govinfo.gov/link/cpd/executiveorder/13201#:~:text=If%20you%20believe%20that%20you,appropriate%20reduction%20in%20future%20payments
Exec. Order 13,202, *Preservation of open competition and government neutrality towards government contractors' labor relations on federal and federally funded construction projects*. (2001). https://www.govinfo.gov/link/cpd/executiveorder/13202
Exec. Order 13,204, *Revocation of executive order on nondisplacement of qualified workers under certain contracts*. (2001). https://www.govinfo.gov/app/details/CFR-2002-title3-vol1/CFR-2002-title3-vol1-eo13204
Exec. Order 13,208, *Amendment to executive order 13202, preservation of open competition and government neutrality towards government contractors' labor relations on federal and federally funded construction projects* (2001). https://www.govinfo.gov/link/cpd/executiveorder/13208
Exec. Order 13,327, *Federal real property asset management* (2004). https://www.govinfo.gov/content/pkg/FR-2004-02-06/pdf/04-2773.pdf

Exec. Order 13,465, *Amending executive order 12989, as amended* (2008). http://www.gpo.gov/fdsys/pkg/FR-2008-06-11/pdf/08-1348.pdf
Exec. Order 13,494, *Economy in government contracting* (2009). https://www.presidency.ucsb.edu/documents/executive-order-13494-economy-government-contracting
Exec. Order 13,495, *Nondisplacement of qualified workers under service contracts* (2009). https://www.whitehouse.gov/briefing-room/presidential-actions/2021/11/18/executive-order-on-nondisplacement-of-qualified-workers-under-service-contracts/
Exec. Order 13,496, *Notification of employee rights under federal labor laws* (2009). https://www.federalregister.gov/documents/2009/02/04/E9-2485/notification-of-employee-rights-under-federal-labor-laws
Exec. Order 13,502, *Use of project labor agreements for federal construction projects* (2009). https://obamawhitehouse.archives.gov/the-press-office/executive-order-use-project-labor-agreements-federal-construction-projects
Exec. Order 13,513, *Federal leadership on reducing text messaging while driving* (2009). https://obamawhitehouse.archives.gov/the-press-office/executive-order-federal-leadership-reducing-text-messaging-while-driving
Exec. Order 13,517, *Amendments to executive orders 13183 and 13494* (2009). https://obamawhitehouse.archives.gov/the-press-office/executive-order-amending-executive-orders-13183-and-13494
Exec. Order 13,627, *Strengthening protections against trafficking in persons in federal contracts*, 77 Fed. Reg. 60,029 (2012). https://obamawhitehouse.archives.gov/the-press-office/2012/09/25/executive-order-strengthening-protections-against-trafficking-persons-fe
Exec. Order 13,658, Establishing a minimum wage for contractors (2014). https://www.federalregister.gov/documents/2014/02/20/2014-03805/establishing-a-minimum-wage-for-contractors
Exec. Order 13,672, *Further amendments to executive order 11478, equal employment opportunity in the federal government, and executive order 11246, equal employment opportunity* (2014). https://www.govinfo.gov/link/cpd/executiveorder/13672
Exec. Order 13,673, *Fair pay and safe workplaces* (2014). https://obamawhitehouse.archives.gov/the-press-office/2014/07/31/executive-order-fair-pay-and-safe-workplaces
Exec. Order 13,706, *Establishing paid sick leave for federal contractors* (2015). https://www.govinfo.gov/link/cpd/executiveorder/13706
Exec. Order 13,738, *Amendment to executive order 13,673* (2016). https://www.govinfo.gov/content/pkg/FR-2016-08-26/pdf/2016-20713.pdf
Exec. Order 13,782, *Revocation of federal contracting executive orders* (2017). https://www.federalregister.gov/documents/2017/03/30/2017-06382/revocation-of-federal-contracting-executive-orders
Exec. Order 13,838, *Exemption from executive order 13,658 for recreational services on federal lands* (2018). https://www.govinfo.gov/link/cpd/executiveorder/13838 83 Fed. Reg. 25,341
Exec. Order 13,897, *Improving federal contractor operations by revoking executive order 13,495* (2019). https://www.federalregister.gov/documents/2019/11/05/2019-24288/improving-federal-contractor-operations-by-revoking-executive-order-13495
Exec. Order 13,940, *Aligning federal contracting and hiring practices with the interests of American workers* (2020). https://www.federalregister.gov/documents/2020/08/06/2020-17363/aligning-federal-contracting-and-hiring-practices-with-the-interests-of-american-workers
Exec. Order 13,946, *Targeting opportunity zones and other distressed communities for federal site locations* (2020). https://www.presidency.ucsb.edu/documents/executive-order-13946-targeting-opportunity-zones-and-other-distressed-communities-for
Exec. Order 13,950, *Combating race and sex stereotyping* (2020). https://www.federalregister.gov/documents/2020/09/28/2020-21534/combating-race-and-sex-stereotyping
Exec. Order 13,985, *Advancing racial equity and support for underserved communities through the federal government* (2021). https://www.federalregister.gov/documents/2021/01/25/2021-01753/advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government
Exec. Order14,026, *Increasing the minimum wage for federal contractors*, 86 Fed. Reg. 22,835 (2021). https://www.federalregister.gov/documents/2021/04/30/2021-09263/increasing-the-minimum-wage-for-federal-contractors
Exec. Order 14,042, *Ensuring adequate COVID safety protocols for federal contractors* (2021). https://www.whitehouse.gov/briefing-room/presidential-actions/2021/09/09/executive-order-on-ensuring-adequate-covid-safety-protocols-for-federal-contractors/.

Exec. Order 14,055, *Nondisplacement of qualified workers under service contracts* (2021). https://www.federalregister.gov/documents/2021/11/23/2021-25715/nondisplacement-of-qualified-workers-under-service-contracts
Exec. Order 14,063, *Use of project labor agreements for federal construction projects* (2022). https://www.presidency.ucsb.edu/documents/executive-order-14063-use-project-labor-agreements-for-federal-construction-projects
Exec. Order 14,069, *Advancing economy, efficiency, and effectiveness in federal contracting by promoting pay equity and transparency* (2022). https://public-inspection.federalregister.gov/2022-05949.pdf
Federal Acquisition Circular 2005–90, 81 Fed. Reg. 58562 (2016). https://www.govinfo.gov/content/pkg/FR-2016-08-25/pdf/2016-19676.pdf. DOL concurrently published guidance on the order. 81 Fed. Reg. 58654. https://www.federalregister.gov/documents/2016/08/25/2016-19678/guidance-for-executive-order-13673-fair-pay-and-safe-workplaces
Farkas v. Texas Instrument, Inc., 375 F.2d 629 (5th Cir. 1967).
Farmer v. Philadelphia Electric Company, 329 F.2d 3, 7 (3d Cir. 1964).
Federal Property and Administrative Services Act, 63 Stat 377 (1949), codified throughout titles 40 and 41 of the U.S. Code.
Florida v. Nelson, 2021 U.S. Dist. LEXIS 246185, (M.D. Flo. 2021).
Georgia v. Biden, 111 Fed. 3d 809 (S.D. Ga. 2021).
GAO. (2015). *Defense acquisition workforce: Actions needed to guide planning efforts and improve workforce capability.* https://www.gao.gov/assets/gao-16-80.pdf
Missouri v. Biden, 2021 U.S. Dist. LEXIS 242142 (E.D. Mo. 2021).
National Defense Authorization Act for Fiscal Year 2012, Pub. L. 112-81 at § 823 (2011).
National Defense Industrial Association. (2022). *Vital signs 2022.* https://www.ndia.org/-/media/vital-signs/2022/vital-signs_2022_final.pdf
Office of Management and Budget. (2021a). *Determination of the promotion of economy and efficiency in federal contracting pursuant to executive order no. 14042*. https://www.govinfo.gov/content/pkg/FR-2021-09-28/pdf/2021-21184.pdf
Office of Management and Budget. (2021b). *Determination of the acting OMB director regarding the revised safer federal workforce task force guidance for federal contractors and the revised economy & efficiency analysis*. https://www.federalregister.gov/documents/2021/11/16/2021-24949/determination-of-the-acting-omb-director-regarding-the-revised-safer-federal-workforce-task-force
Office of Federal Procurement Policy. (2021). *Issuance of agency deviations to implement executive order 14042*. https://www.whitehouse.gov/wp-content/uploads/2021/09/FAR-Council-Guidance-on-Agency-Issuance-of-Deviations-to-Implement-EO-14042.pdf
Perkins v. Lukens Steel Co., 310 U.S. 113 (Sup. Ct. 1940).
Santa Cruz Lesbian & Gay Community Center v. Trump, 508 F. Supp. 3d 521 (N.D. Cal. 2020).
Saturday Night Live. (2014). How a bill does not become a law. https://www.youtube.com/watch?v=JUDSeb2zHQ0
Small Business Reauthorization Act of 1997. Pub. L. No. 105–135 (1997).
Trottman, M. (2016, August 24). Companies bidding for federal contracts must start disclosing labor-law violations. *Wall Street Journal.* https://www.wsj.com/articles/companies-bidding-for-federal-contracts-must-start-disclosing-labor-law-violations-1472064576
Wheeler, L. (2015, September 10). Federal contractors tell Obama: Stop picking on us. *The Hill.* https://thehill.com/policy/energy-environment/253169-federal-contractors-tell-obama-stop-picking-on-us/
UAW-Labor Employee & Training Corp. v. Chao (Chao), 325 F.3d 360 (DC Cir. 2003).
(2021).

Defense Industrial Base Analysis: Body Armor

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Abstract

This defense industrial base analysis encourages critical analysis of a U.S. Department of Defense project facing typical management oversight questions regarding industrial base planning within defense acquisition. The case centers on the capability and capacity of the defense industrial base to develop and produce body armor for warfighters. The case study incorporates the perspectives from key stakeholders to include commercial industry companies, congressional committees, DoD senior leadership, and the program management/acquisition chain of command. Considerations include the balancing of limited resources against competing priorities, sustaining inventory for wartime readiness, managing the demand for increased capability, and balancing surge requirements with industry capacity. The case study reinforces critical thinking in uncertain environments, documents lessons learned for sound project management, and provides exposure to the complexities of public sector acquisition and body armor manufacture.

Keywords: industrial base planning, acquisition, inventory management, congressional oversight, Defense Production Act, industry competition, and innovation

Introduction

The U.S. Army program manager (PM) for Soldier Protection and Individual Equipment (SPIE) was wrapping up another busy week one Friday afternoon in March 2015 when her phone rang. On the other end was the Program Executive Office (PEO) congressional affairs contact officer (CACO) and the PEO public affairs officer (PAO). Both indicated that there were issues and questions centered around the body armor plates that Soldiers fit into ballistic vests, whose function it is to provide protection against fragmentation, pistol and rifle threats. The PAO was concerned about news media coverage, and the CACO was relaying a warning order to be ready to support Army leadership as they prepare for congressional hearings on the Army's portion of the President's Fiscal Year (FY) 2016 budget request. Apparently, the commercial companies who manufacture body armor had provided Congress and media an information paper painting an unacceptable situation with respect to the sustainment of a viable body armor industrial base (see Figure 1).

Well, so much for the weekend, she thought as she started to think about the documents she would need over the weekend to write information papers and prepare presentations to educate, yet again, Army senior leaders, congressional staff, and potentially congressional members on body armor plates. The PM called in her deputy to start to schedule meetings with the proper stakeholders early the following week.

These concerns jeopardized the planned milestone C decision for approval from the milestone decision authority (the PEO Soldier for this acquisition category III program) to award low-rate initial production contracts for next-generation armor plate protection. The PEO had already approved the acquisition strategy (AS) for the milestone review. The AS included industrial base planning as required by DoD acquisition regulations and guidelines. The PEO now was requesting to delay the planned milestone until after the Army had addressed these new concerns from industry that were shared with Congress. The PEO wanted to get ahead of any negative media coverage and update the AS accordingly. A substantial change of the planned milestone would affect the acquisition program baseline's cost and schedule and put the procurement funding at risk if not obligated and expended by the end of the FY.

U.S. Hard Body Armor Industry in Crisis

The Department of Defense (DoD) with the assistance of Congress has spent hundreds of millions of dollars to establish a world-leading industrial capability to design and manufacture state-of-the-art body armor plates. These plates, called Enhanced Small Arms Protective Inserts (ESAPI), are the bullet stopping technology that has saved so many lives in combat. At one point in 2007, the U.S. had seven major manufacturers of ESAPI under contract and in sustainable production. Since that time, the industrial base has consolidated as requirements have increased and standards have been tightened to a point where there are only two viable manufacturers that can meet current and potential future surge requirements for ESAPI – BAE Systems & 3M-Ceradyne. These are the only remaining companies that can produce ESAPI in an increasingly hostile battlefield environment. Both companies are on the verge of exiting the ESAPI manufacturing business primarily due to decreased demand in DoD contracting and the lack of a DoD ESAPI industrial base sustainment strategy. In the event of another major regional conflict, the potential is high for U.S. warfighters to be sent into battle with less than the best available body armor. This same situation was faced in 2003, when our forces were sent into Iraq and Afghanistan either without body armor or without the best available body armor.

The key critical impact of losing the ESAPI industry is that DoD loses the ability to surge manufacturing quickly in the event of a major regional conflict. This coupled with the lack of inventory controls and the absence of aging standards or surveillance testing protocols on current stocks is leading to a potential problem. These decisions (or lack thereof) will impact not only the primary ESAPI manufacturers, they will affect an entire supply chain of companies that supply key component parts like ceramic tiles and high molecular weight polyethylene. These sub-components are highly engineered and specific to ESAPI designs.

This has real impacts on critical manufacturing jobs in the U.S. These are skilled jobs that require training and precision. ESAPI is not just another piece of gear. It is a highly engineered, precisely manufactured, life-saving product. Every production run of ESAPI is stringently and exhaustively tested in a destructive ballistic test that verifies and validates that each ESAPI protects and functions to the most rigorous specifications. Very few items in the DoD inventory are routinely put through these types of tests.

If DoD allows the ESAPI industry to close down, it could have long-term impacts. This industry was not created overnight, and it will not be re-established overnight. Americans who cannot be easily replaced will lose their jobs. Equipment will be sold off or mothballed. Entire segments of the supply chain may be forced to abandon their support and investment in ESAPI.

Figure 1. Paper Provided to Congress from Industry.
(3M Paper, personal communication, 2015).

Understanding Body Armor Procurement

Over the last two decades, the Army had greatly improved the personal protective equipment (PPE) that soldiers wore into battle. Soldier PPE against ballistics threats primary included helmets, vests, and groin protection. Soldiers wore ballistic vests to protect the torso. Ballistic vests included layers of polymer (para-aramid or ultra-high molecular weight polyethylene [UHMWPE]) fibers woven into fabrics that provided soldiers protection against fragmentation and handgun threats (referred to as “soft armor”). To protect against rifle threats, soldiers inserted armor plates (referred to as “hard armor”) into sleeves or pockets in their ballistic vests. The current Army vest was the improved outer tactical vest (IOTV), which accommodated four hard armor plates—identical front and back plates and two side plates (see Figure 2). The Army had two versions of hard armor plates available to soldiers depending on the threat. The standard issue for each deploying soldier was two enhanced small arms protective inserts (E-SAPI) and two enhanced side ballistic inserts (E-SBI) to be used with the IOTV providing full protection. The Army also had an inventory of X-threat small arms protective inserts (X-SAPI) and X-threat side ballistic inserts (X-SBI) that offer a higher-level protection than E-SAPI and E-SBI. The Army procured hard armor plates with annual operations and maintenance (O&M) appropriations (i.e., one-year money) because plates were considered expendable items (despite also classified as critical safety items) and using O&M dollars maintained budget flexibility. The average unit procurement cost (AUPC) for E-SAPI/X-SAPI was approximately $450, and the AUPC for E-SBI/X-SBI was approximately $250. The PM maintained the technical procurement specifications for hard armor plates and managed the qualification and acceptance testing of hard armor plate contracts along with the Defense Logistics Agency (DLA), the procurement activity for sustainment buys of hard armor. The legacy hard armor plate program was in the operations and sustainment (O&S) phase of the acquisition life cycle—well past the initial Army acquisition objective of 966,000 sets of plates. For the procurement of expendable PPE, additional quantities of hard armor plates (beyond the initial Army acquisition objective) were required to replace the initially procured items as they wore out. As a result, Headquarters Department of the Army (HQDA) G-4 worked with the Tank and Automotive Command (TACOM) Organizational Clothing and Individual Equipment (OCIE) Central Management Office (CMO) to program funding annually to replace hard armor plates using sustaining program evaluation group (SS PEG) funding (jointly overseen by the HQDA G-4 and Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA[ALT]). The TACOM OCIE CMO procured Army PPE sustainment requirements through DLA Troop Support (DLA TS) contracts.

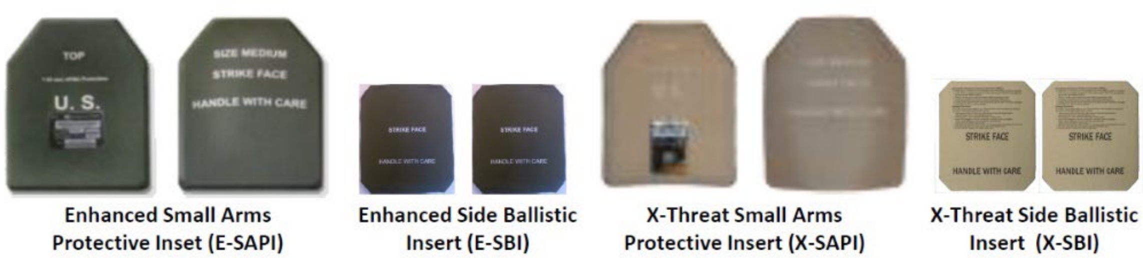


Figure 2. Hard Armor Issued to Soldiers.
(Program Manager Soldier Protection and Individual Equipment [PM SPIE], personal communication, June 2014).

E-SAPI and X-SAPI replaced SAPI originally worn by Soldiers in the outer tactical vests (OTVs). These hard armor plates had stringent requirements in manufacturing contracts using performance-based specifications—meaning the Army specified ballistics testing, interoperability, and interface requirements—but did not specify the processes and materials (the "how") contractors used to manufacture the plates. The use of performance-based specifications maximized competition, allowed for innovation, and protected each company's intellectual property in terms of specific materials and manufacturing processes. Each manufacturer used different materials and processes, but the hard armor plates all met the same performance requirements and were visually indistinguishable. Over time, in collaboration with researchers at the U.S. Army Research Lab and U.S. Army Natick Soldier Research, Development and Engineering Center, commercial industry had innovatively developed and manufactured higher performing hard armor plates. To meet the Army requirements/constraints for size, weight and ballistic protection, industry vendors for the development and manufacture of hard armor plates settled into an optimal mix of materials and processes.

Hard armor plates protected the Soldier's vital torso area and were therefore limited in maximum size dimensions. A trade-off existed between weight of plates and the ballistic protection they provided. Generally, heavier plates could potentially provide greater ballistic protection but they also degraded mobility and increased battlefield fatigue. Commercial industry found that the best way to meet the performance requirements had been to assemble a hard armor plate consisting of the followings layers:

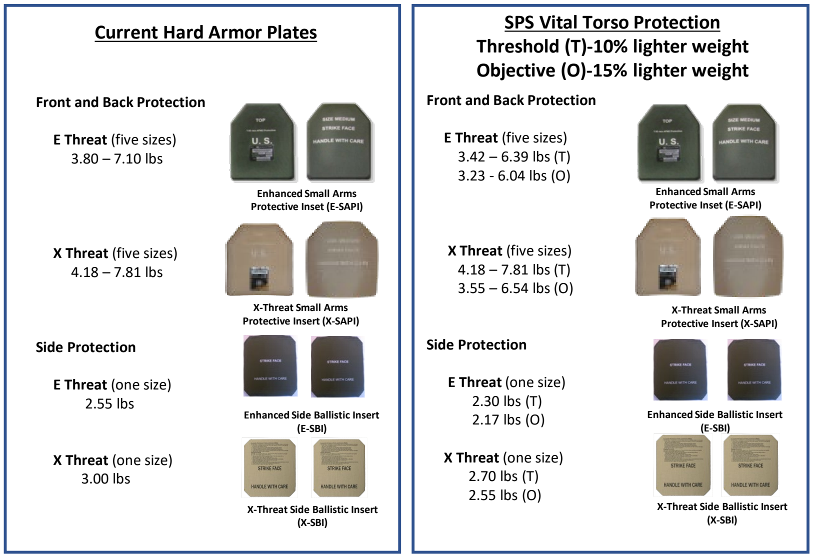
- A core ceramic tile (made from either silicon carbide [SiC] or boron carbide [B_4C]) provides protection against ballistic threats and usually cracks when impacted by an incoming round.
- Behind the ceramic plate is a crack arrester (made from aluminum [Al] or titanium [Ti]), a thin sheet of metal mesh that helps maintain the integrity of the ceramic tile if cracked when impacted by a threat round.
- Behind the crack arrester are layers of armor polymer fibers weaved into thin sheets and then fused together (made of para-aramids like Kevlar© or ultra-high molecular weight polyethylenes). These layers absorb any fragmentation that makes it through the ceramic tiles and any ceramic particles from cracked tiles.
- A cloth covering is then fitted around all the layers so that plates appear visually indistinguishable.

Commercial industry was given the freedom to innovate and use any combination of materials as long as the plates meet the performance requirements (primarily ballistic protection, size, and weight). For example, X-SAPI and X-SBI were manufactured using SiC ceramic plates, but E-SAPI and E-SBI were manufactured with B_4C ceramic plates. Generally, B_4C is lighter but more expensive then SiC. X-SAPI and X-SBI were designed to protect against specific armor piercing threat rounds. Some armor piercing rounds induce a phase change in B_4C crystals in which they became amorphous losing structural integrity. Therefore, the higher performing (from a ballistics protection standpoint) X-SAPI/X-SBI incorporated less expensive raw ceramic powder than the less performing E-SAPI/E-SBI. The trade-off being weight in this situation—the Army accepted the E-SAPI/E-SBI level of ballistic protection at a lower weight and higher expense. For the crack arrestor, the important derived specification requirement was to match the thermal expansion coefficient of the crack arrestor material with the thermal expansion coefficient of the ceramic material. Generally, Ti matches this requirement better even though it's heavier and more expensive than Al. Finally, the processes being used to manufacture the plates varied between commercial vendors. The ceramic tiles were made from SiC and/or B_4C powder, which is put under heat and pressure for a period to form a ceramic tile with the desired properties. Different processes (sintering or hot pressing) result in different ceramic properties resulting in varying levels of ballistic protection. The bottom line is that the hard armor plates were highly engineered, as claimed by commercial industry in Figure 1, with an optimized design to meet the stringent performance requirements.

In May 2013, the Army approved and funded the Soldier Protection System (SPS) program of record with a milestone B approval to award engineering and manufacturing development contracts (PM SPIE, personal communication, May 21, 2013). The SPS was the first Army PPE program that integrated the development of the five different parts of the PPE ensemble simultaneously. SPS was to provide Soldiers with an integrated, scalable, tailorable PPE ensemble with protection level equal to or greater than current levels and at a lighter weight. Figure 3 provides an overview of the SPS components.

Figure 3. Soldier Protection System Overview.
(PM SPIE, personal communication, May 21, 2013).

The newer hard armor plates of SPS were named vital torso protection (VTP). The approved capabilities development document (CDD) contained one key performance parameter (KPP) for the VTP: provide equivalent ballistic level of protection as current E-SAPI/E-SBI/X-SAPI/X-SBI at 10% lighter weights (see Figure 4).



[Note: The five sizes of plates are extra small (XS), small (S), medium (M), large (L), and extra-large (XL); side plates only come in one size; lbs means pounds.]

Figure 4. SPS VTP Description.
(PM SPIE, personal communication, May 21, 2013).

Two companies, 3M (which owns Ceredyne) and BAE Systems, were awarded engineering and manufacturing development (EMD) contracts for VTP hard armor in September 2013. The EMD contracts had firm fixed price options to develop and deliver VTP plates for ballistic testing. The competing vendors delivered plates for two rounds of first article testing. After successfully passing ballistic testing, the SPS VTP program prepared for a milestone C, low-rate initial production (LRIP) option contract award, planned for June 2015. The program office shared the results of the development program with the Army requirements community (HQDA G-3/5/7 and the Army Training and Doctrine Command). HQDA G-3/5/7, via approved requirements documents, determined the Army acquisition objective for SPS to be 266,000 sets of plates. Procurement of the SPS was planned, programmed, and budgeted with O&M dollars in the Army equipping program evaluation group (EE PEG), overseen by the HQDA G-3/5/7 and ASA(ALT). The SPS procurement funding was placed in the program element managed by the PM, who worked with the Army Contracting Command to award the procurement contract options. Figure 5 presents the EMD results that the competitors achieved with VTP plates. As a result of what was learned to be technically feasible and manufacturable during the EMD phase, HQDA G-3/5/7 modified the requirements in the VTP capability production document (CPD) to achieve the ballistic protection of current hard plates with a weight threshold of 7% less and an objective weight reduction of 30% less than current plates. The AUPC for the VTP (E-SAPI/X-SAPI) was approximately $700, and the AUPC for the VTP (E-SBI/X-SBI) was approximately $450. For this acquisition effort, the big “A” acquisition system worked as intended. The results of the EMD phase from the Defense acquisition management framework were used to inform and update the formal production requirements document from the Joint Capabilities Integration and Development System (JCIDS). The Army also prioritized appropriate resources in the planning, programming, budgeting, and execution (PPBE) system for the procurement of the SPS VTP plates.

Vendor	Variant	Weight Reduction	Composition
Vendor A	E-SAPI	**10%**	B_4C + ultra high molecular weight polyethylene (UHMWPE)
Vendor B	E-SBI	**9%**	B_4C/SiC + UHMWPE
	X-SAPI	**8%**	SiC + UHMWPE
	X-SBI	**14%**	SiC + UHMWPE

- Average E variant weight reduction: 9.5% reduction in weight over legacy E-SAPI/E-SBI ***or*** 1.4 lbs reduction per set
- Average X variant weight reduction: 11% reduction in weight over legacy X-SAPI/X-SBI ***or*** 1.98 lbs reduction per set

Figure 5. SPS VTP Development Testing Summary.
(PM SPIE, personal communication, June 3, 2015).

Resourcing and Congressional Considerations

As part of the PPBE system, the Department of Defense (DoD) annually prepares the FY budget, called the budget estimate submission or BES. After adjudication, the BES transitions into the President's budget (PB) request, which is submitted to Congress for review each year in February. The FY16 PB was submitted to Congress in February 2015. Following submission of the PB, congressional hearings are scheduled to help members of Congress and professional staff members understand the PB and subsequently draft important legislation—specifically the annual National Defense Authorization Act (NDAA) and the annual Appropriations Act. The NDAA authorizes programs, policies, and services' end strengths, while the Appropriations Act provides the DoD with permission to obligate dollars (i.e., it basically provides specific DoD funding for programs). The DoD cannot spend government money on programs without those programs first being authorized in an NDAA and subsequently funded in the Appropriations Act.

The House Armed Services Committee (HASC) and the Senate Armed Services Committee (SASC) are responsible for writing the annual NDAA. The House Appropriations Committee (HAC) and Senate Appropriations Committee (SAC) write the annual Appropriation Act. In this case, SASC/HASC/SAC/HAC professional staff members reached out to the appropriate U.S. Army offices to notify them of potential issues with body armor plate industrial base (IB) and associated requested funding levels in the FY16 PB request. Potential issues with NDAA language are coordinated within the U.S. Army through the Office of the Chief of Legislative Liaison (OCLL), whereas potential issues with the appropriation funding levels are coordinated through the Budget Liaison Office in the Army Budget Office within the Office of the Assistant Secretary of the Army for Financial Management and Comptroller (ASA[FM&C]).

An area of emphasis for HASC/SASC/HAC/SAC is the health of the IB in times of limited budgets and declining resources. Of particular interest to the committees is the health of the body armor IB, especially the hard armor plates (which provide ballistic protection) worn by soldiers and marines in their ballistic vests. Congress has repeatedly asked for information regarding the health of the body armor IB. The FY13 NDAA HASC report "directed the Secretary of the Army to provide a briefing to the congressional committees that provides an assessment of the long-term sustainment requirements for the body armor industrial base in the United States, to include supply chains for both hard and soft armor" (H.R. Rep. No. 112-479, 2012, p. 59). The next year, section 253 of the FY14 NDAA required "the Secretary of Defense to provide a report on the comprehensive Research and Development strategy of the Army Secretary to achieve significant reductions in the weight of body armor" (NDAA, 2013, p. 127). Finally, the FY15 NDAA Senate report required the Secretary of the Army to conduct a "technical study and business case analysis on the requirements, cost, benefit, feasibility, and advisability of the replacement and refurbishment of the various body armor plates used in personal protective equipment" (S. Rep. No. 113-176, 2014, p. 33).

General Guidance On Industrial Base Planning

DoD acquisition directives and regulations require IB planning for all acquisition programs of record. The documentation and results of IB planning for programs is usually embedded within the acquisition and contracting strategies. The DoD Instruction (DoDI) 5000.02, Operation of the Adaptive Acquisition Framework, dated January 23, 2020, states, "PMs will consider acquisition strategies that leverage international acquisition and supportability planning to improve economies of scale, strengthen the defense industrial base" (Office of the Under Secretary of Defense for Acquisition & Sustainment [OUSD(A&S)], 2020, p. 10). The accompanying DoDI 5000.02T, Operation of the Defense Acquisition System, provides more guidance under IB analysis and considerations for PMs, stating that

> Program management is responsible for incorporating industrial base analysis, to include capacity and capability considerations, into acquisition planning and execution. The industrial base considerations should be documented in the Acquisition Strategy and include identification of industrial capability problems (e.g., access to raw materials, export controls, production capabilities) that have the potential to impact the DoD near- and long-term, and identification of mitigation strategies that are within the scope of program management. (OUSD[A&S], 2020, p. 85)

Chapter 2, "The Industrial Base," in *Defense Manufacturing Management Guide for Program Managers* contains comprehensive guidance for IB planning (DoD, 2012). The PM's IB planning responsibilities originate from the Defense Production Act of 1950, of which two titles are still authorized and relevant:

- Title I—Priorities and Allocations (the authority to demand priority for defense-related products under contract)
- Title III—Expansion of Productive Capacity and Supply (the authority to provide incentives to develop, modernize, and expand defense productive capacity; DoD, 2012).

The authorities of Defense Production Act of 1950 cannot force commercial companies to enter government contracts with the DoD. These titles allow the DoD to incentivize commercial industry to enter into contracts with the DoD and subsequently enable the DoD to place "ratings" on the contracts. Work on "rated" contracts would be prioritized over "nonrated" contracts. The procurement contracts of legacy hard armor and the SPS VTP development contracts were rated as "DO" contracts, meaning that vendors were required to prioritize these efforts over "nonrated" efforts but not as high as "DX" rated contracts if they had any. The FY11 NDAA changed the DoD organization for defense IB policy by establishing the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy (MIBP) with the following responsibilities:

- Stimulate and support vigorous competition and innovation in the defense IB, and
- Establish and sustain cost-effective industrial and technological capabilities that assure military readiness and superiority (DoD, 2012).

Subsequent legislation solidified the importance of IB planning in defense acquisition programs; 10 U.S.C. 44 § 2440 required consideration of the national technology and IB in the development and implementation of acquisition plans for each major defense acquisition program. A PM is responsible for knowing the capabilities of their IB and integrating those considerations in their risk assessments, acquisition planning, and program implementation. Five specific statutory requirements with the DoD for IB planning are identified in 10 US.C. 148:

- Section 2501 sets national security objectives for the IB
- Section 2502 establishes the IB council, headed by the Secretary of Defense
- Section 2503 establishes a program for the analysis of technology and the IB
- Section 2504 requires an annual IB report to be submitted to Congress
- Section 2505 requires periodic assessments of the IB

DoDI 5000.60 Industrial Base Capabilities Assessments (OUSD[A&S], 2018) and the accompanying DoD 5000.60-H (DoD, 2013) provide policy, identify responsibilities for assessing defense industrial capabilities, and detail the process for conducting assessments of defense IB capabilities. DoDI 5000.60 mandates that government funds will not be used to preserve an IB capability unless national security requirements are at risk and unless it is both cost effective (benefits exceed costs) and time effective (OUSD[A&S], 2018). DoDI 5000.60 also emphasizes the PM's responsibility to perform IB assessments for the milestone decision authority in support of program milestones (OUSD[A&S], 2018). Critical to the success of any program is the ability of the acquisition team to understand the capacity to produce, the capability to produce, and the financial stability required to produce the items required by warfighters. Industrial base planning may include the following industrial preparedness measures:

- Modernizing or expanding facilities
- Developing improved production techniques
- Awarding "pilot line" contracts
- Establishing or maintaining standby production lines
- Maintaining a warm production base
- Acquiring and maintaining plant equipment packages with all the necessary special tools, dies, fixtures, and special test equipment
- Establishing and maintaining multiple production sources
- Conducting special studies
- Pre-stocking raw materials, semi-finished materials, components, and assemblies
- Awarding multi-year contracts
- Establishing programs to increase the retention of personnel with key technical skills
- Exercising authority of the Federal Acquisition Regulation and Defense Production Act

- Recommending design changes or waivers
- Underwriting the establishment/maintenance of U.S. production sources for critical defense material when no current U.S. source exists

Hard Armor Industrial Base Planning

In response to the requirement from the FY13 and FY14 NDAAs, the Army prepared a report for Congress entitled *Secretary of the Army's Response to Congressional Defense Committees on Body Armor Research & Development and Sustainment Strategies* on March 28, 2014 (personal communication, March 28, 2014). The report provided a status of current PPE systems, an overview of research and development efforts to improve protection and reduce Soldier load (weight), and a PPE IB assessment. The Army's goal was to maintain at least two vendors to maintain competition and promote innovation. With respect to hard armor plates, the Army acknowledged two vendors, BAE Systems and 3M–Ceradyne, as producing current plates through DLA contracts. These same two vendors were awarded SPS VTP development contracts for lighter-weight hard armor plates. The HQDA G-4 highlighted that current inventory of hard armor plates were available to meet contingency and training requirements in the near term. In this same report, DLA stated the short-term risk assessment (FY14 and FY15) for hard armor IB as significant due to a considerable drop in demand and vendors operating below their stated minimum sustaining rates (MSRs). DLA assessed the long-term risk (FY16 and beyond) as significant due to a low demand, dependence on the DoD, and an 18-month estimate to reconstitute the capability if vendors stopped production.

The Army program management office updated its hard armor industrial base assessment in June 2014, concluding that the current planned funding levels for sustainment buys of legacy E-SAPI/X-SAPI and E-BSI/X-SBI, combined with planned SPS procurements of VTP E-SAPI/X-SAPI and VTP E-SBI/X-SBI, would fall below the funding levels required for the MSRs of the vendors. Only BAE Systems and 3M–Ceradyne remained qualified vendors for hard armor plates. 3M–Ceradyne stated that their MSR of production was 12,000 plates per month, and BAE's MSR was 10,000 plates per month (PM SPIE, personal communication, June 2014). The Army inspected about 550,000 hard armor plates per year with nondestructive test equipment (NDTE), using X-ray technologies to check for ceramic cracking and delamination issues from 2008 through 2014 (PM SPIE, personal communication, June 2014). Based on the failure rate (or washout rate) of the total inspected plates per year, the service life of E-SAPI and X-SAPI was estimated to be 10 years, and the service life of the E-SBI and X-SBI was estimated between 34 and 69 years (PM SPIE, personal communication, June 2014). The Army also concluded that the washout rate did not depend on the age of the plates (PM SPIE, personal communication, June 2014).

In August 2014, the Institute of Defense Analysis (IDA) published a report for DLA entitled *Department of Defense Hard Body Armor (HBA) Industrial Base and Supply Chain Assessment: Boron Carbide (B_4C) Crude and Refined Powders.* The report found that the current hard armor vendors were reliant on limited and specific commercial sources for B_4C powder but that a healthy global IB existed for B_4C powder should DoD have future supply challenges (Institute of Defense Analysis [IDA], personal communication, July 16, 2014).

The Office of Manufacturing and Industrial Base Policy (MIBP) published a study of the hard armor industry by the RAND Corporation as part of the comprehensive sector-by-sector, tier-by-tier (S2T2) analysis in September 2014 (Office of the Under Secretary of Defense for Manufacturing and Industrial Base Policy, personal communication, September

12, 2014). The S2T2 is a standardized industrial base analysis approach and methodology for assessing the health of the defense IB. Its objectives are to

- Establish early warning indicators and identify IB risk
- Analyze the effect of DoD portfolio decisions on the IB
- Analyze single points of failure, unreliable suppliers, overreliance on foreign sourcing, and areas of limited competition, particularly at the lower tiers of the supply chain
- Define plans and strategies for mitigating identified IB risks
- Support long-term planning and investment decisions by and across the Services

The S2T2 process assessed the fragility (characteristics that make a specific capability likely to be disrupted, answering the following questions: will the DoD receive what it needs, when it needs it?) and criticality (characteristics that make a specific capability difficult to replace if disrupted with a capability defined as either a technology, part, component, or product). The hard armor industry segments included hard body armor (systems integration), ceramic tiles, B_4C ceramic powder, UHMWPE fibers and laminates, and aramid fibers and weaving. Recommendations included the following for the entire supply chain from the system integrator to tile manufacturer to ceramic powder supplier and the UHMWPE/aramid fiber producers/weavers:

- Consider funding to MSRs of production.
- Consider stockpiling hard armor plates or B_4C powder.
- Consider IB maintenance contracts (IBMC) to help preserve capability and surge capacity. IBMCs cover fixed costs while production remains lower than full surge capacity.
- Consider increasing the investment in future hard armor plates, ceramic tiles, and/or UHMWPE/aramid fibers for either increasing protection and/or achieving lighter weight.

One important consideration from the S2T2 analysis that complicated IB planning was that the manufacturers had different business operating models. 3M–Ceradyne operated with a vertically integrated business model—meaning the company owned and operated a mine for the raw ceramic powder, a ceramic tile manufacturer, and a hard armor plate integration and assembly plant, all in different locations. BAE Systems, on the other hand, operated with a horizontally integrated business model—meaning the company procured ceramic tiles from the commercial market and then owned and operated the hard armor plate integration and assembly plant at a single location.

In February 2015, the RAND Corporation completed a comprehensive assessment of the PPE on behalf of the Office of the Under Secretary of Defense for Acquisition, Technology & Logistics (OUSD[AT&L]). A subset of the RAND report findings included

- The DoD has large inventories of current designs and little need to buy more in the short term.
- Few alternative markets for military-grade PPE exist, so the industry is shrinking.
- Industry is unlikely to invest in research and development for PPE in the absence of large DoD contracts.
- The most critical technologies are ceramic tiles, high-performance polyethylene, and aramid fibers. (Younossi et al., 2015)

The report recommendations included

- Consider implementing industrial strategies to ensure future access to critical technologies, such as
    - Implement IBMCs for hard body armor and ceramic tiles to cover a share of fixed costs while production remains low.
    - Stockpile or establish a U.S. source for B_4C ceramic powder.
- Employ a best-value approach to source selections with an increased emphasis on criteria tied to weight, ballistic performance, and form/fit improvements rather than a cost-focused strategy, which would help incentivize innovation.
- Continue to use a multipronged strategy to support the research and development ecosystem, given that innovations can arise from various sources. (Younossi et al., 2015)

The RAND report summarized the hard armor supply chain in Figure 6.

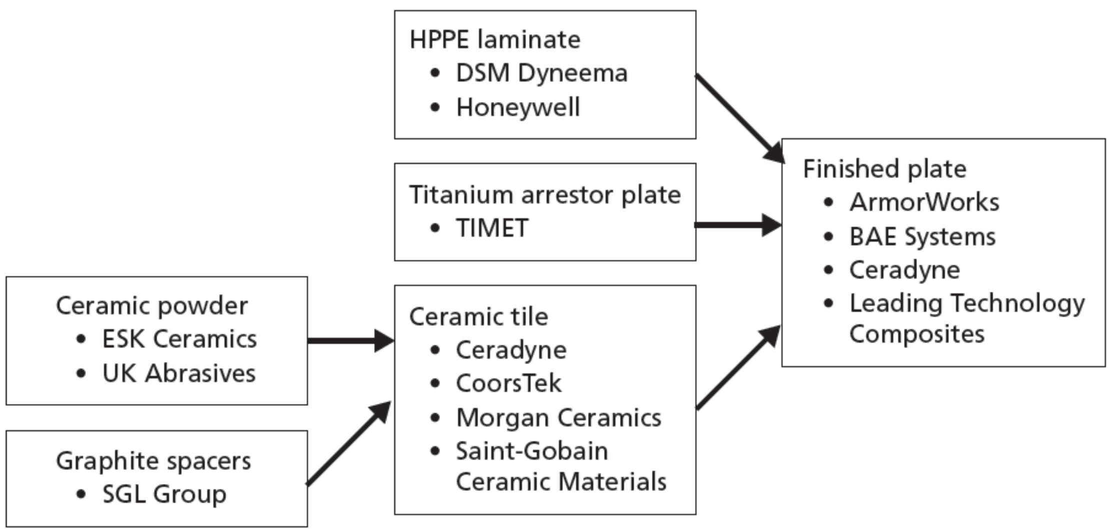


Figure 6. Hard Armor Supply Chain.
(Younossi et al., 2015).

As directed in Public Law 113-66, the FY14 NDAA, the OUSD(AT&L) provided Congress with the *Department of Defense Report to Congress on Personal Protection Equipment* in February 2015 (OUSD[AT&L], 2015). This report built upon the conclusions on the previously referenced studies. With respect to IB concerns, the report listed the following risk mitigation steps being considered: “the use of Industrial Base Maintenance Contracts, stockpiling, changes in procurement strategies, and qualification of domestic suppliers” (OUSD[AT&L], 2015, p. 14). More generally, “Opportunities to rely on commercial markets, demand for defense unique products, cooperative international developments and foreign sources, and adequate transfer of technology are key factors to sustaining a healthy industrial base capable of responding to future requirements” (OUSD[AT&L], 2015, p. 14). The report continues:

> Funding available for initial procurement of SPS during the FY2016–2020 timeframe will likely be at or potentially even below most producers’ Minimum Sustaining Rates of production. Therefore, as soon as it is practicable after SPS subsystems have entered into FRP, the Army should

> consider ceasing the sustainment of older versions of body armor and helmets, and apply its sustainment funds toward procuring SPS variants of body armor and helmets. This "Modernization through Sustainment" strategy would help to ensure that the Army is modernizing its stockpile of PPE assets, even as it begins initial procurement of the SPS. In addition, and equally as important, using sustainment funds to procure the latest systems will help the Army to maintain and support the most current and capable production base. (OUSD[AT&L], 2015, p. 21)

In response the FY15 NDAA, the Army completed a report to Congress entitled *Technical Study and Business Case Analysis of Body Armor Plates* in February 2015 (Headquarters, Department of the Army [HQDA], 2015). The service life of current hard plates was determined by the Army and presented in Table 1.

Table 1. Hard Armor Service Life and Washout Rates.
(HQDA, 2015).

	Expected Service Life	**Annual Washout Rate**
E-SAPI	10.3 years	6.48%
E-SBI	42.2 years	1.63%
X-SAPI	17.6 years	3.86%
X-SBI	85.2 years	0.81%

The Army's PEO Soldier calculated the estimated service life from the annual washout rate of currently fielded hard body armor. The washout rate was based on the total number of plates that failed inspection, divided by the total number of plates inspected during the years 2008 to 2014. The PEO's methodology and results were validated by the Army Materiel Systems Analysis Activity (AMSAA) and were based on hard armor surveillance testing data collected from nondestructive test equipment. The appendix contains the Army's business case analysis presented to Congress in this report.

Case Study Questions to Consider

The PM and deputy PM considered the wealth of information that existed with respect to the hard armor IB planning. As they pulled together the various reports and studies, they formulated a list of questions to address with stakeholders to prepare senior Army leaders for congressional hearings regarding the body armor IB and the concerns raised by commercial industry:

- Who were the stakeholders for hard armor IB?
- What were the DoD/Army and industries' assessments of the hard armor IB, and why did they differ?
- What did the DoD/Army do with the FY15 $80 million funding Congress provided for hard armor plates?
- What was the hard armor IB plan moving forward?
    - Should the Army buy higher performing SPS plates at a higher cost or lower performing legacy plates at a lower cost?

- What was the inventory requirement for plates from an operational standpoint?
- Should the Army buy plates to the operational requirement or to maintain the industrial base?
- Was preserving one or two vendors preferred when maintaining the industrial base?

- What were the advantages and disadvantages of various options to preserve the IB: funding as MSRs, stockpiling, awarding IBMCs, pursuing FMS sales, and/or investing in future innovations?
- What were the recommended hard armor IB actions for Congress to consider with respect to potential NDAA language and potential marks to the PB request in the Appropriations Act?

Conclusions

IB planning challenges are routinely faced by PMs as they formulate acquisition strategies for their assigned programs. The DoD and services face IB challenges across the portfolio of DoD products and services provided to the warfighters. Stakeholders' identification and engagement remain critical to thoroughly study all options and consider second- and third-order effects of various options. A difficult trade-off balance exists between the affordability of investing in a healthy and robust IB for every warfighter capability. At the one end of the affordability spectrum, it's important to determine the minimum viable level to sustain the production of warfighter capability and support surge capability/capacity for contingency and emergency operations to maintain readiness. At the other end of the affordability spectrum, it's important to encourage broad participation by commercial industry with companies of all sizes to compete and innovate in order the push the technology envelope to produce better performing warfighter products and services. Limited budgets force the services to accept risk in certain areas because of the ever-increasing demand for greater capabilities and the need to maintain an IB capable of preserving national security interests. The balancing of these IB priorities requires a thoughtful, data-driven approach to optimize limited resources.

References

DoD. (2013, November). *Assessing defense industrial capabilities, A DoD Guide to DoD 5000.60H* [Handbook].

DoD. (2012, October 16). *Defense manufacturing management guide for program managers.* https://www.dau.edu/guidebooks/Shared%20Documents%20HTML/Defense%20Manufacturing%20Management%20Guide%20for%20PMs.aspx

Headquarters, Department of the Army (HQDA). (2015, February). *Technical study and business case analysis of body armor plates*.

H.R. Rep. No. 112-479 (2012). https://www.govinfo.gov/content/pkg/CRPT-112hrpt479/pdf/CRPT-112hrpt479.pdf

National Defense Authorization Act for Fiscal Year 2014, Pub. L. No. 113-66 (2013). https://www.congress.gov/113/plaws/publ66/PLAW-113publ66.pdf

Office of the Under Secretary of Defense for Acquisition & Sustainment. (2020, January 23). *Operation of the adaptive acquisition framework* (DoDI 5000.02). Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2020-01-23-144114-093

Office of the Under Secretary of Defense for Acquisition & Sustainment. (2018, August 31). *Defense industrial base assessments* (DoDI 5000.60). Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500060p.pdf

Office of the Under Secretary of Defense for Acquisition & Sustainment. (2020, January 23). *Operation of the defense acquisition system* (DoDI 5000.02T). Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002T.pdf?ver=2020-04-22-083324-963

Office of the Under Secretary of Defense for Acquisition, Technology & Logistics. (2015, February). *Department of Defense report to Congress on personal protection equipment*. Department of Defense.

S. Rep. No. 113-176 (2014). https://www.congress.gov/113/crpt/srpt176/CRPT-113srpt176.pdf

Younossi, O., Pint, E. M., Weichenberg, G., Ahdiyyih, S., Critelli, S., Horn, K., & Sollinger, J. M. (2015, Februry). *Assessing the U.S. industrial base for personal protective equipment for the U.S. military, competition and innovation*. RAND Corporation.

Appendix. Business Case Analysis

This appendix is adapted from the report to Congress entitled *Technical Study and Business Case Analysis of Body Armor Plates* (HQDA, 2015).

Hard Armor Production Status

3M–Ceradyne (Cosa Mesa, California) and BAE Systems (Phoenix, Arizona) produce E-SAPI plates under DLA TS contracts. Ceradyne delivers 9,000 plates per month, and deliveries will be complete by the second quarter of FY16 (2QFY16). BAE delivers 6,000 plates per month and will complete deliveries by 1QFY16. BAE's contract expires for new delivery orders in July 2015, and Ceradyne's contract has expired for new delivery orders. Leading Technology Composites Inc. has an indefinite delivery, indefinite quantity (IDIQ) contract in place for E-SBIs that expires on May 30, 2016. There are no contracts for X-SAPI or X-SBI, as they are not being used, and the Army is maintaining a stockpile of 147,000 sets of X-SAPI and 150,000 sets of X-SBI for future contingencies.

Based on the status of the current stockpile, the Army has no plans to procure any additional E-SAPI or E-SBI plates with sustainment funding after current deliveries under DLA TS contracts are completed. The Army does plan to begin LRIP of lighter-weight E-SAPI and E-SBI, and X-SAPI and X-SBI plates under the SPS program beginning in 4QFY15. The number of complete sets of SPS hard body armor that will be produced per year in full rate production (FRP) is estimated to be 20,760 per year. FRP begins in FY16. This equates to 41,520 E-SAPI and X-SAPI plates, and 41,520 E-SBI and X-SBI plates.

For the purposes of comparison to stated industry MSR of production, the planned production rates amount to five to ten months of production per year for one producer. Production and inventory levels are presented in Figures 7, 8, and 9. On-hand inventories of hard armor plates by DLA and the Army enabled the calculation of plate inventories level per year.

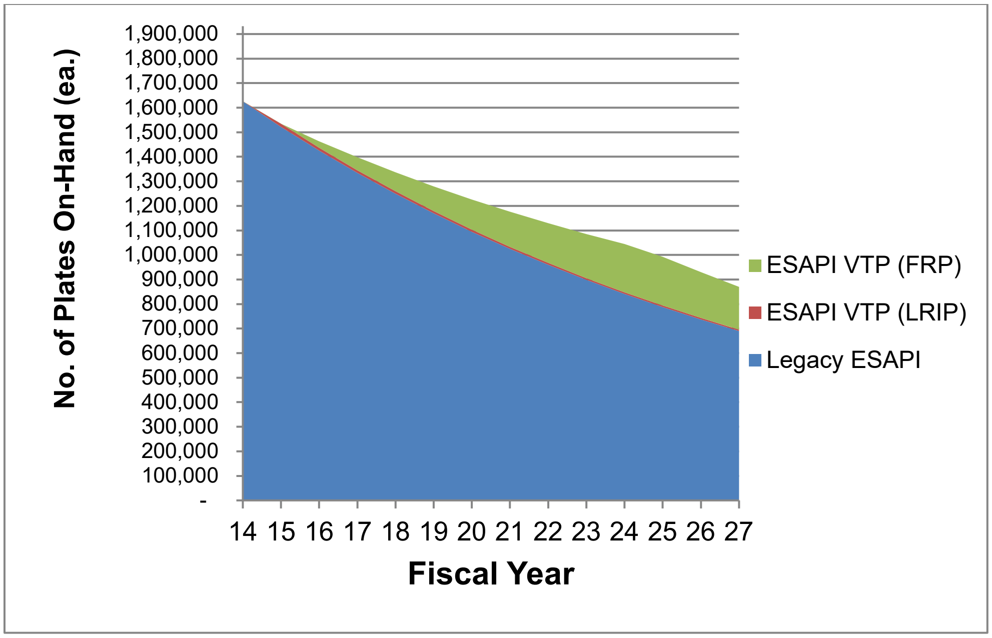


Figure 7. E-SAPI Expected Inventory Levels.
(HQDA, 2015).

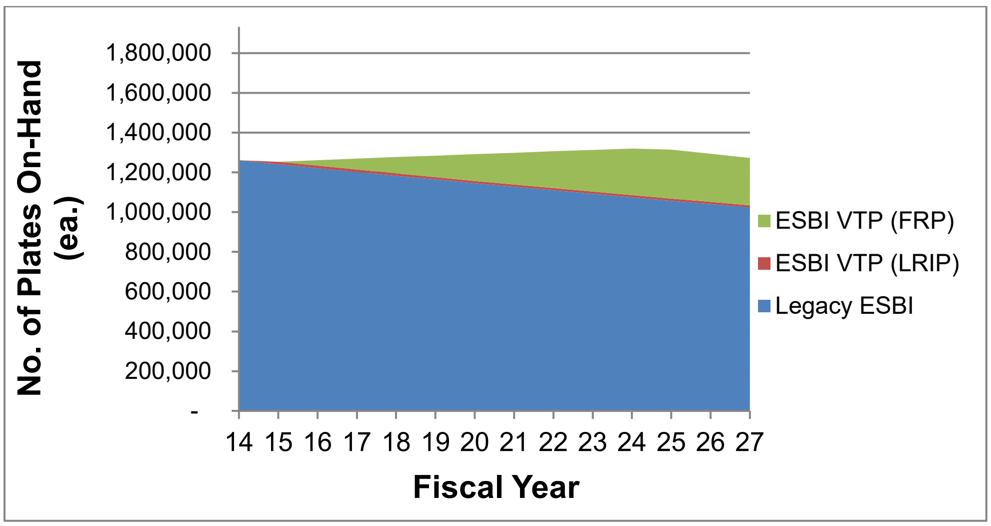


Figure 8. E-SBI Expected Inventory Levels.
(HQDA, 2015).

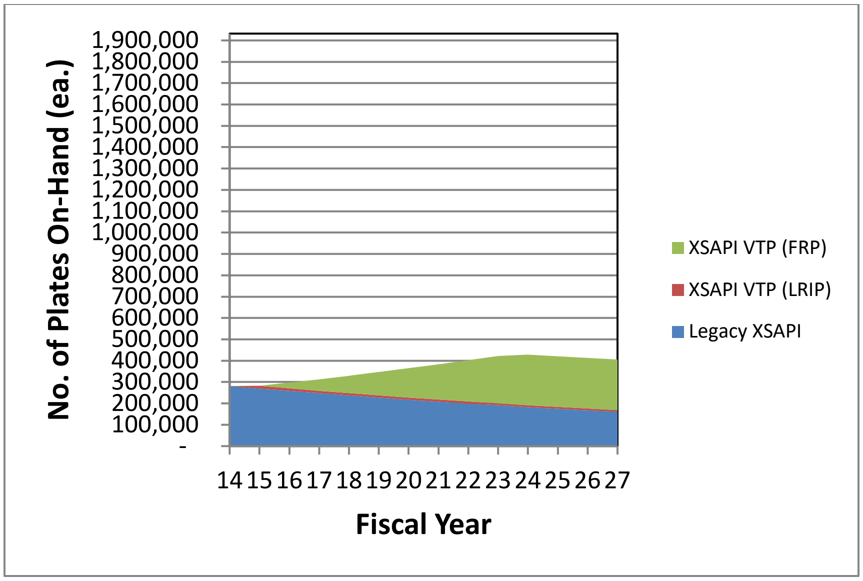


Figure 9. X-SAPI Expected Inventory Levels.
(HQDA, 2015).

Hard Armor Industrial Base Study

The SPS provides a modular, scalable integrated system of mission tailorable ballistic protective subsystems at a reduced weight, while maintaining the same level of ballistic protection and mobility provided by the current PPE systems. The SPS system includes VTP hard armor.

The Army not will require quantities of SPS hard armor plates to be manufactured in sufficient quantities from FY15 to FY20 to support two hard body armor contractors. The stated MSR of the Army's two current producers ranges between 6,000 and 12,000 torso plates (E-SAPI or X-SAPI) per month.

The Office of the Secretary of Defense (OSD) and the DLA have recently completed studies to address the industrial base. The OSD study was conducted by the RAND National Defense Research Institute to address section 146 of the FY14 NDAA. The OSD study generated the following key findings and recommendations relating to hard body armor:

- Recognize that reduced procurement is inevitable in the short term due to the existence of large inventories of hard body armor.
- Continue to foster innovation and competition through the development process.
- Focus research, development, test, and evaluation (RDTE) investments on more innovative efforts with alignment to long term acquisition priorities.
- DoD should sponsor studies of the feasibility of IBMCs aimed at prime contractors and ceramic tile producers to cover a share of fixed costs while production remains low.
- Contract for MSR if possible and affordable.

The DLA study was accomplished by Deloitte and recommends an IBMC be awarded in FY16 for only one supplier and include a ceramic tile manufacturer. This IBMC should be targeted to preserve surge production capability.

Path Forward

In the FY15 NDAA, $80 million in funding authorization was included for the body armor IB. The Army intends to use the $80 million to procure the lighter weight SPS VTP E-SAPI and E-SBI, and X-SAPI and X-SBI plates for production in FY16 in lieu of procuring legacy plates. Table 2 quantifies the discriminating differences between legacy plates and SPS VTP plates. The congressional add will procure a minimum of 35,320 complete sets of lighter body armor (front, back, and side plates), utilizing an SPS VTP existing contract.

Table 2. Hard Armor Plate Comparison.
(HQDA, 2015).

	Material	**Weight** (each)	**Cost** (each)	**Capability**
Legacy E-SAPI	Boron Carbide (B_4C)	5.45 lbs	$472	7.62 mm hardened steel penetrators and **some** 5.56 mm tungsten carbide penetrators
Legacy X-SAPI	Silicon Carbide (SiC)	6.00 lbs	$450	7.62 mm tungsten carbide penetrators and 7.62 mm hardened steel penetrators
VTP E-SAPI	Boron Carbide & Silicon Carbide	5.07 lbs	$719	7.62 mm hardened steel penetrators and **some** 5.56 mm tungsten carbide penetrators
VTP X-SAPI	Silicon Carbide	5.58 lbs	$708	7.62 mm tungsten carbide penetrators and 7.62 mm hardened steel penetrators

The Slow Destruction of the Defense Industrial Base

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Abstract

The National Security Innovation and Industrial Base (NSIB) is becoming detached from the greater U.S. economic base. Specifically, in a departure from most of U.S. history, much of the domestic economic engine—private industry—is choosing not to work with the federal government in general, and the Department of Defense (DoD) in particular. At the same time the federal government is losing access to leading commercial solutions, those companies who are committed to remaining in the NSIB are hamstrung by statutes and government policies that inhibit innovation and adaption. Until the federal government looks inward and matches policies to the realization that it cannot dictate to industry the terms of contracts, the DoD will often get what it pays for: less innovation, less access to leading commercial companies, fewer commercial capabilities incorporated into national security capabilities, and a loss of ground in the race for technology overmatch. This article identifies some of the policies and regulations driving these trends and proposes areas ripe for legislation and policy changes that could begin to inject more vitality and innovation into the NSIB.

Introduction

The National Security Innovation and Industrial Base (NSIB) is the bedrock upon which American military strength is built.[8] This national security base draws its strength from the economic powerhouse that is the U.S. economy. In recent years, however, a strange and disturbing trend has emerged. The NSIB is becoming detached from the greater U.S. economic base. Specifically, in a departure from most of U.S. history, much of the domestic economic engine—private industry—is choosing not to work with the federal government in general, and the Department of Defense (DoD) in particular. This drifting of private industry

[8] We use the term National Security Innovation and Industrial Base because we believe that innovation and industrial strength both matter, and the term defense industrial base does not capture the full gamut of national security–to include intelligence services and other agencies that support national security.

is occurring precisely at a time that the federal government increasingly relies on commercial technologies.

The pace of technological change is accelerating every year, and we have known for decades that the DoD needs to better align business practices with those of the private sector to reap the benefits of commercial innovation. In 1995, the Clinton administration released the policy document *Dual-Use Technology: A Defense Strategy for Affordable, Leading-Edge Technology,* the technology strategy corresponding to acquisition reform outlined in the Federal Acquisition and Streamlining Act of 1994. This strategy ambitiously set out to mirror defense business processes around commercial practices to make it easier to incorporate commercial technology into defense programs. Then Under Secretary of Defense for Acquisition and Sustainment Paul Kaminski (1995) detailed the need for the DoD to "place greater reliance on the commercial sector to reduce costs, shorten acquisition cycle times and retain technologically advanced defense equipment." More recently, the 2018 National Security Strategy noted that "Technologies that are part of most weapon systems often originate in diverse businesses as well as universities and colleges" (The White House, 2018, p. 21).

Many DoD purchases incorporate or depend on commercial technologies such as cloud computing, software, and other information technology (IT) capabilities. In 2022, the DoD's list of 14 critical technology areas vital to national security identified only three that are defense-specific (hypersonics, directed energy, and integrated sensing and cyber). The vast majority of critical technologies on this list are either the result of "existing vibrant commercial sector activity" (Under Secretary of Defense for Research and Engineering, 2022, p. 4) or emerging technologies being developed in the private sector or in collaboration with the DoD. Some of the commercial technologies identified are artificial intelligence, autonomy, microelectronics, space technology, advanced computing and software, and human-machine interfaces (pp. 3–6).

Despite this reliance on commercial capabilities, defense acquisition and business processes continue to become more complex, more heavily regulated, and out of synch with the private sector. The consequences of this trend for U.S. military strength are considerable. The DoD and other national security agencies are not leveraging the most advanced technologies and capabilities the commercial markets have to offer – but many of our competitors and potential adversaries are. Start-ups have access to global capital and markets, innovation is diversifying across borders, and technology development in areas relevant to the military is proliferating. The U.S. failure to leverage commercial industry is a recipe for losing our military, cyber, and intelligence advantages.

But the situation is perhaps even more dire. At the same time the federal government is losing access to leading commercial solutions, those companies who are committed to remaining in the NSIB are hamstrung by statutes and government policies that inhibit innovation and adaption. Members of the NSIB (such as traditional defense contractors) are at a severe disadvantage when competing with industry for high-skill talent critical to innovation, dedicating resources to R&D, and staying ahead of the technology and innovation curve. In some cases, the United States is behind the technology curve and needs innovation and R&D in the NSIB to catch up to potential adversaries, such as in hypersonics. Gen. David Thompson, vice chief of space operations, admitted at the Halifax International Security Forum in October 2021, "We're not as advanced as the Chinese or the Russians in terms of hypersonic programs" (Erwin, 2021).

This article identifies some of the policies and regulations driving these trends and proposes areas ripe for legislation and policy changes that could begin to inject more vitality and innovation into the NSIB. The issues identified in this paper are but a sample—and a good starting point of attack— to address the numerous policies that, as currently being implemented, are unnecessarily harming the long-term vitality of the NSIB. We expounded on only a few of the examples below, and glossed others, due to space constraints.

The Incredible Shrinking NSIB

The NSIB is shrinking. According to a recent report by the U.S. Government Accountability Office (GAO), from FY2011 to FY2020, the number of small businesses receiving DoD contract awards decreased by 43% (dropping from 42,723 to 24,296), even as obligations to small businesses increased by approximately 15% (GAO, 2021).

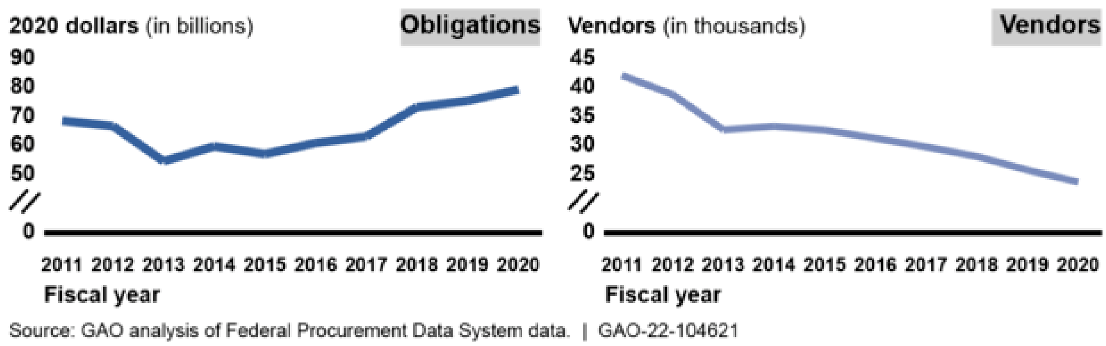

Figure 1. DoD Small Business Contract Obligations and Vendors, FY2011–2020 (GAO, 2021)

This phenomenon extends to *all businesses*, as companies of all sizes are choosing not to work with the DoD. As the GAO (2021) pointed out, “The number of larger businesses receiving contract awards fell by 7.3 percent per year on average from 2011–2020, while the number of small businesses receiving contract awards fell by 6 percent per year” (p. 9). Analysis from Bloomberg Government (2021) shows this trend continuing in FY2021. By their count, the number of prime vendors declined from 142,000 to 97,000 in the past decade. As they point out,

> *I tried to work for the federal government for five years and then gave up because it is just not worth it. In the commercial sector, time to market made it more worth my while.*

> The federal industrial base is shrinking even as contractors are asked to respond efficiently to increasingly complex requirements and crises … A decade-long, 23% increase in contract spending since fiscal 2012 means larger and fewer contracts are going to larger and fewer companies while agencies rationalize burdensome portfolios to keep pace with urgent priorities such as pandemics, cyberattacks, wars, climate change, and infrastructure modernization. (Bloomberg Government, 2021)

The past decade has seen variability in defense toplines, averaging a 10% decline from 2011 to 2020 (adjusted for inflation). However, this decline does not align with the 31–36% drop in vendors (Duffin, 2021).

The decline in industry participation in the government marketplace also stands in sharp contrast to the overall U.S. economy. U.S. GDP grew by 34% from 2011 ($15.6 trillion) to 2020 ($20.9 trillion; The World Bank, 2022). The total number of businesses in the U.S. economy also grew, increasing 7% from 2010 to 2019 (U.S. Census Bureau, 2021).

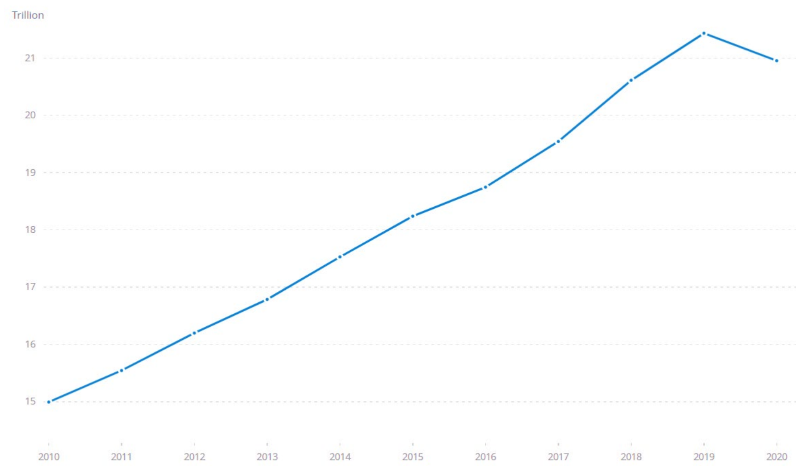

Figure 2. U.S. Gross Domestic Product, 2010–2020
(The World Bank, 2022)

As the above data indicate, even increased defense and government spending is not a sufficient enough incentive to persuade companies to work with the DoD.

How to Reverse the Trends in the NSIB

The DoD, to its credit, recognizes the need to expand the base. In its February 2022 report, *State of Competition Within the Defense Industrial Base*, the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD[A&S]) stated:

> To counteract the trend of overall shrinking of the DIB, DoD should endeavor to attract new entrants to the defense marketplace by reducing barriers to entry. This will be accomplished through small business outreach, support, and use of acquisition authorities like other transaction (OT) authority and commercial solutions opening (CSO) that provides DoD the flexibility to adopt and incorporate commercial best practices to reduce barriers and attract new vendors. (OUSD[A&S], 2022, p. 2)

Unfortunately, "outreach" is not the problem, and other proposed DoD solutions do not address the root causes of what is happening. As the largest buyer in the United States, companies of all stripes are well aware of the buying power of the DoD. More importantly, they are well aware of the challenges working for the Department. Increasing the use of different contracting vehicles like Other Transactions, while a positive step, is not a solution. And as the DoD slowly puts more regulation and bureaucracy on OTs, Middle Tier Authorities, and other flexibilities, the value proposition of these contracting vehicles decreases.

There is much blame to go around as to the current state. Congress, the DoD, industry, and the oversight organizations share responsibility. But the first and most important step to strengthen, expand, and revitalize the NSIB is for the DoD (and Congress) to understand that it has the largest impact on the NSIB and marketplace behavior. Secretary of Defense Lloyd Austin (2021) articulated this issue at the Reagan Forum, stating, "for far too long, it's been far too hard for innovators and entrepreneurs to work with the department."

> *We are still moving unbelievably slow...We are so bureaucratic, and we are so risk-averse...When you have a competitor...like China...you have to be able to move fast, and we still move way too slow.*
>
> General Hyten, chairman of the Joint Chiefs of Staff

But while the DoD's rhetoric hits the right notes, its actions are different and are the driving force behind the troubling NSIB trends. Companies eschew working with the DoD for several reasons, but based on our research and experience, some of the primary factors are

- Intellectual property (IP) rights
- Cash flow and risk return alignment
- Bureaucracy that slows down both acquisition timelines and transitions to scaling up contracts
- Policies that inhibit good-business decision-making
- Failure to structure meaningful follow-on procurement opportunities

Some of these factors also inhibit traditional defense contractors from being more innovative; delivering capabilities quicker, more efficiently, and at better price points; and attracting top tier workforce talent to work in the NSIB. Additional factors inhibiting current members of the NSIB from being more innovative include being unable to compete with the private sector for highly skilled workers and adhering to poorly thought-out and developed requirements. In the following pages, we discuss some of the policies creating these barriers to innovation.

Barriers to Increasing Innovation and Efficiency in the NSIB

Workforce – A barrier for Innovation and Efficiency in the NSIB

In 2017, the Section 809 Panel commented on the need to make the DoD a more attractive customer in the new, dynamic defense marketplace by transforming rules and regulations and supporting the workforce to attract the best and brightest the country has to offer (Advisory Panel, 2017). We believe this extends to the federal contractor workforce as well. Employee salaries of the NSIB have failed to keep pace with those offered by the private sector in large part due to the laws, regulations and contracting policies of the federal government.

Skilled workers are increasingly choosing not to work in the NSIB for a variety of reasons, including salary caps fueled by Cost Accounting Standards (CAS), continuing resolutions that put programs (and jobs) at risk, regulatory requirements applied only to federal contractors, and bureaucratic contracting and security clearance rules that make it difficult for contractor employees to begin work with government clients. Collectively, these government- and defense-unique practices are making the NSIB a less attractive place for individual employees to work. And in today's economic environment, skilled employees have options.

We recommend that Congress and the DoD take steps to make it easier for the NSIB to recruit and retain a skilled workforce and more quickly onboard contractor personnel to support agency missions, some of which are highlighted below.

Offering Competitive Salaries to Top Tier Contractor Talent

Government contractors are unable to match the salaries offered by industry for top tier talent. While paying less may reduce costs in the short term, we believe that cost savings are outweighed by the effects of losing top tier contractor talent in the long term. When successful, innovative, and capable employees leave the NSIB for private industry, innovation suffers, continuity of service is disrupted, timelines for delivering solutions can be delayed, and costs associated with replacing the departing workers are accrued. Two drivers of this phenomenon are the CAS and the continued prevalence of Lowest Price Technically Acceptable contracting.

The way CAS rules operate, wages and related costs are capped, disincentivizing companies from competing with commercial industry for top tech talent. CAS-covered companies could choose to compete for such talent and offer salaries above the allowable cost cap, but doing so would require the companies to accept lower profits.

Cost Accounting Standards – A Case Study

Congress created Cost Accounting Standards in 1970 to safeguard against potential overcharges on government contracts. These standards stipulate how contractors should allocate costs on defense cost-type and certain fixed-price contracts. Under CAS, allowable contractor costs are charged to the government under the contract; unallowable costs are not. Government oversight, accountability, and audit processes are aligned to ensure CAS standards are met. If a contractor or a business has CAS-covered contracts that in the aggregate exceed certain thresholds, all related business systems must be CAS compliant. So far so good. However, in today's markets and the way CAS is structured and executed, CAS is causing more harm than good.

The negative impact of CAS as currently structured will be discussed at various points in this paper.

Skilled workers with STEM specialties remain in high demand across the American economy, as there is a growing gap between the need for workers with technical expertise (such as cybersecurity and engineering) and the relevant number of workers in the United States. The DoD's 2020 *Annual Industrial Capabilities Report* noted a shortage of skilled workers across numerous defense-specific industries, noting particular specialties such as software engineering, manufacturing of missiles and munitions, nuclear weapons, space capabilities, and electrical engineering (OSD[A&S] Industrial Policy, 2021, pp. 86–109). In 2020, the median income for computer and information technology occupations exceeded $90,000 (U.S. Bureau of Labor Statistics, 2021). Online job posting sites list the current average salary for a cybersecurity engineer at over $100,000, with higher paying positions approaching the $150,000 range (Glassdoor, 2022). And Apple reportedly paid bonuses of $200,000 to top software and hardware engineers (Gurman, 2022).

These wage figures do not encompass full compensation packages that top-tier, highly skilled, and sought-after employees frequently command in the private sector field. The most highly skilled and sought-after experts in IT and cybersecurity are being offered multiples of the average. According to companies we have interviewed, employees have been lured away for salaries and compensation packages that defense contractors simply cannot match under the CAS rules. But it is these innovators that are critical to delivering advanced capabilities.

CAS should also be revisited to allow companies to recruit and retain top technology and STEM talent critical to innovation and maintaining a highly qualified and in-demand workforce who are heavily recruited by, and often leave for, private sector jobs.

To enable the NSIB to compete for top talent, Congress should

- Amend 10 U.S.C. 3744(a)(16) to increase the cap for specified STEM positions and
- Redefine "HCE" under the IRS to provide flexibility for employers to develop and implement innovative compensation structures and practices to enable better competition for, attraction of, and retention of critical STEM talent whose skills are vital to our national security.

Lowest Price Technically Acceptable Contracting

Even when CAS is not a concern, the prevalence of Lowest Price Technically Acceptable (LPTA) contracts makes it difficult for government contractors to build a workforce that has the necessary skills. As the Congressional Research Service noted, oft-cited criticisms of how LPTA is being used include that

> [t]he use of LPTA conditions the government market to offer potentially less desirable goods and services because the incentive structure encourages firms to reduce their prices as long as their product remains above the threshold of technical acceptability. Further, critics argue that LPTA contracts are not always the most effective and efficient approach to ensuring quality and performance in the long term; these analysts argue that the use of LPTA may sacrifice long-term value for short-term savings. (Peters, 2021, p. 2)

Yet the DoD still uses LPTA in instances where quality matters. According to a GAO study of federal contracts using LPTA source selection processes in FY2018, the top four DoD contracting components used LPTA for 25% of competitive contracts over $5 million. These included contracts for services, including IT services, professional support services, and research and development on defense systems—despite the legislative prohibition against using LPTA for such specialized service. (See Section 813 of the FY2017 NDAA). In contrast, civilian agencies used LPTA for only 7% of the same type of contracts (GAO, 2019, pp. 14–16).

In conversations with the GAO researchers, the civilian agencies explained why they were less likely to use LPTA. In one example,

> GSA officials told us their agency often procures services where it is beneficial for industry to propose solutions to a stated need, rather than GSA dictating the solution, such as professional services or information technology systems for a secure network solution. In these cases, officials said they would not have the technical specifications that an LPTA process would require. (GAO, 2019, p. 15).

Based on the GAO's research, civilian agencies appear more willing than the DoD to let industry collaborate on the structure and cost of service contracts to ensure a quality deliverable.

Security Clearance Reform – Getting Contractors Cleared and Working

The security clearance process creates hurdles for the defense industry to hire and retain the workforce it needs to operate efficiently and meet defense demands. In response to the 2022 *Vital Signs* survey of defense contractors, 63% of respondents said that the availability of cleared labor presented a moderate or significant problem (NDIA, 2022, p. 21). In 2021, the average time to complete an initial top-secret review was 176 days, or six months. It took about the same time for reinvestigations, an average of 170 days (Office of Management and Budget, 2022, p. 12).

In Maryland, home to many defense contractors, a 2019 study estimated that about 5% of all jobs requiring a security clearance were unfilled (9,187 vacancies compared to 161,379 filled positions; Irani et al., 2019, p. 20). One Virginia-based IT service provider for the federal government admitted, "we have upwards of 120 plus offers pending a clearance process at any given time—these are people who have accepted an offer and are waiting to go in. … I would say we probably lose 20-30 percent of placements by the time they are cleared" (Greater Washington Partnership, 2019, p. 16). Adding to this challenge is that an increasing number of STEM students at American universities are foreign born, creating a population unable to acquire security clearances—further restricting the pool of qualified workers (OSD[A&S] Industrial Policy, 2021, p. 102).

All of this means there is increased competition for the same small pool of technically skilled workers who are eligible for a security clearance. In such a tight labor market, workers are less likely to wait 6–8 months to begin working when they can be employed more quickly by a commercial company that does not require a security clearance – particularly when such companies often pay more than government contractors whose billing rates are determined by government labor categories. The dearth of new employees receiving clearances creates shortages of technically skilled labor in the cleared workforce. To fill positions, government and industry compete for existing talent, thereby driving salaries up and creating shortages on classified projects elsewhere.[9]

Amazon is recruiting individuals with security clearances in the National Capital Region (NCR) with starting salaries of $120,000 for holders of TOP SECRET clearances with no relevant experience or degree, a rate that exceeds the General Schedule rates for similar work. According to a 2018 survey conducted by Eagle Hill Consulting (2022), 71% of Washington, DC, Metro Area tech employees would leave their job for Amazon for a better salary and 33% would do so for a better workplace culture. The recent tightening of the job market and the increased number of people quitting jobs exacerbates these trends.

The government must make drastic improvements in the time required to investigate and clear new employees. Otherwise, cleared industry will be unable to hire adequate numbers of STEM experts, which will cause staffing disruptions and cost increases throughout the cleared workforce.

Regulations and Policies Affecting the NSIB Workforce

Laws, regulations, and policies that uniquely impact government contractors drive skilled members of the national security workforce away, including continuing resolutions and government shutdowns that suspend or delay programs or require employees to go on

[9] Poaching is a common challenge cited by many human resources professionals at defense contractors. See, for instance, Greater Washington Partnership (2019, p. 16).

unpaid or paid leave (often at the expense of the company), bid protests that often leave employees waiting weeks or even months on end to begin work on a project, or efforts to use the government procurement system to promote public policy. These combine to make it difficult for NSIB companies to recruit and retain a skilled workforce. One prime recent example is the effort to impose a vaccine mandate on the workforce.

In September 2021, President Biden issued Executive Order (EO) 14042 requiring defense contractors to adhere to COVID-19 protocols, including mandatory vaccination, masks, and physical distancing. This EO translated into a contract clause, FAR 52.223-99, Ensuring Adequate COVID-19 Safety Protocols for Federal Contractors, which was scheduled to go into effect on December 8, 2021. Defense contractors scrambled to mitigate the impact on their workforce with only a few months' notice. More importantly, thousands of employees notified their NSIB companies that they planned to quit and leave for the private sector instead of complying with the government contractor-unique requirement (Isidore & Langmaid, 2021).

Numerous defense contractors reacted to the mandate by hiring new employees in an attempt to offset the predicted loss of unvaccinated workers. In October, Raytheon was in the process of hiring more workers, anticipating the potential loss of "several thousand" employees (Insinna, 2021). The impact of the mandate would be felt more intensely by smaller businesses. Wes Hallman, senior vice president for strategy and policy at NDIA, shared in October that these smaller companies "have specific employees that have specific skillsets and specific security clearances to perform on contract. So even if they lose onesies and twosies, that's going to have a real impact on their ability to deliver on contracts and in some cases, may prevent them from delivering on contracts" (Insinna, 2021).

Ultimately, in response to several court injunctions preventing the mandate from being carried out, the DoD told contracting officers to stop enforcing the vaccine mandate on December 8, 2021 (Thompson Hine, 2022). We do not take a position on the vaccine mandate and do not believe that the vaccine mandate, *in and of itself*, would have necessarily caused irreversible, irreparable long-term harm to the NSIB that outweighed the public policy value of an effective mandate. Rather, we use this as but one example of how government actions, when taken in the aggregate, combine to push employees out of the NSIB.

Another CAS Obstacle – Inhibiting R&D Investment

Purely commercial companies invest in R&D and risk their capital for the promise of financial reward and profit. In 2018, U.S. businesses invested $452.1 billion of their own money in R&D. Of that investment, only $17 billion–4% of the total—went toward defense R&D goods or services provided to the federal government. (In the same year, the DoD invested $15 billion in federally funded R&D performed by companies; National Science Foundation, 2020).

A risk-reward construct incentivizes companies to invest in R&D and to pay higher salaries to recruit top tech talent. And profit they do. Private sector companies enjoy healthy profit margins. CAS-covered companies are not offered this same risk-reward opportunity. Their profit is essentially capped, which is the essence of cost and certain fixed-price contracts. Companies with cost contracts accept lower reward because of the lower risk—capital is not risked because costs are covered by the contract.

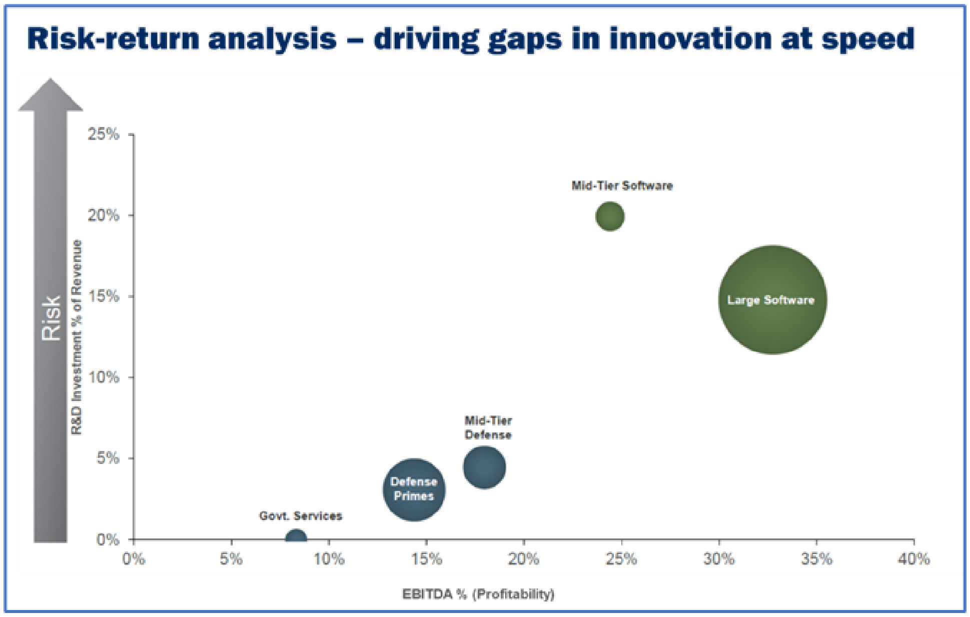

Figure 3. Risk-Return Analysis – Driving Gaps in Innovation at Speed
(ManTech, 2019)

The way CAS rules operate, the allowability of R&D and related costs are capped, disincentivizing companies from investing in R&D beyond the allowable cost limit.

As the DoD and the NSIB strive to be faster, more nimble, and more flexible, traditional CAS standards should be revisited to promote the ability of defense-focused firms to innovate or identify best available commercial products and facilitate integrating innovation and commercial products into a solution before traditional requirements-based RFPs are issued.

Contracting at the Speed of Relevance

According to a Bloomberg government-wide analysis, "[T]he time it takes between the release of a final solicitation to the award of a contract—procurement acquisition lead time, or PALT—rose 72% in five years" (Murphy, 2021). While the DoD performed better than most agencies, with an average PALT of 63 days, prime contracts with estimated values of more than $100 million—including weapon and IT systems—averaged 308 days (Murphy, 2021). Some particularly delayed programs include the Air Force's Enterprise Cyber Capabilities at over 790 days, the Army Common Hardware Systems-6th Generation (640+ days), the Air Force's Mission Partner Cmd/Ctrl/Intel Infor Sharing (630+ days) and the Army's TADSS Maintenance Program 2 (280+ days). These delays cost money and delay delivery of capability. But such delays are not always necessary.

According to a recent report conducted by the National Defense Industrial Association (NDIA), when asked, "What is the most important thing the federal government can do to help the Defense Industrial Base?", the top answer from industry members was "streamline the acquisition process" (NDIA, 2022, p. 54). In business, time is money, and the delays in awarding contracts and executing agreements is a strong disincentive to work for the DoD. Such delays also increase costs to contractors (which are ultimately passed on to the DoD) and delay capabilities from getting to warfighters.

A similar challenge occurs in the effort to recruit industry to conduct prototypes. Companies are generally not interested in prototype contracts for the prototype itself, but for the potential for follow-on production. Yet a common complaint heard from industry and senior DoD officials is that successful prototypes often fail to get to production due to budget and funding gaps—the valley of death. Too many experiences conducting prototypes that succeed in achieving benchmarks but fail to move to production in any reasonable timeframe (sometimes years, if at all) due to bureaucratic or funding failures will eventually dissuade companies from undertaking the prototypes in the first place. When successful prototypes do transition to production, the DoD often chooses inefficient contracting paths that cost more money and take more time than necessary. In recent years, the DoD has opted to use FAR-based contracts for follow-on production for successful OT prototypes even though the statutory OT authorities allow for quicker and less costly transitions to follow-on production.

Congress and the DoD, working with industry, should take on this challenge to increase the speed of delivering capabilities. While there are many possible ways of doing so, we propose three specific approaches:

- Increase the use of follow-on production authorities offered by Other Transactions,
- Increase the use of price-based offers, and
- Allow contracting officers to forego submission of certified cost and pricing data when recent purchases for the same product or service have already established price reasonableness.

Price-Based Offers

In the case of the Columbia Class Submarine, both the Navy and their prime contractor, Electric Boat, recognized a need to utilize a different approach following the extended negotiations concerning the Virginia Block V submarines. Although the Navy initially released a traditional request for proposals, following conversations with the contractor, this approach was amended to develop a priced offer along with an understanding on terms and conditions. Under such an approach, the government drew on past data on the Columbia and other submarine programs to initiate an offer to the contractor.

This approach allowed the contractor to avoid the costs associated with developing a proposal and sped up the negotiating process. The contractor did not spend time developing a bid and proposal, and the government did not spend time and resources to evaluate that proposal. Instead, both parties were able to leverage existing data to establish a deal, resulting in an award several months earlier than what was originally planned. We emphasize that for this to work, both parties need to be aligned and empowered to make decisions, and a level of trust and good faith must exist. (Developing trust and good faith could be the subject of its own paper.)

Pre-Established Price Reasonableness

The DoD often spends more than a year negotiating a price for a “lot” of products. Negotiations for the next “lot” often start immediately after prior negotiations complete. In these instances, little has materially changed from the prior negotiation, no new information has surfaced, and no new insights have been gleaned. Yet, the DoD often begins the new negotiations from scratch, wasting time and squandering both government and industry resources—with no appreciable improvement in contract cost or performance.

To improve the efficiency of negotiations, we believe a contracting officer should be encouraged to consider recently negotiated prices *if they are satisfied that the previously negotiated price remains a valid reference*. If they are not so satisfied, they retain the option of rejecting the previously negotiated price.

Expanding the NSIB

The ability for companies to earn a fair and reasonable profit is important to the success of the NSIB and our national security. If companies do not believe that the NSIB is a viable marketplace to succeed and flourish, they will choose—in fact they are choosing—to compete in the more lucrative commercial marketplace and spurn the NSIB.

It is the promise of profit that motivates companies to invest, develop new capabilities, and compete in the marketplace. Profit is the down payment for the next generation of solutions to satisfy the requirements of tomorrow. For example, Pfizer reported gross profit of 27% for 2021, largely due to revenue from the COVID-19 vaccine (Richter, 2022). In an accompanying statement, Pfizer Chairman and Chief Executive Officer Dr. Albert Bourla explained how his company entered the pandemic with the ability and willingness to invest for the collective good:

> We committed to use all of the resources and expertise we had at our disposal to help protect populations globally against this deadly virus … We put billions of dollars of capital on the line in pursuit of those goals, not knowing whether these investments would ever pay off. (Richter, 2022)

The pharmaceutical industry is one example of an industry that applies healthy profit margins to future R&D efforts that can benefit national welfare and security. However, the U.S. federal government does not fully utilize profit to incentivize defense contractors to make investments in R&D, information technology modernization, and cyber security, resulting in lost opportunities.

Too often, the DoD pursues policies that seek to save money in the short term at the expense of driving companies out of the marketplace, with the long-term ramifications of disincentivizing industry. Another example is the way the DoD misunderstands the value of intellectual property (IP) rights.

Intellectual Property and Data Rights

Nothing is going to drive a company away from the DoD faster than fear of losing control over its IP. Chapter 275 of Title 10, *Proprietary Contractor Data and Rights in Technical Data*, opens with a simple principle, written as a requirement for the secretary of defense, that recognizes this simple truism: “The Secretary of Defense shall prescribe regulations to define the legitimate interest of the United States and of a contractor or subcontractor in technical data pertaining to an item or process.”

The interests of the United States in proprietary and technical data are straightforward—the more the DoD owns and has access to such data, the easier it is for the DoD to ensure technology can be sustained over its life cycle, either in-house or by a contractor who competes for and gains access to these rights from the DoD. What seems to be less recognized is that it is in the long-term interest of the DoD to protect industry’s rights in proprietary and technical data. The most recent NDIA report on the health of the industrial base stated, “Intellectual Property rights are essential to the health of the DIB. The perception of risks to IP rights shapes investor’s willingness to invest in research and development and commercialization activities” (NDIA, 2022, p. 36).

IP rights represent the crown jewels of industry and the lifeblood of company competitive advantages. The DoD seems to fail to recognize this, too often seeking broader IP and technical data rights, and not wanting to pay for such rights.

The Regulatory Morass

Companies seeking to enter the NSIB must contend with a multitude of laws and regulations that are cost- and time-prohibitive, disrupt established supply chains, and require implementation of new systems, processes, and procedures. And in return for this effort, the promise is sometimes profit margins lower than those available in the private sector, plus threats to maintaining control over IP.

Just to give some examples, companies operating in the private sector who wish to work for the DoD as a traditional contractor must

- Prepare for cybersecurity standards on Cybersecurity Maturity Model Certification (CMMC);
- Abide by Section 889 requirements that prohibit the federal government from entering into or extending or renewing contracts with any entity that "uses any equipment, system, or service that uses covered telecommunication equipment or services as a substantial or essential component of any system, or as critical technology as part of any system;"
- Adhere to Buy American requirements that can disrupt supply chains and hurt cost competitiveness in the commercial market;
- Install costly IT and Cost Accounting Systems; and
- Build out a compliance capability to deal with government-unique requirements and potential government audits or congressional investigations and hearings.

Cost Accounting System as a Barrier to Entry

According to the GAO (2017),

> *...a number of companies chose not to develop products for DOD due to contract terms and conditions that would be expensive to implement, including establishing a government-unique cost accounting system that would be needed to comply with the standards. (p. 15)*

To ease the CAS limitations on industry, Congress included section 820 in the FY2017 National Defense Authorization Act, which required the Cost Accounting Standard Board to conform CAS, where possible, with Generally Accepted Accounting Principles (GAAP). We believe the effort has not gone far enough to reverse the impact on CAS of purely commercial companies.

These are but some of the challenges facing companies who consider joining the NSIB. And the reward for overcoming these hurtles can be profit margins below those offered by commercial markets.

Margins That Do Not Compete With Commercial Markets

Under the Truthful Cost or Pricing Data Act (formerly known as the Truth in Negotiations Act, or TINA), government contractors and subcontractors must submit certified cost or pricing data (TCoPD) for negotiated contracts, subcontracts, or modifications above the threshold, if the government contract is awarded without "adequate price competition." The contractor must provide "accurate, complete, and current data" about costs to ensure that the negotiated price is "fair and reasonable." Contracting officers can also request a “price adjustment remedy” if a contractor did not previously provide sufficient data (FAR 15.4).

This requirement often delays the contracting process (Adjei & Hendricks, 2021, p. 24). It also is sometimes used to squeeze margins from contractors, making the DoD a less lucrative—and therefore unappealing—customer.

The recent case of TransDigm demonstrates a tendency to object to what is considered excess profit in the case of sole-source contracts. The DoD Office of the Inspector General (2021) considered any profit over 15% to be excessive and suggested the contractor voluntarily refund profits above that range. Coca-Cola, by contrast, reported gross profit margins of 60.3% in 2021, up from 59.3% in 2020 (The Coca-Cola Company, 2022). And as mentioned above, Pfizer’s commitment to protecting the health of global populations—a mission comparable to defense contractors supporting national security—resulted in a 27% profit margin in 2021.

Conclusion

The DoD recently issued the report, *State of Competition Within the Defense Industrial Base*. We believe that the DoD got it backwards. The question is not, what are companies doing to compete for the DoD’s business? It should be, what is the DoD (and Congress) doing to compete with commercial market buyers to induce industry to work with the DoD?

Until the federal government looks inward and matches policies to the realization that it cannot dictate to industry the terms of contracts, the DoD will often get what it pays for: less innovation, less access to leading commercial companies, fewer commercial capabilities incorporated into national security capabilities, and a loss of ground in the race for technology overmatch.

References

Adjei, S., & Hendricks, C. (2021). *Increasing defense contractor competition in a predominantly sole-source contracting environment*. Naval Postgraduate School. https://dair.nps.edu/handle/123456789/4529

Advisory Panel on Streamlining and Codifying Acquisition Regulations. (2017, May). S*ection 809 panel interim report.* https://discover.dtic.mil/wp-content/uploads/809-Panel-2019/Interim-Report/Sec809Panel_Interim-Report_May2017.pdf

Austin, L. (2021, December 4). *Remarks by Secretary of Defense Lloyd J. Austin III at the Reagan National Defense Forum*. Department of Defense. https://www.defense.gov/News/Speeches/Speech/Article/2861931/remarks-by-secretary-of-defense-lloyd-j-austin-iii-at-the-reagan-national-defen/

Bloomberg Government. (2021, March 21). *Chart of the week: Federal industrial base consolidation leads to vendor count below 100,000* [Email].

The Coca-Cola Company. (2022). *Annual report for 2021*. https://investors.coca-colacompany.com/filings-reports/annual-filings-10-k

DoD Office of the Inspector General. (2021, December 13). A*udit of the business model for TransDigm Group Inc. and its impact on Department of Defense spare parts pricing*. https://www.dodig.mil/reports.html/article/2871623/audit-of-the-business-model-for-transdigm-group-inc-and-its-impact-on-departmen/

Duffin, E. (2021, November 10). *U.S. military spending from 2000 to 2020*. Statista. https://www.statista.com/statistics/272473/us-military-spending-from-2000-to-2012/

Eagle Hill Consulting. (2022). *D.C. tech workers ask: Should I stay, or should I go to Amazon?* https://www.eaglehillconsulting.com/insights/dc-workforce-amazon-should-i-stay-or-should-i-go/

Erwin, S. (2021, November 21). Space Force general: U.S. has a lot of catching up to do on hypersonic missile technology. *SpaceNews*. https://spacenews.com/space-force-general-u-s-has-a-lot-of-catching-up-to-do-on-hypersonic-missile-technology/

GAO. (2017, July). *Military acquisitions: DoD is taking steps to address challenges faced by certain companies.*

GAO. (2019, September 26). *Federal contracting: Information on agencies' use of the lowest price technically acceptable process*. https://www.gao.gov/products/gao-19-691

GAO. (2021, October 14). *Small business contracting: Actions needed to implement and monitor DoD's small business strategy.* https://www.gao.gov/products/gao-22-104621

Glassdoor. (2022). *How much does a cyber security engineer make?* https://www.glassdoor.com/Salaries/cyber-security-engineer-salary-SRCH_KO0,23.htm

Greater Washington Partnership. (2019). *Security clearances: Clearing the path to more job opportunities.* https://greaterwashingtonpartnership.com/wp-content/uploads/2020/06/2019.11.GWP_Security-Clearances_Clearing-the-Path-to-More-Job-Opportunities.pdf

Gurman, M. (2022, March 25). *Apple pays another round of rare $200,000 bonuses to some staff*. Bloomberg. https://www.bloomberg.com/news/articles/2022-03-25/apple-pays-another-round-of-rare-200-000-bonuses-to-some-staff

Insinna, V. (2021, October 29). Defense companies brace for workforce loss due to vaccine mandate. *Breaking Defense*. https://breakingdefense.com/2021/10/defense-companies-brace-for-workforce-loss-due-to-vaccine-mandate/

Irani, D., Siers, M., Bast, E., Frye, R., Leh, J., Nickey, Z., & Wetzler, N. (2019, October 7). *A Study of employment in the state's defense industry*. Towson University Regional Economic Studies Institute.

Isidore, C., & Langmaid, V. (2021, October 28). *72% of unvaccinated workers vow to quit if ordered to get vaccinated*. CNN. https://www.cnn.com/2021/10/28/business/covid-vaccine-workers-quit/index.html.

Kaminksi, P. (1995). Preface. *Dual-Use technology: A defense strategy for affordable, leading-edge technology*. Office of the Assistant Secretary of Defense for Economic Security, Homeland Security Digital Library. https://www.hsdl.org/?view&did=712456

ManTech. (2019). *Risk-return analysis – Driving gaps in innovation at speed* [PowerPoint presentation provided to authors].

Murphy, P. (2021, September 20). *Procurement acquisition lead time increases 72%*. Bloomberg Government. https://www.bgov.com/core/news/#!/articles/QZQ8H7DWLU68

National Defense Industrial Association. (2022, February). *Vital signs 2022: The health and readiness of the defense industrial base*.

National Science Foundation. (2020, December 16). *Business research and development: 2018, detailed statistical tables*. National Center for Science and Engineering Statistics. https://ncses.nsf.gov/pubs/nsf21312.

Office of Management and Budget. (2022). *Security, suitability, and credentialing performance accountability council*. https://www.performance.gov/assets/files/Personnel_Vetting_Reform_Progress_2022_Q1.pdf

Office of the Secretary of Defense for Acquisition and Sustainment Industrial Policy. (2021, January). *Fiscal year 2020 industrial capabilities report to Congress.* https://media.defense.gov/2021/Jan/14/2002565311/-1/-1/0/FY20-INDUSTRIAL-CAPABILITIES-REPORT.PDF

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2022, February). *State of competition within the defense industrial base*. https://media.defense.gov/2022/Feb/15/2002939087/-1/-1/1/STATE-OF-COMPETITION-WITHIN-THE-DEFENSE-INDUSTRIAL-BASE.PDF

Peters, H. M. (2021, December 15). *Defense primer: Lowest price technically acceptable contracts*. Congressional Research Service.

Richter, F. (2022, February 9). *Pfizer revenue boosted by Covid-19 drugs*. Statista. https://www.statista.com/chart/25434/pfizer-annual-revenue/

Thompson Hine. (2022, February 17). *Update on federal contractor and subcontractor vaccine mandate*. https://www.thompsonhine.com/publications/update-on-federal-contractor-and-subcontractor-vaccine-mandate
Under Secretary of Defense for Research and Engineering. (2022, February 1). *Technology vision for an era of competition*. https://www.cto.mil/wp-content/uploads/2022/02/usdre_strategic_vision_critical_tech_areas.pdf
U.S. Bureau of Labor Statistics. (2021). Computer and information technology occupations. *Occupational Outlook Handbook*. https://www.bls.gov/ooh/computer-and-information-technology/home.htm
U.S. Census Bureau. (2021). *2010 SUSB annual data tables by establishment industry*. https://www.census.gov/data/tables/2010/econ/susb/2010-susb-annual.html
The White House. (2018). *National security strategy*.
The World Bank. (2022). *Gross domestic product (current US$) – United States*. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=US

Analyzing the Composition of the Department of Defense Small Business Industrial Base

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Abstract

This paper explores the composition of the Department of Defense (DoD) small business (SB) industrial base by analyzing public records for companies registered to do business with the government and publicly available DoD contract and subcontract award data from 2015 through 2021. We demonstrate that although the amount of money DoD awarded to SBs grew by almost 68% between 2015 and 2021, the total number of SBs in the defense market shrank nearly 23% concurrently. The decline in SBs can be attributed to the fact that SB program policies fail to address the underlying issues that keep small and nontraditional companies from navigating the defense market successfully. Furthermore, SB policies enable the largest SBs–which include companies that generate hundreds of millions or billions of dollars in DoD revenue annually–to expand their market share, irrespective of price, quality, or innovativeness. To contextualize these findings, we provide an overview of the history and stated objectives of DoD SB initiatives and utilize qualitative research to understand the experiences of individual SBs in the defense market. We offer a series of concrete recommendations to improve how the DoD SB program is structured and measured, to enable it to better meet its objectives.

Introduction

For nearly 70 years, the U.S. government (USG) has afforded small businesses (SBs) preferential treatment in the federal procurement process by limiting competition for certain contracts to SBs. Congress justifies SB set-aside contracts ("SB set-asides") on the basis that "the Government should aid, counsel, assist, and protect … the interests of small-business concerns in order to preserve free competitive enterprise … and to maintain and strengthen the overall economy of the Nation" (Small Business Act and Small Business Investment Act, 1). Likewise, the Small Business Administration (SBA) website states that SB set-aside contracts exist to "help small businesses compete for and win federal contracts" and to "help provide a level playing field for small businesses" (U.S. SBA, n.d.-b). In its "Small Business Program Guide for Government and Industry," the Army Corps of Engineers (n.d.) summarizes that the congressional philosophy for the SB program is to

- Utilize the annual federal budget to promote Small Business Programs
- Promote economic stability through the use of Small Businesses to enhance the nation's defense
- Preserve and promote free enterprise
- Maintain a viable industrial base
- Ensure competitive economic climate

- Provide opportunities for entrepreneurship and inventiveness

A 2007 House committee report stated that the basis for SB contracting programs "is the positive economic benefits they provide, as well as assisting small businesses to overcome the complexities of the system" (Dilger & Blackford, 2022). The report emphasizes that SB programs "are designed to increase and diversify small contractors with the intent of expanding the federal supplier base" so as to increase competition and product diversity, improve product quality, and reduce prices. The report also notes that "these contracting initiatives lower barriers to entry in a wide range of markets for small businesses … [which] provides greater market access for small firms' [products] and services. … Such access is critical to generating positive macroeconomic benefits, including higher job creation, wage growth, and greater income distribution."

In spite of these stated objectives, the success of the SB set-aside program has been measured primarily by whether the government meets Congressionally established set-aside procurement goals. Specifically, Congress directs the USG to allocate 23% of eligible procurement spend for SBs annually, with procurement goals from within this spend for subsets of the SB program including woman-owned SBs, small disadvantaged businesses, HUBZone SBs, and service-disabled veteran-owned SBs.

Assessing the amount of money awarded to SBs as a share of overall government spending does little to evaluate the impact of the SB program on the industrial base, the economy, or the competitive environment for products and services in the USG. Our research aimed to provide a more comprehensive assessment of the DoD SB program vis a vis its stated objectives. Specifically, we conducted a quantitative analysis of SB suppliers to DoD annually from Fiscal Year (FY) 2015 through FY2021 and analyzed trends in the data related to SBs' DoD procurement obligations and subcontracting practices. For additional context, we interviewed DoD SBs and reviewed USG contracting policies that impact all suppliers. We conclude that rather than achieving its stated objectives, the DoD SB program reduces opportunities for SBs, creates a less competitive economic climate, and weakens the defense industrial base (DIB); and throughout the paper, we offer a series of recommendations for reforming the program—both how it is structured and how it is measured—to improve its outcome.

Sizing the Small Business Defense Industrial Base

Considering that one objective of the SB set-aside program is to expand and diversify the industrial base, the number of SB contractors supporting the DoD should be increasing over time. We sought to evaluate this metric by calculating the number of SB contractors to DoD (DoD SBs) each year from FY2015–FY2021.

Research Note: Timeframe

We selected FY2015–FY2021 as our analysis period because it allowed us to assess year over year trends as well as a wide range of features associated with DoD SBs. Unless otherwise noted, quantitative analyses referenced in the paper are associated with FY2015–FY2021.

Sizing the Overall DIB

To assess trends in the SB DIB, we needed to identify and isolate SBs from the DoD vendor pool. First we created a mirror of the Federal Procurement Data System (FPDS), the clearinghouse for all USG procurement data. Next, we isolated the data to all DoD-funded procurements from FY2015 through FY2021. To calculate the annual number of DoD-funded vendors, we grouped the data by FY and calculated the number of distinct DUNS numbers across all active procurements from that FY. Table 1 shows the total number of DoD vendors by year.

Table 1. Total DoD Supplier Base, Annually

Fiscal Year	Count of Distinct DoD Funded DUNS Numbers
2015	68,257
2016	66,290
2017	64,184
2018	61,242
2019	57,746
2020	54,418
2021	52,597

Classifying the Small Businesses

Next, we categorized each distinct vendor as either an SB or an entity other than an SB ("large business" or "LB"). Size standards vary based on industry; government reporting on size standards is inconsistent; and company size can change from one year to the next. To classify each DoD vendor, we developed a classification system that weights multiple features associated with a DUNS number using data from FPDS and the System for Award Management (SAM) Entity Registration Database to designate it as an SB or LB accordingly.[10] For instance, some FPDS contract actions indicate the use of an SB in a field labeled "business size determination," and there are other references to set-asides in the FPDS data. So, for each DUNS number, the system considers all historic contract actions from FPDS–not just the contract actions associated with it from FY2015–FY2021. SAM data can also reference features such as "Business Type" and "Set-Aside Type," which often correlate to SBs, so the system considers data from these fields when classifying each DUNS as well. Table 2 outlines the features used to classify each entity by data source.

Table 2. Small Business Classification Features

Data Source	Feature			
	Business Size Determination	Set-Aside Contract Feature	Business Type	Set-Aside Type
FPDS	X	X		
SAM			X	X

[10] For the purposes of our technical approach, each DUNS number corresponds to either an SB or an LB. FPDS contains a higher volume of features that, while less accurate than SAM features, in some cases allowed us to categorize a business as an SB even if it is not currently active in SAM; or even if is not currently registered as an SB in SAM, but was considered an SB for the majority of our analysis period.

Recommendation: "Single Source of Truth" for Defining SBs

The fact that the USG does not adhere to a consistent classification system for defining SBs severely limits any effort to comprehensively evaluate the SB program, including efforts to assess the share of overall DoD spend awarded to SBs.

In a subsequent section, we discuss the need to modify revenue and employee thresholds for what qualifies as "small" by USG standards. However, irrespective of qualification criteria, it is essential that a company's status as small or large is reported consistently across government data sources. We recommend the USG establish and maintain a "small business registry" for all active DUNS numbers containing detailed information about their SB contract awards and, if necessary, distinguishing between revenue they generated as an SB versus revenue they generated as a large business (since the same company can qualify as "small" for certain contracts but not others). This registry would eliminate the need to cross-reference FDPS and SAM to determine which contract awards were SB set-asides.

Sizing the SB DIB

Using the previously outlined classification system, we calculated the number of distinct SBs contracting with the DoD annually. **As shown in Table 3, over the last 6 years the number of SBs that were awarded defense-funded contracts declined nearly 23%, from 48,322 to 37,294.** ***Contrary to the stated objectives of the SB set-aside program, the number of small contractors within the defense market is shrinking.***

Table 3. SB Suppliers to DoD

Fiscal Year	Count of Distinct DoD Funded SB DUNS Numbers
2015	48,322
2016	46,952
2017	45,609
2018	43,505
2019	40,940
2020	38,703
2021	37,294

Funding to the SB DIB

Next, we calculated the amount of DoD funding awarded to small versus large businesses. **As shown in Table 4 and Figure 1, while overall defense spending increased by 46%, the amount of money DoD awarded to SBs grew by almost 68%, from ~$54 billion in 2015 to ~$91 billion in 2021.** In other words, ***as the pool of SB vendors contracted, the DoD awarded substantially more in contracts to SBs–both in total dollars and as a share of overall spending.***

Table 4. Breakdown of DoD Spend by Business Size

Fiscal Year	Total DoD Funded Procurement	Total DoD Funded Procurement to SBs	Total DoD Funded Procurement to LBs	% DoD Funded Procurement Awarded to SBs
2015	$294,357,455,264	$54,500,060,463	$239,857,394,801	18.51%
2016	$318,628,870,367	$58,858,890,994	$259,769,979,374	18.47%
2017	$344,813,865,145	$62,493,984,962	$282,319,880,183	18.12%
2018	$386,911,953,179	$74,865,344,991	$312,046,608,188	19.35%
2019	$427,876,600,900	$81,259,290,822	$346,617,310,078	18.99%
2020	$465,451,566,836	$87,928,706,954	$377,522,859,882	18.89%
2021	$428,635,700,550	$91,584,868,966	$337,050,831,584	21.37%
Total	$2,666,676,012,242	$511,491,148,151	$2,155,184,864,091	19.18%

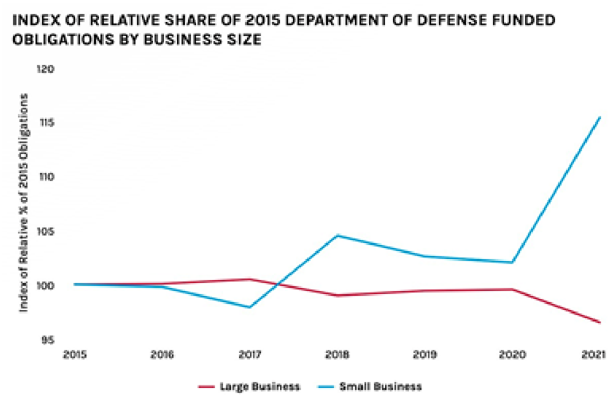

Figure 1. Index of Growth in DoD Procurement to Small vs. Large Businesses

Total Spend to SBs: A Myopic Measure of Success

If you consider the proportion of DoD spend allocated to SBs as the primary performance metric, the DoD SB program appears successful, with nearly 20% of procurement awarded to SBs annually. However, the fact that the pool of SB vendors simultaneously shrank not only runs counter to the intended purpose of the program, but also suggests anti-competitive forces at play. **The more the DoD procured from SBs, the fewer SBs benefited. In a free, competitive market, increasing the amount of money spent on SBs should attract a growing number of SBs into the DIB.**

Rather than providing “greater market access for small firms’ goods and services,” as the House report asserts, **DoD SB policies have made the DoD increasingly reliant on fewer suppliers, thereby reducing the variety of available products and services and posing risks to the health and resilience of the industrial base.**

The DoD and USG should not measure the success of the SB program exclusively by the share of overall procurement awarded to SBs. **To assess the program relative to its stated objectives, they must consider a subset of key metrics, such as the total number of SB suppliers each year and the number of new SBs working with DoD annually.**

Composition of the SB DIB

For a shrinking number of SBs to receive a substantially greater share of overall DoD procurement suggests that these SBs, or a subset of them, dramatically increased their DoD revenue during our analysis period. To better understand these trends, we explored the distribution of DoD funding to the individual SBs.

SB DoD Revenue

We calculated the total defense funded procurement for each of the 93,306 distinct SB DUNS in our dataset. Table 5 presents the top 20 SBs that received the most DoD funding during the analysis period. It is apparent that **businesses can receive hundreds of millions, or even billions of dollars, in DoD contracts annually and *still* qualify as small.** Furthermore, **the top 20 SBs alone received more than $53.6 billion in DoD funded procurement–over 10% of all DoD funding to SBs.**

Table 5. DoD Procurement to the Top 20 Small Businesses

Company Name	Total DoD Funding, FY2015–FY2021	FY2015	FY2016	FY2017	FY2018	FY2019	FY2020	FY2021
ATLANTIC DIVING SUPPLY INC.	$15,720,363,970	$1,114,565,311	$1,250,613,527	$1,609,645,315	$2,509,511,257	$3,233,362,687	$3,138,616,046	$2,864,049,826
MODERNATX INC.	$8,167,157,644	$0	$0	$0	$0	$0	$1,255,697,789	$6,911,459,855
FEDERAL RESOURCES SUPPLY COMPANY	$3,639,062,189	$191,105,314	$190,329,295	$233,348,924	$288,268,243	$339,501,133	$2,017,338,638	$379,170,642
TORCH TECHNOLOGIES INC.	$2,793,079,298	$230,809,413	$297,477,436	$343,020,172	$407,159,701	$506,888,808	$534,814,811	$472,908,957
AMERICAN ROLL-ON ROLL-OFF CARRIER LLC	$2,127,079,115	$162,123,014	$121,500,994	$299,618,926	$402,194,232	$409,332,723	$401,249,517	$331,059,709
W. S. DARLEY & CO.	$2,116,004,701	$88,187,907	$104,757,067	$137,284,656	$290,071,939	$447,459,381	$619,533,680	$428,710,071
SUPPLYCORE INC.	$2,063,094,270	$216,465,938	$270,658,624	$287,081,017	$483,843,845	$314,088,442	$238,994,116	$251,962,287
NOBLE SALES CO. INC.	$1,596,066,944	$82,503,610	$146,790,206	$214,925,343	$419,501,578	$343,312,708	$163,182,149	$225,851,349
PATRIOT CONTRACT SERVICES LLC	$1,527,239,912	$211,826,458	$208,532,530	$202,886,173	$201,692,062	$229,600,183	$249,576,431	$223,126,075
SCIENCE AND ENGINEERING SERVICES INC.	$1,504,421,418	$161,310,210	$198,748,354	$203,236,582	$230,739,555	$399,540,265	$201,691,936	$109,154,516
INTUITIVE RESEARCH AND TECHNOLOGY CORPORATION	$1,356,791,448	$243,750,490	$271,883,798	$141,934,429	$132,888,518	$161,577,735	$150,588,243	$254,168,235
REDSTONE DEFENSE SYSTEMS	$1,348,465,209	$409,931,908	$290,605,504	$268,598,914	$364,629,509	$20,055,527	-$4,559,932	-$796,221
PETROMAX REFINING COMPANY LLC	$1,318,910,681	$0	$50,639,235	$168,748,000	$289,379,308	$175,004,910	$210,103,376	$425,035,852
AASKI TECHNOLOGY INC	$1,297,017,594	$268,424,777	$185,202,403	$138,632,480	$73,974,621	$185,177,343	$281,011,125	$164,594,844
LINQUEST CORPORATION	$1,242,341,667	$93,040,472	$116,169,557	$145,481,202	$191,800,933	$246,554,703	$226,637,383	$222,657,417
STERLING COMPUTERS CORPORATION	$1,201,065,386	$113,739,696	$139,257,654	$194,142,865	$207,344,777	$206,333,948	$177,827,869	$162,418,578
OASIS SYSTEMS LLC	$1,185,405,811	$46,900,883	$90,364,813	$115,206,223	$137,248,228	$282,548,753	$238,203,287	$274,933,625
RADIANCE	$1,174,024,159	$74,488,287	$106,085,426	$146,400,995	$160,501,398	$262,801,414	$186,364,266	$237,382,374

TECHNOLOGIES INC.								
PROGENY SYSTEMS CORPORATION	$1,140,344,606	$90,349,414	$187,885,609	$89,783,297	$182,629,973	$172,766,058	$213,144,546	$203,785,709
PLACID REFINING COMPANY LLC	$1,138,393,266	$261,394,162	$137,389,081	$142,381,210	$228,259,639	$53,777,964	$125,369,386	$189,821,824
Total	$53,656,329,288							

As shown in Table 6 and Figure 2, **the number of SBs that received more than $100 million in DoD funded procurement in 2021 was 3.23x that of 2015. By comparison, the number of DoD SBs awarded $1 million or less in DoD procurement *shrank*** **by 32%.** ***An increase in SB spend has disproportionately benefited the "largest" SBs, enabling them to dramatically expand their DoD market share while the DoD market became less opportune for the smallest businesses.***

Table 6. Count of SBs with $100M+ in DoD Procurement, Annually

Fiscal Year	Count of SBs with $100M+ DoD Procurement	Count of SBs with <$1M in DoD Procurement
2015	26	34,205
2016	38	32,727
2017	48	31,100
2018	66	29,070
2019	79	26,538
2020	84	24,352
2021	84	23,337

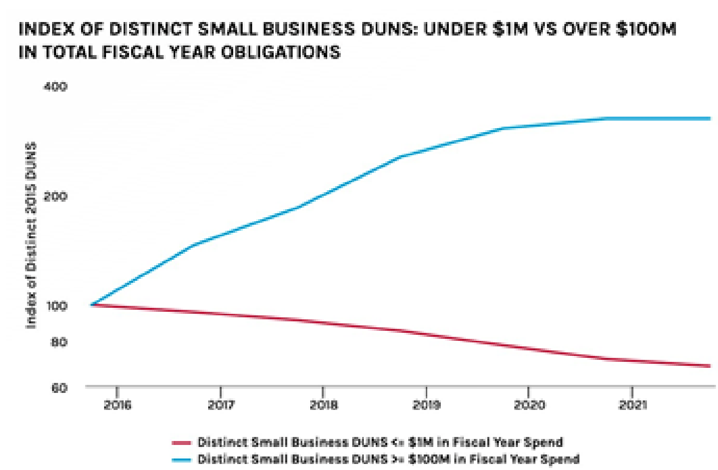

Figure 2. Index of SBs with <$1M DoD Revenue vs. SBs with $100M+ DoD Revenue

Small by What Standards?

The SBA defines an SB based on its average number of employees over the past 12 months or average annual receipts (U.S. Department of State, 2020). In the case of Atlantic Diving Supply, for instance, although it generates billions in DoD revenue annually, it has fewer than 500 employees. Based on its NAICS code, it qualifies it as an SB by SBA standards.[11]

The fact that a company with billions in DoD procurement can qualify as an SB offers one explanation for a relatively few number of SBs consuming a disproportionate share of overall DoD SB spend. Because the sole measure of success for the DoD SB program is whether the DoD awards 23% of prime contract spend to SBs, **enabling certain types of companies to compete as SBs regardless of their revenue incentivizes the DoD to work with—and award large contracts to—these larger SBs. Since the DoD is not incentivized to exceed the 23% set-aside goal, smaller SBs are in turn crowded out of the defense market.** It also creates an easily gameable system whereby a company can outsource aspects of work to teaming partners and subcontractors in order to keep employee headcount artificially low to maintain its SB status despite significant revenue.

Recommendation: Redefine SBs

Current policies, which enable—even encourage—firms with hundreds of millions or billions of dollars in DoD revenue to compete for SB contracts, have created an inhospitable environment for smaller companies. Based on our analysis, it is evident that the system favors the largest SBs at the expense of smaller ones, which runs counter to the stated purpose of the SB Program. Furthermore, the size standards the SBA and DoD apply to government contractors are unreasonable. Most Americans do not consider a company that generates hundreds of millions or billions of dollars in revenue, or a company with a multibillion dollar market capitalization, to be “small.” To the extent Congress and the USG permit procurement policies that afford special treatment to SBs, qualifying companies should, at the very least, *be* small. We therefore recommend that the SBA change the criteria for qualifying as an SB.

Further research is required to determine revenue/employee caps for qualifying as an SB, but as a frame of reference, the average revenue for the largest SBs in the private sector (companies with 100–499 employees) was approximately $41 million in 2007 (Godlewski, 2020). Regardless of NAICS code, revenue, rather than number of employees, should be the primary consideration to qualify as an SB. Employee count is more difficult to track and can be obfuscated through subcontracting/teaming arrangements and/or independent contractors. Additionally, in the age of automation, businesses across sectors can achieve substantial growth without expanding their workforce.

Furthermore, there is a tremendous amount of opacity around size standards in general. The SBA Table of Size Standards is 49 pages long and contains confusing and arbitrary criteria. For instance, NAICS 339112, “Surgical and Medical Instrument Manufacturing,” has an SB size standard of 1,000 employees while NAICS 339113, “Surgical Appliance and Supplies Manufacturing” has a size standard of 750 employees

[11] ADS has faced controversy regarding its SB set-aside status, but ultimately had its SB set-aside status reaffirmed.

(U.S. SBA, 2017). NAICS 448110, “Men’s Clothing Stores,” has a size standard of $12 million in revenue; NAICS 448120, “Women’s Clothing Stores,” has a size standard of $30 million in revenue; and NAICS 448130, “Children’s and Infants’ Clothing Stores,” has a size standard of $35 million in revenue. Firms can and do register for multiple NAICS codes, and the government can also issue waivers to enable companies that exceed these standards to qualify as small. Collectively, these inconsistent, complex, and subjective standards are difficult to enforce, favor entrenched businesses that understand the system and how to maximize it to their advantage, and discourage new entrants. We recommend the SBA engage an independent panel of U.S. demographic experts, data scientists, and industry experts to overhaul and streamline SBA size standards.

Subcontracting in the SB Ecosystem

Because a DoD SB, like a large business, can win a contract as the prime and allocate work to teaming partners and/or subcontractors, we sought to evaluate the effects of subcontracting practices on the SB DIB. Depending on the contract type, there are certain restrictions on how much of the work an SB is permitted to outsource to subcontractors/partners, as shown in Figure 7. **If these requirements are met, SBs can outsource work to subcontractors regardless of size, including large businesses.**

Contract Type	Rule
Services	SB Prime must provide 50%+ of the contract cost for personnel
Supply	SB Prime must perform work for 50%+ of the cost of manufacturing the supplies, not including the cost of materials, unless the business qualifies as a non-manufacturer
General Construction	SB Prime must perform 15%+ of the cost of the contract with its own employees, not including the cost of materials
Specialty Construction	SB Prime must perform 25%+ of the cost of the contract with its own employees, not including the cost of materials
The SB Prime can utilize “similarly situated subcontractors,” or subcontractors with the same required size and SB program status as the SB Prime, to meet these performance requirements.	

Figure 7[12]. SB Subcontracting Limitations

Sizing the SB Subcontractor Industrial Base

To analyze the subcontracting data, we leveraged data from USASpending, which contains information about subcontract awards, including instances in which an entity served as the prime contractor, and how much and to whom it awarded subcontracts. We isolated subcontracting data from USASpending for FY2015–FY2021, where the prime contract award was funded by the DoD and where the prime contractor was a vendor from our DoD SB dataset.

For this analysis, we isolated all prime contractor SBs with at least $10,000 in defense-funded procurement between FY2015–FY2021. Doing so streamlined the data and

[12] These limitations apply to SB set-aside contracts $150K+.

reduced the potential impact of government reporting errors on the results. Of the 76,286 SBs with at least $10,000 in defense-funded procurement, we identified 863 SBs that awarded DoD-funded subcontracts during our analysis period ("SB Primes").

It is important to note that while we were able to associate a subcontract award to its prime contractor and we were able to verify that both prime and subcontract funding came from the DoD, due to computational limitations, we could not link the subcontract action to its specific prime contract award action. To proxy the prime/subcontractor relationships, we linked DoD-funded subcontract awards from FY2015–FY2021 that were affiliated with the 863 SB Primes into our data set.

As shown in Figure 8, these 863 SB Primes received approximately $242 billion in defense funded procurement from FY2015–FY2021. During that same timeframe, they collectively subcontracted ~$91 billion in defense-funded subcontract awards.

Total SB Prime DoD Procurement, FY 2015–FY2021	Total DoD-Funded Outlays to Subcontractors by SB Primes, FY2015-FY2021
$242,013,278,183	$91,171,095,487

Figure 8. DoD-Funded Subcontract Awards Associated with SB Primes

Who Are the Subcontractors?

Next we sought to analyze the universe of companies that performed as subcontractors to DoD SB Primes ("subcontractors"). Filtering the USASpending subcontracting data associated with our SB Primes to isolate unique DUNS, we determined that the 863 DoD SB Primes collectively worked with 13,924 unique subcontractors. At first glance, we recognized many of the world's largest government contractors among the names. Figure 9 provides a snapshot of 10 large government contractors that perform as subcontractors to DoD SB Primes and the DoD subcontracting dollars awarded to them during our analysis period.

Subcontractor Name	Total DoD-Funded Subcontract Awards, FY2015–FY2021
ACCENTURE	$7,427,637
BOEING	$183,412,223
BOOZ ALLEN HAMILTON	$1,326,752,662
DELOITTE	$120,403,176
GENERAL DYNAMICS	$542,271,351
HARRIS CORPORATION	$572,658,238
L3	$861,609,111
LOCKHEED MARTIN	$284,056,045
NORTHROP GRUMMAN	$541,770,770
RAYTHEON	$341,913,820

Figure 9. Snapshot of Large Subcontractors

As evidenced by the revenue generated by these 10 companies through DoD SB set-asides, DoD SB policies benefit the most entrenched government contractors. We were interested in understanding the extent to which other LBs also performed as subcontractors to DoD SB primes. We classified the 13,924 subcontractors in the data as "small" or other than small ("large") using the same approach we employed when classifying

SBs from the overall pool of DoD vendors. However, the process requires the subcontractor DUNS to be associated with a procurement action directly funded by DoD from FY2015 through FY2021—in other words, for us to determine whether a subcontractor was an SB, that subcontractor also needed to have been a prime contractor to DoD from FY2015–2021. Of the 13,924 subcontractors in the data, 6,537 had no associated DoD prime contract awards during the analysis period. Because we were unable to determine the size of these businesses, we labeled them "unknown."

As shown in Figure 10, 2,177 subcontractors—approximately **16% of all subcontractors to DoD SB Primes during our analysis period—were large businesses. Collectively these LBs were awarded more than $24 billion in DoD-funded subcontract awards, which represents nearly 27% of all DoD-funded subcontract procurement from FY2015–FY2021.** Taken as a percentage of the total ~$511.4 billion DoD SB procurement during the same period, **$24 billion represents 4% of DoD SB spend.**[13]

Subcontractor Type	Count	Total DoD Funded Subcontracts from DoD SB Primes, FY2015–FY2021
SMALL BUSINESS	5210	$43,194,628,990
OTHER THAN SMALL BUSINESS	2177	$24,207,193,451
UNKNOWN	6537	$23,769,273,045

Figure 10. Breakdown of Subcontractors to DoD SB Primes, by Business Size

Recommendations: Subcontracting Reforms

There are merits to permitting LBs to subcontract to SBs. The policy allows certain SBs to compete for and win work they would be unable to perform without the assistance of a large, experienced contractor. The streamlined procurement process for set-asides also incentivizes LBs to engage with the SB community, which helps SBs' innovative capabilities reach the warfighter. However, the policy has resulted in LBs receiving a substantial amount of money earmarked for SBs. We therefore recommend that contract dollars that flow through SBs to LBs be excluded from SB procurement goals.

Furthermore, there is no evidence to suggest that current subcontracting policies enable more SBs to participate in the defense market—on the contrary, the SB DIB continues to contract in spite of them. Liberal teaming and subcontracting policies also create opportunities for the largest SBs to partner with one another as similarly situated contractors, making the defense market even harder for smaller SBs to penetrate. Just as

[13] Because we cannot resolve subcontract awards to specific prime contract actions, it is possible that some portion of subcontract awards are associated with prime contract awards that predate our analysis period. It is also possible that some subcontract awards are associated with classified prime contracts wherein the prime contact value is not made public, but certain subcontract procurement data is unclassified. As a result, this calculation is a proxy.

the USG and DoD must reconsider how they define SBs to be more reasonable and aligned with the views of taxpayers, so too must they reassess subcontracting policies.

Subcontracting Data: Limitations & Further Research

Pursuant to FAR 4.1403(a), all contracts that report to FPDS with subcontracts over $30,000 must report first-tier subcontract data. However, from working with the data, we believe that public records pertaining to government subcontract awards are to some extent incomplete and are less reliable than prime contract award data. There can also be significant lags between when the DoD awards a prime contract and when subcontract dollars are outlaid. Further research is required to ascertain gaps in public records for subcontracting data. While we cannot determine how this limitation may affect the efficacy of our results, the broader trends we identified in the subcontracting data provide valuable insights.

Additionally, as shown in Figure 11, when we analyzed the amount of DoD procurement SB Primes awarded to subcontractors from FY2015–FY2021, we found that 37 SB Primes appeared to have outlaid more in DoD-funded subcontract awards than they received in DoD-funded prime contract awards during the same period. In other words, according to the data, from FY2015–FY2021 Torch Technologies had ~$5.5 billion in DoD-funded procurement, yet there were ~$27.2 billion worth of DoD-funded subcontract awards associated with Torch during that same period. Likewise, A&D Fire Sprinklers received ~$8.8 million in DoD procurement but had ~$71 million in affiliated DoD-funded subcontract awards.

SB Prime	Total DoD Procurement, FY2015–FY2021	Total Associated DoD Subcontract Award Outlays, FY2015–FY2021	%Total DoD Procurement Subcontracted
IE-PACIFIC INC	$414,933,772	$3,951,765,106	952.38%
A&D FIRE SPRINKLERS INC	$8,810,415	$71,040,705	806.33%
TECOLOTE RESEARCH INC	$1,423,163,688	$8,269,466,123	581.06%
RA BURCH CONSTRUCTION CO INC	$627,474,597	$3,371,236,769	537.27%
TORCH TECHNOLOGIES INC	$5,583,425,252	$27,207,753,458	487.30%
ADGC BONITA PIPELINE JV	$9,629,749	$42,865,581	445.14%
A&D-DORADO JOINT VENTURE LLP	$14,576,277	$64,534,551	442.74%
NOREAS ENVIRONMENTAL SERVICES LLC	$81,476,858	$335,706,927	412.03%
ASSURANCE TECHNOLOGY CORPORATION	$812,546,967	$3,256,627,173	400.79%
ALUTIIQ GENERAL CONTRACTORS LLC	$103,568,080	$387,876,239	374.51%
ANALYSIS COMPUTING & ENGINEERING SOLUTIONS INC	$32,076,047	$114,361,141	356.53%
STORMWATER PLANS LLC	$50,045,437	$141,033,739	281.81%
WALGA ROSS GROUP 2 JV	$52,833,910	$148,203,722	280.51%
BLACK RIVER SYSTEMS COMPANY INC	$432,776,550	$1,200,501,496	277.40%
1CYBERFORCE LLC	$13,539,676	$36,611,639	270.40%
ALUTIIQ GENERAL CONTRACTORS LLC	$110,308,752	$294,784,776	267.24%
SOLVUS GLOBAL LLC	$227,036	$600,000	264.28%
APTIMA INC	$395,504,344	$972,253,276	245.83%
MUNRO CONSTRUCTION COMPANY INC	$2,478,218	$5,492,610	221.64%

ALUTIIQ CONSTRUCTION SERVICES LLC	$72,611,308	$150,799,451	207.68%
ROSS GROUP CONSTRUCTION CORPORATION	$328,251,640	$665,465,786	202.73%
WALGA ROSS GROUP JV	$175,234,420	$355,115,556	202.65%
A&D GC INC	$74,203,984	$149,927,006	202.05%
ITSTARS2 LLC	$10,163,613	$19,640,936	193.25%
LUKOS-VATC JV LLC	$199,797,768	$347,746,602	174.05%
H F WEBSTER ENGINEERING SERVICES INC	$7,521,910	$12,840,503	170.71%
WALGA MTE LLC	$17,151,826	$26,804,564	156.28%
SHEFFIELD KORTE TEAM LLC	$56,054,522	$85,963,900	153.36%
MILSUP LLC	$12,326,498	$16,891,230	137.03%
ASRC BUILDERS LLC	$360,278,865	$482,793,017	134.01%
ALUTIIQ COMMERCIAL ENTERPRISES LLC	$845,764,485	$1,112,413,698	131.53%
TECH-MARINE BUSINESS INC	$555,375,489	$696,846,588	125.47%
BRISTOL-CANNON JV LLC	$8,550,879	$10,728,642	125.47%
GRACON LLC	$47,128,505	$55,839,532	118.48%
ALUTIIQ MANUFACTURING CONTRACTORS LLC	$36,366,794	$39,115,654	107.56%
ASSURED INFORMATION SECURITY INC	$1,687,968,801	$1,810,475,399	107.26%
AKIMA GLOBAL LOGISTICS LLC	$2,071,751	$2,129,336	102.78%

Figure 11. DoD SB Primes With More in Subcontracting Outlays Than Prime Contract Awards

We contacted 15 of these companies via email indicating that they appeared to have outlaid more in DoD-funded subcontracts than they received in direct procurements and invited them to provide us with feedback and context. Two companies responded, one via email and one by phone. Both simply stated that the figures we cited were inaccurate but offered no further explanation. Despite their feedback, our data is accurate according to USASpending. We also emailed USG points of contact associated with a subset of Torch Technologies' largest subcontract actions in hopes of gathering more information, but we did not hear back. Additionally, we spoke with several DoD contracting experts about these findings. They were surprised by the data and had no clear explanation as to how or why a contractor would outlay substantially more in subcontracts than it received in direct procurements.

Possible theories included administrative errors (government personnel inputting data incorrectly); instances where monies were awarded to a company in an earlier year and used in later years; and/or instances where classified prime contract award data was not in the public realm, but subcontracting data associated with that contract was publicly available. Further research is required to better understand this finding; if, when and why this activity is permitted in prime/subcontractor relationships; reporting practices inside of the government that obfuscate how companies partner and subcontract; and how these practices affect the composition of the DoD SB industrial base. In future research, we would also strive to link subcontract actions with their prime contract.

Consolidation of the SB DIB

As the largest SBs expanded their DoD market share, thousands of other SBs ceased working in the defense market. As previously referenced in Table 3, the number of

DoD SBs shrank nearly 23% from FY2015 to FY2021, from 48,322 to 37,294. While we have concluded that SBA size standards and subcontracting policies favor larger SBs and measuring the success of the DoD SB program based on the share of DoD spend awarded to SBs incentivizes DoD stakeholders to award larger contracts to fewer suppliers, we were interested in understanding other factors contributing to SB attrition from the defense market.

Technical Approach & Research Limitations

For the purposes of our research, we define a company as "leaving" the defense market if it had associated DoD contract actions at one point during our analysis period, but not in the subsequent year(s). For instance, an SB with DoD contract actions in FY2016 and FY2017, but no DoD contract actions from FY2018–FY2021, was treated as "leaving" the DoD market in FY2018.

There are generally four explanations for why a company would no longer appear in the dataset during the analysis period:

- It went out of business entirely.
- It ceased working in the defense market but continued to work commercially.
- It ceased working in the defense market but began working, or continued to work, with other USG customers.
- It was acquired or it merged with another company (and it may or may not continue to support the DoD through this new entity).

We cannot discern which of these explanations applies to an individual SB in our data. We recommend further research to explore the possibility of joining additional data sources for analysis, including non-DoD-funded USG procurement data, to help determine the status of an SB. Irrespective of this limitation, the results of a shrinking SB DIB are the same: a less robust industrial base, with less supplier diversity. The consolidation also undermines the purported economic benefits of the SB program.

Why SBs Leave the DoD: The Cost of Doing Business

One significant factor that has resulted in SBs leaving the DoD market is the rising costs associated with working with defense customers.

In 2020, the DoD implemented the Cybersecurity Maturity Model Certification (CMMC), a mandatory security requirement for contractors and subcontractors. Compliance burdens companies with numerous hard and soft costs. Companies must now devote internal resources for planning, documentation, training, and assessments. Outsourcing an assessment comes with an estimated cost of $15,000–$45,000, and investments to reach requisite certification levels range from $3,000–$100,000 (Dawson, 2021).

New security requirements have also resulted in additional insurance requirements, including new and/or increased professional liability and cyber insurance policies. According to Insureon, an online insurance marketplace for SBs, the median cost for cyber liability insurance for SBs is $1,675 annually ("How Much Does Cyber Liability Insurance Cost?"). Coverage requirements for DoD SBs, however, often far exceed the average. For example, PW Communications is a certified woman-owned SB that has performed on contracts for the Defense Information Systems Agency (DISA) since 2012. In 2020, PW Communications was required to obtain additional professional liability/cyber insurance policies to continue supporting DISA. PW Communications paid $13,576 for these new policies in 2021, and $18,333 in 2022. Robert Chamberlain, the Founder and President of Monterey Technologies, Inc., an engineering firm that has supported DoD customers since the 1980s, estimates that his firm had to invest more than $100,000 over the last 2 years to satisfy new security requirements.

As these costs rise, larger SBs have the ability to absorb them more easily. They further benefit because these costs, which are untenable for smaller SBs, drive competitors out of the market.

Balancing the Risks

While increased security requirements are necessary to respond to evolving threats, the DoD must be cognizant of the impact current and future requirements have on SBs. At a certain point, SBs will not be able to justify the costs, particularly relative to the ease with which they can work in the commercial market. The DoD should consider offset strategies to reduce the cost burdens on SBs.

Shifting Procurement Strategies

Shifts in DoD and Defense Logistics Agency (DLA) procurement strategies over the last decade have also severely impacted the ability for specialized SBs to support DoD customers. In 2012, the DoD and DLA began implementing a contract bundling practice called "Captains of Industry" (COI) that involves awarding multi-year, multi-billion dollar sole-source contracts to large Original Equipment Manufacturers (OEMs) and large aerospace integrators. These contracts bundle a large number of National Stock Numbers (NSNs) that were historically purchased individually into one single contract. The intention of the COI program was to deliver cost savings, value, and other benefits to the DoD (DoD IG, 2021). According to a February 2021 DoD Office of Inspector General (IG) report along with a study conducted by the Small Business Aerospace Industrial Coalition (SBAIC), there is no indication that COI bundling policies have yielded cost savings or on-time deliveries (Small Business Aerospace Industry Coalition, 2021).

COI has, however, rerouted millions in DoD contract dollars from components manufacturers and other SBs to large integrators and OEMs. **The IG report estimates that SB participation has declined by 61% in the COI program**. SBAIC has reported that many of its 200 member companies—which have gross revenue under $20 million and specialize in manufacturing and supplying military aerospace spare parts, components, and assemblies—have been financially devastated as a result of these bundling policies. Several have gone out of business entirely, with others on the brink of bankruptcy.

Other factors that inhibit small and nontraditional companies' ability to succeed in the defense market, which we identify and explore in earlier research, include but are not limited to:

- Complex, anticompetitive solicitation processes: It is extremely difficult for companies to identify relevant requirements due to the design of SAM.gov. If and when companies find relevant opportunities, the majority of DoD solicitations require responses within 21 days of when they are published, and the vast majority of these solicitations/requirements are not written clearly (Bresler & Bresler, 2021).
- Redundant requirements: USG/DoD stakeholders do not coordinate outreach efforts. As a result, dozens and sometimes hundreds of distinct stakeholders solicit the same capabilities concurrently. SBs cannot participate in all of them and have limited ability to prioritize them.
- Lack of awareness across the DoD about what capabilities SB suppliers possess: DoD stakeholders rely on certain suppliers because they do not know that other

qualified vendors exist–even if these alternative vendors already support other defense customers.

Simply limiting competition for certain contracts to SBs does not address these underlying issues. **Until the SBA, DoD, and USG address them, the defense market will continue to prove inhospitable for non-entrenched suppliers.** The fact that the procurement process, even for set-aside contracts, disproportionately benefits companies with institutional knowledge of the system also means that the DoD ends up awarding contracts to SBs that understand the system, rather than companies with the "best" or most competitive offering—particularly considering the DoD is *obligated* to award a certain percentage of annual procurement to SBs. **Thus, just as SB policies contribute to the *failure* of some SBs, they also prop-up certain companies that would and/or should naturally go out of business.** Permitting SBs to evade full and open competition for certain opportunities, in general, is also the opposite of "preserving free competitive enterprise." With a portion of the market excluded from the competitive process, SBs are not incentivized to innovate and/or reduce costs in ways they would be if free market forces were at work.

Conclusions

Rather than "leveling the playing field," government set-aside policies enrich the largest SB vendors and fail to benefit the groups they were designed to serve. They afford preferential treatment to entities that understand the system and how to maximize it to their advantage. As these entities consolidate power, they can withstand the costs and procedural challenges that keep smaller, would-be competitors from succeeding. Compounding these issues is the fact that arbitrariness, opacity, and lack of standardization around USG and DoD size-standards make it difficult to evaluate the results of the set-aside program in general.

While this paper focuses on the SB program broadly, the issues we identified become more acute in the context of set-aside policies for companies that qualify for preferential treatment in the procurement process based on other USG-defined criteria, such as where the business is located and the socioeconomic and/or demographic features of a company's owners. **These initiatives do not make it easier for members of set-aside communities to navigate the defense market on a practical level. Instead, they create new, increasingly insulated/anticompetitive avenues for entities well-versed in government contracting to exploit the system.**

In conclusion, **until the real challenges keeping small and nontraditional companies from succeeding in the public sector are addressed, the DoD and USG must award contracts based on technical merit, innovativeness, price, and ability to perform**—not based on the size of a company or the demographic features of its owners. They must rigorously analyze the composition of the industrial base on an ongoing basis using consistent, verifiable data; and commit to addressing the underlying causes if and when certain types of businesses are underrepresented.

References

Bresler, A., & Bresler, A. (2021). *Why marketing matters: Strengthening the defense supplier base through better communication with industry*. https://dair.nps.edu/bitstream/123456789/4404/1/SYM-AM-21-097.pdf

Dawson, S. (2021, November 12). *The costs of CMMC: What to expect*. Core Business Solutions. https://www.thecoresolution.com/the-costs-of-cmmc-what-to-expect#:~:text=Official%20assessment%20costs%20have%20yet,final%20cost%20area%20is%20maintenance

Department of Defense Office of Inspector General. (2021, February 11). *Audit of the Defense Logistics Agency's sole source captains of industry strategic support*. https://www.dodig.mil/reports.html/Article/2503562/audit-of-the-defense-logistics-agencys-sole-source-captains-of-industry-strateg/

Dilger, R. J., & Blackford, R. C. (2022). *An overview of small business contracting*. Congressional Research Service. https://sgp.fas.org/crs/misc/R45576.pdf

Godlewski, N. (2020). *Small business revenue statistics (2021): Annual sales and earnings*. Fundera. https://www.fundera.com/resources/small-business-revenue-statistics

Insureon. (n.d.). *How much does cyber liability insurance cost?* https://www.insureon.com/small-business-insurance/cyber-liability/cost#:~:text=Cyber%20liability%20insurance%20costs%20for%20Insureon%20customers&text=Many%20small%20business%20owners%20

Schwellenbach, N., & Szakonyi, D. (2020, August 3). *Whistleblowers said this company is a fake small business. It got a PPP loan*. Project On Government Oversight. https://www.pogo.org/investigation/2020/08/whistleblowers-said-this-company-is-a-fake-small-business-it-got-a-ppp-loan/

Small Business Aerospace Industry Coalition. (n.d.). *Aerospace components*. https://www.sbaic.net/

Small Business Aerospace Industry Coalition. (2021). *Contract bundling and micro-purchasing thresholds*. https://drive.google.com/file/d/1BMClSufprUnIA3GXZlAuatNiOU3iPYWn/view

Temin, T. (2021, May 24). What Atlantic Diving Supply says about itself and its DLA contract. *Federal News Network.* https://federalnewsnetwork.com/contracting/2021/05/what-atlantic-diving-supply-says-about-itself-and-its-dla-contract/

U.S. Army Corps of Engineers. (n.d.). *Small business program guide for ... - United States Army.* https://www.mvr.usace.army.mil/Portals/48/docs/SB/SBPGuide.pdf

U.S. Congress. (2006). *Federal Funding Accountability and Transparency Act of 2006*.

U.S. Congress. (2021). *Small Business Act and Small Business Investment Act of 1958*. https://www.govinfo.gov/content/pkg/COMPS-1834/pdf/COMPS-1834.pdf

U.S. Department of State. (2020, December 1). *What is a small business?* https://www.state.gov/what-is-a-small-business/

U.S. Small Business Administration. (n.d.-a). *Set-aside procurement*. https://www.sba.gov/partners/contracting-officials/small-business-procurement/set-aside-procurement#:~:text=General%20construction%20contracts%3A%20The%20small,including%20the%20cost%20of%20materials

U.S. Small Business Administration. (n.d.-b). *Types of contracts*. https://www.sba.gov/federal-contracting/contracting-guide/types-contracts

U.S. Small Business Administration. (2017). *Table of small business size standards matched to North American Industry Classification System codes*. https://www.sba.gov/sites/default/files/2019-08/SBA%20Table%20of%20Size%20Standards_Effective%20Aug%2019%2C%202019.pdf

PANEL 4. BUILDING AND SECURING THE FLEET

Wednesday, May 11, 2022	
9:40 a.m. – 10:55 a.m.	**Chair: Rear Admiral Tom J. Anderson, USN, Program Executive Officer, Ships** ***A Case for Continuous Concept Development in Ship Design*** Jonathan Page, OPNAV N96 ***Labor Market Impacts on Navy Shipbuilding & Fleet Efficiency*** Billy Fabian, Govini Dr. Jen Gebhardt, Govini

Rear Admiral Tom J. Anderson, USN—is a native of North Brunswick, New Jersey. He was commissioned in 1991 through the Naval Reserve Officer Training Corps (NROTC) Program at Boston University where he received a Bachelor's of Science degree in Mechanical Engineering.

Anderson's tours as a Surface Warfare Officer included USS Capodanno and USS Arleigh Burke, where he coordinated the first two Chief of Naval Operations availabilities of the DDG 51 Class.

Upon selection to the Engineering Duty Community in 1996, he attended the Naval Postgraduate School where he earned a Master's of Science degree in Mechanical Engineering. He also completed the Total Ship Systems Engineering Curriculum and became a California State Licensed Professional Engineer.

Ashore, he has served in a variety of industrial, fleet, program office and headquarters assignments in ship design and construction, maintenance, budgeting, and requirements. His ashore assignments include: Naval Sea Systems Command executive assistant; Littoral Combat Ship Shipbuilding program manager; Office of the Chief of Naval Operations requirements officer; chief engineer and post-delivery branch head for the DDG 51 Class; and Commander, Naval Surface Forces, Atlantic, mine warfare type desk officer.

Anderson's first flag assignment was commander, Naval Surface Warfare Center, leading more than 17,000 scientists, engineers, technicians and support personnel, providing research, development, test and evaluation for the future Navy as well as in-service engineering and logistics support for the operational naval forces. Anderson also served as the Department of Defense executive manager for Military Explosive Ordnance Disposal Technology and Training, with oversight responsibilities for joint military EOD systems and training.

Most recently, Anderson served as the commander, Navy Regional Maintenance Center and Naval Sea Systems Command director, Surface Ship Maintenance and Modernization. He was responsible for managing critical ship modernization and maintenance, training, Foreign Military support contracts, and inactivation programs.

Currently, Anderson is serving as program executive officer, Ships, where he is responsible for Navy shipbuilding for surface combatants, amphibious ships, logistics support ships, support craft, and related foreign military sales.

Anderson's personal awards include the Legion of Merit (four awards), Meritorious Service Medal (three awards), and Joint Service Commendation Medal. He is a member of the Acquisition Professional Community with Level III certifications in Program Management, Production Quality Management, and Systems Engineering.

A Case for Continuous Concept Development in Ship Design

Jonathan Page, CDR, USN—is an Engineering Duty Officer currently serving as Future Ships Requirements Officer in the Surface Warfare Directorate on CNO's staff (OPNAV N96F3A1). His previous tours include Deputy Ship Design Manager for DDG(X), Associate Professor of the Practice at MIT, OIC of Supervisor of Shipbuilding Bath Detachment San Diego, and the DDG 1000 program office. He is currently pursuing an interdisciplinary doctorate in Design Engineering from MIT. [Jonathan.e.page.mil@us.navy.mil]

Abstract

Prevailing in a competition, especially a strategic competition, requires agility greater than your competitor. This agility is needed across the spectrum of operations, including acquisition, but the current acquisition process takes at least ten years to deliver modern, relevant ships to the Fleet. A measurable portion of this time is spent in the early stages with Capability-Based Analyses, Analyses of Alternatives, and conceptual designs. These analyses and concepts are often less relevant at the vessel's delivery because of the added time for preliminary design, concept design, detail design, and construction. As an alternate approach, this paper suggests using a continuous analysis process coupled with Set-Based Design methods, just as Toyota did, to reduce these timelines and have relevant concepts ready to transition to design and construction, potentially cutting the cycle time for ship design in half.

Introduction

Today, the U.S. Navy finds itself in a strategic competition with peer adversaries that desire to upset the existing rules-based international order (Office of the Secretary of the Navy, 2020, 2021). The Navy realizes this requires multi-pronged strategies that encompass everything from technology development to tactical training and that they must execute these strategies with speed and purpose (Kitchener et al., 2021; Office of the Chief of Naval Operations, 2018; Office of the Secretary of the Navy, 2020).

Maintaining this competitive edge poses intriguing challenges. Technology advances at a blistering pace, but all ships are significant capital investments with long service lives, complicating the ability to outfit all ships with the most modern equipment. Further, it is not just our technology that advances, but that of adversaries and competitors—who get a vote in the required capabilities of our fleet. Some of those competitors have capable first-rate navies and seek to challenge existing conventions reaching far beyond their territorial seas (Commander Naval Surface Forces, 2021). Therefore, since technology and requirements change before, during, and after constructing a capital ship, adapting and responding to change faster than competitors is probably better than trying to out-build them.

Additionally, the challenges facing the Navy are multiplicative and non-linear. Maintaining a competitive edge would be difficult enough if the geopolitical landscape changed quickly and the Navy responded to new threats in new locations. It would be difficult enough if technology continued to change at its current rate and we had to maintain or exceed its pace. It would be difficult enough if laws required better environmental stewardship from our designs. It would be difficult enough if the mission requirements for the Navy from Combatant Commanders continued to grow across the spectrum from peacetime, deterrence, and power projection to hostilities, and the Navy had to do its best to fulfill them all. It would be difficult enough with the Budget Control Act, flat investment accounts, and Continuing Resolutions for over a decade. It would be difficult enough to consider that vessels tend to stay in service for 20 years and more and that the requirements and use of surface vessels will change in that time frame. However, the U.S. Navy must address all these with its existing fleet of fewer than 300 ships and the fleet we are investing in today. According to the Fiscal Year 2021 shipbuilding plan, the Navy will add between nine and 20 ships per year to the battle force count (Office of the Chief of Naval Operations, 2020).

Designing and delivering a warship is a complex undertaking. It is appropriate to think of a warship as a system of systems since it manifests as the integration of hull, mechanical, electrical, communications, combat, life support, habitability, navigation, and other systems; each managerially or operationally independent but functionally codependent (Walden et al., 2015). Each of these systems interfaces with the others and is tightly coupled in the design solution. Many combat and communications systems are complex enough to be independent acquisition programs within Joint Capabilities Integration and Development System (JCIDS), Defense Acquisition System (DAS), and Planning, Programming, Budgeting and Execution (PPBE). Ship classes often warrant a bespoke design with efforts exceeding one million hours. Nevertheless, even the ship classes that are not new or unique and borrow many characteristics from an existing ship class take just as long and require as many resources because of the complicated interdependencies of the parts of a ship. The third flight of the Arleigh Burke Class destroyer, the new Constellation Class frigate, and large deck amphibious ships present recent examples of this phenomenon (Dodaro, 2021).

Despite these myriad challenges, the Navy and its acquisition workforce continue the work to deliver necessary platforms and capabilities to the fleet to conduct its enduring roles of sea control, power projection, deterrence, maritime security, and sealift in support of the rules-based international order. In 2017, the Navy conducted a Capabilities-Based Assessment of its Future Surface Combatant Force, including large surface combatants, small surface combatants, and uncrewed vessels. This analysis resulted in an approved Initial Capabilities Document (ICD) in 2018 for the combatant forces. In recognition of the current and future uncertainty germane to investments of large capital ships, the Navy designated flexibility as a top priority for the future fleet. That same year, the Navy conducted a Requirements Evaluation Team (RET) to allocate appropriate requirements from the ICD to the large surface combatant, now known as DDG(X). The Chief of Naval Operations (CNO) approved the initial parameters from that study's results, asking the community to continue challenging the requirements and better understand the cost-capability trades of the design space. He also requested completion in time to award a detail design contract within five years, by 2023 (Office of the Chief of Naval Operations, 2018).

Under the circumstances, those charged with continuing the requirements and design efforts chose to use set-based methods to accomplish their task. They anticipated a need to utilize this concurrent engineering approach to manage the complexity and knowledge creation of the undertaking efficiently. They recognized they needed a different process with different toolsets to bring together a diverse national team of talent from government and industry. They knew status quo ship design methods would not adequately analyze and value architectural decisions and features that intentionally incorporated adaptability and robustness in balance with other requirements efficiently and affordably.

Their set-based process is an extendable case study with transferrable knowledge points to inform similar activities early in a ship's life cycle. Reducing the time while increasing the rigor of these early stages can play an essential part in delivering necessary capabilities to warfighters at the speed of relevance instead of ship acquisition.

Set-Based Design

The first known introduction of set-based design came from Ward's doctoral dissertation involving the design of a notional power train using catalog parts (Ward, 1989). Since then, the concept of SBD, as an alternate to point-based design (PBD), proliferated in research and practice (Toche et al., 2020). When researchers studied Toyota, they found success that seemed paradoxical: delaying decisions made better cars faster than the competition (Ward et al., 1995). They concluded that Toyota's design and development system contributed to the company's success in important ways distinct from its production system (Sobek II et al., 1999). Those investigators coined the term set-based concurrent engineering, which many people now refer to as SBD.

These principles first transferred to the naval engineering domain with Singer's dissertation (Singer, 2003). Singer introduced the SBD method to the Navy at a Society of Naval Architects and Marine Engineers (SNAME) Ship Design Committee meeting in June 2007 (Singer et al., 2017). This introduction led to a policy memorandum from the Commander of Naval Sea Systems Command outlining high-level goals to establish relevant toolsets and capabilities to conduct SBD for early phases of ship design (Naval Sea Systems Command, 2008). This policy inspired a summary article introducing SBD to the naval engineering community (Singer et al., 2009). These actions sparked several follow-on academic investigations. Frye applied the principles to a submarine design (Frye, 2010). Gray expanded the domain by testing the use of fuzzy logic systems to introduce uncertainty in the design space (Gray, 2011). Hannapel developed a new multi-disciplinary optimization algorithm inspired by SBD principles (Hannapel, 2012). McKenny extended the decision support framework for managing large-scale teams (McKenney, 2013). The principle also inspired practical applications in naval vessels' early-stage design and requirements generation. The Ship-to-Shore Connector program provides the first example of SBD in the U.S. Navy (Mebane et al., 2011). The Amphibious Combat Vehicle for the U.S. Marine Corps (Burrow et al., 2014) and Small Surface Combatant Task Force (Garner et al., 2015), which led to the Constitution-class frigate, followed soon after. This knowledge, and more, created a Technical and Research Bulletin to help guide naval engineers in the practice of SBD (Singer et al., 2017).

In essence, SBD is a design method that uses sets of alternatives to reason about the design space instead of iterating on point solutions. Reasoning using sets allows the designer to account for options, variations, ranges, uncertainty, and other aspects that do not exist in point solutions. The sets exist at every level of abstraction in the design structure at which a designer must consider options, variation, ranges, or uncertainty. Reasoning using a set allows the designer to consider elements of the set that are infeasible and remove those portions from further consideration, avoiding unnecessary analyses. Subsequently, they can consider dominant solutions. Domain boundaries do not limit either consideration because of the intersections inherent in the sets. In other words, if appropriate, one domain may remove a portion of another domain's trade space if the intersection of the two domains dictates that outcome. Similarly, dominance is a system issue and must consider impacts on intersecting sets for conceptual robustness; dominance within a domain is neither necessary nor sufficient for selection in the global design space. The SBD method converges to the final solution by systemically removing inferior alternatives from further consideration.

At its core, SBD reduces design risk by removing elements from the design space vice selecting them. In SBD, the design team eliminates portions of the design evaluated as infeasible or dominated. These decisions withstand scrutiny because infeasibility is highly unlikely to change with time. Therefore, the team can accommodate new information, including requirements changes, in less complicated ways. Further, these types of decisions can be made on partial information; if one domain declares a portion of the design space infeasible, that portion is infeasible for all domains. This aspect means domains can work semi-autonomously to develop and analyze their sets, enabling a dispersed team to progress. SBD minimizes rework and incurs less technical risk in the product by delaying decisions until options are proven feasible. In contrast, PBD selects each element and characteristic at the beginning of the process, when the least amount of design information is known. This method effectively rules out thousands or millions of potentially dominant solutions and with much less justification documented. This method expects rework, iterating around this design point through each domain in succession to reach a converged design. In other words, it expects that one will select the wrong point at the beginning, in contrast to SBD, which endeavors to remove these points at the last responsible moment.

In their breakthrough article, Ward et al. (1995) listed the advantages they saw in the seemingly paradoxical SBD approach at Toyota:

1. Enabling reliable, efficient communication.
2. Allowing for greater parallelism in the process, with more effective, early use of sub-teams.
3. Basing the most critical, early decision on data.
4. Promoting institutional learning.
5. Allowing for a search of globally optimal designs.

Therefore, SBD is most appropriate when a design project has: 1) a large number of design variables, 2) tight coupling among those variables, 3) conflicting requirements, 4) flexibility in those requirements allowing for trades, and 5) required learning for a solution (Singer et al., 2017). These characteristics accurately describe the environment of early-stage naval vessel design activities.

Early-Stage Acquisition and Design of Ships

Ship design and acquisition count as major capability acquisitions and follow the two-pass seven-gate process (Office of the Secretary of the Navy, 2019). Each program is tailored into the system at the appropriate gate and milestone according to its maturity. Tailoring a program into a stage in the middle or end of the DAS does not relieve it of the products necessary at previous stages. Each platform still requires the equivalent of a Capability-Based Analysis (CBA), Analysis of Alternatives (AoA), Capabilities Development Document (CDD), and many other statutory and relevant products. Ship acquisition programs constantly tailor the process to remove low-rate initial production and engineering development models (EDM) at the system level: when appropriate, the programs produce EDMs for subsystems.

The acquisition system provides rigor to the process to deliver the right capabilities to the warfighters, but not in a necessarily timely manner. As of 2020, 44 programs that had achieved Initial Operational Capability (IOC) averaged almost 115 months to reach that milestone, and 35 other programs that had yet to complete IOC had an average planned time of more than 130 months (Dodaro, 2021). To put a fine point on this, from the time the DoD makes a Material Development Decision to delivering the first useable article has traditionally taken almost 10 years, on average. Shipbuilding programs exceed this average, as construction times tend to be considerably long (Dodaro, 2021). For instance, the Navy started the program for the USS *Gerald R. Ford* (CVN 78) in June 2000, awarded the construction contract in September 2008, delivered in May 2017 (Dodaro, 2021), with IOC in December of 2021 (*Navy League 2022*, 2022). Even the Arleigh Burke-class destroyers, with decades of learning on the 68 delivered ships and the current backlog of 18, take at least five years from fabrication start to delivery (Dodaro, 2021). Many factors affect these timelines such that substantial improvement to construction timelines may be limited. The phases of the acquisition life cycle before production decisions and detail design awards provide a better opportunity for decreasing the overall timeline.

The ship design team's phases line up with the acquisition process, albeit tailored due to the complexity of the undertaking and the end product. The Concept Design phase aligns with CBAs, AoAs, and pre-Milestone A activities. Concept Design is sometimes broken down into pre-AOA, AoA, and Pre-Preliminary Design. As the name implies, in this phase, designers are creating concepts used in analyses to perform the CBAs and AoAs and develop a draft CDD. They are sometimes as simple as baseball card-like sets of characterizations. They may be as complex as a balanced ship concept design with a hull form, arranged systems, and performance characteristics validated with physics-based models. After Milestone A, the Preliminary Design (PD) phase follows a system engineering process to allocate requirements to systems and establish a baseline for the System Functional Review (SFR). After the SFR, the Contract Design (CD) phase allocates the functions to systems and creates a technical data package for contract award. This phase culminates in the Preliminary Design Review (PDR) before Milestone B. After Milestone B, the Navy awards a Detail Design and Construction (DD&C) contract to a shipbuilder. Detail Design efforts culminate in the Critical Design Review (CDR) with the shipyard, typically a precursor to starting construction.

The design phases of a ship's acquisition contribute to the cycle time between an MDD and IOC. Selected Acquisition Reports (SAR) and data from 12 non-nuclear surface programs help relate this. SARs from T-AO, LHA 8, LPD 17, FFG 62, LCS, DDG 1000, and DDG 51 were available. Note that the SARs for LPD 17 and DDG 51 contained data for their Flight upgrades, also, and these were considered classes of their own for purposes of the analysis. Additionally, data regarding the Coast Guard's Icebreaker program and knowledge of DDG(X) filled in the data set. The analysis reveals that the average time for concept design activities is 41 months, PD activities are 16 months, and CD activities are 18 months. Thus, on average, we spend almost five years establishing a baseline and then a year-and-a-half producing the ship specifications and project peculiar documents, timelines that rival those of DD&C. Coupled with this, concept design activities average more than $80 million, PD averages approximately $290 million, and CD averages more than $650 million. Certain ship classes could be considered outliers in this data set, even though it is relatively small, specifically LCS and DDG 1000. When treating those classes as outliers, the concept design average increases to $100 million, while the PD average falls to about $120 million, and the CD average drops to about $150 million. Table 1 summarizes these results, rounded to the nearest month or million dollars.

Table 3: Summary of SAR Analysis

	Concept Design Time (months)	Concept Design Cost ($M)	Preliminary Design Time (months)	Preliminary Design Cost ($M)	Contract Design Time (months)	Contract Design Cost ($M)	Sum (months)	Sum ($M)
Class Average	41	84	16	290	18	650	75	1,024
With Removing "Outliers"	46	100	16	119	16	148	78	367
Class Median	45	67	17	72	18	84		

The table presents the data in aggregate without giving the individual source data. This is appropriate since each program has a unique story, and the Navy tailored its acquisition activities accordingly. Therefore, presenting individual data may distract from the larger picture that regardless of the acquisition story, today's design process paradigm requires considerable time and money. Further, some stories that create long design times or higher costs matter, so the table presents both average and median values. The higher averages in PD and CD tend to align to acquisition stories with EDMs and land-based test sites, practices that still hold value for some future ship classes.

When collating the design phases with the DD&C phase, the average ship delivery happens about 13.5 years after an MDD. Therefore, if one assumes two years of operational test and evaluation, it takes more than 15 years to deliver a capability to the fleet once the material need is identified. This is insufficient considering the pace of change in the world coupled with strategic competition.

Ship acquisition activities before Milestone B have other important characteristics in the aggregate. One is that they take a project-by-project approach. When the Navy completes an MDD, a team organizes to start executing the rest of the process. This project-by-project approach limits the ability for learning, especially Enterprise learning. Further, this project-by-project approach tends to generate knowledge specific to that ship class. There is no incentive for a program to investigate anything outside its requirements. This can lead to behavior where new requirements get piled into new ship classes, driving costs higher and scheduling longer since no previous efforts created transferrable knowledge. Further, the initiation of a program is challenging and inconsistent. Some programs stand up immediately after an MDD; some do not stand up until after CBAs and AoAs. This means engineers and designers conduct these early-stage activities with little and sometimes no acquisition inputs. Some new ship programs are assigned to existing program offices already in production, which stretches the bandwidth of those personnel further since, typically, no personnel are added for this tasking. Therefore, a second-order effect is their loss of focus on the ships in production or fleet introduction. Part of this effect derives from the alternative scope, language, and outcomes from the early-stage efforts that are inherently different than those of detail design, construction, delivery, and transfer.

The project-by-project approach creates other second-order effects, also. One is that Enterprise issues like arctic, flexibility, model-based system engineering, digital engineering, and automation are challenging to fund unless tied to a program and its requirements. Another effect is that although the Navy desires to engage our industry partners early, few contract vehicles are appropriately suited and dedicated to accomplishing this. In general, the project-by-project approach does a poor job of managing and level-loading the naval engineering workforce of the nation. The same is true for the toolsets they use.

The process DDG(X) used over the last four years provides a framework that addresses some of these issues with its SBD methodology. It provided frequent and meaningful engagement regarding cost capability trades with the resource sponsor and was adaptive to changes and queries. It created reusable knowledge for use in processes and future design efforts. The design team proved SBD could scale to a system of systems level, making it appropriate to apply to these other early-stage efforts. The Small Surface Combatant Task Force (SSCTF) also employed SBD to help generate the requirements. However, successful SBD cannot be executed project-by-project; it must be continuous and enduring to reap its rewards fully. One such idea to implement these ideas and avoid some of the current pitfalls of early-stage ship acquisition efforts is Collaborative, Enduring, Concepts and Tools (COLLECT).

Collaborative, Enduring Concepts and Tools (Collect) and the Analytic Engine

COLLECT proposes invigorating the early-stage activities of non-nuclear surface ship programs in a framework called the Analytic Engine. It envisions creating more robust connections between the various early-stage activities like Naval Capabilities Integration Process From The Sea (NCIP-FTS), Future Surface Combatant Force (FSCF) Analysis, and others.

The engine also seeks to invigorate the national engineering workforce and bolster concept design work to inform the other analyses in collaboration with our national partners. The national engineering workforce includes vendors, shipyards, industry partners, contract support, warfare centers, the S&T enterprise, academia, and other appropriate performers and stakeholders. It will take lessons learned from the concept design work on DDG(X) and extend them to the surface enterprise. In doing so, COLLECT can continually provide viable concepts to other studies like NCIP And FSCF. These concepts will have known cost-capability trades and be ready for program transitions between phases.

The analytic engine is the collection of all these activities (NCIP, FSCF, COLLECT, and others) acting in concert to create defendable requirements and resourcing decisions. The engine operates continuously; it is enduring. Each execution year, the engine will run analysis cycles and develop knowledge instead of waiting for the next MDD. The studies intend to continuously validate the CBA and resultant ICDs, updating them appropriately based on new information from appropriate sources. The continuous concept design work can also feed continuous AoA studies on an annual cycle in line with PPBE. The continuous concept design work requires continuous development of tools to support that work.

Notably, the proposal centralizes these activities within an organization. This organization is notionally a program office that is staffed with acquisition professionals to establish contracts, execute funding, institute systems engineering rigor with configuration control, and consider sustainment and testing early in these concept phases. Centralizing the early design activities in one organization allows for better institutional learning. It provides a logical proponent for the Enterprise issues like arctic capabilities, automation, and digital engineering. It also develops a workforce trained in the early stages to complement and interact with those better trained for Milestone B and subsequent activities. Transitions from the early-stage program office to the later-stage program offices would be tailored by the programs between Milestone A and Milestone B.

Connecting the Proposal with the Problem

The fundamental problem statement presented here is the time and cost of warship acquisition in an era of Strategic Competition. On average, the cycle time of a ship class from MDD to IOC is more than 15 years, which allows too much time for technology development, obsolescence, and adversary advancement and adaptation. Further, the cost of the platform development averages over $1 billion, and even when removing outliers that affect the average exceeds $360 million in research money to get a program to detail design and construction. Partitioning the timeline to view the pre-Milestone B problem reveals 78 months, with most of that spent pre-Milestone A. This means each program, on average, spends over $55 million per year on pre-Milestone B activities.

The analytic engine and COLLECT attempt to tackle both metrics. First, continuously executing CBAs, AoAs, and concept development naturally decreases the time those take. Ideally, when the engine is at its “Full Operational Capability,” these efforts replace the project-by-project CBAs and AoAs, effectively having outcomes “on the shelf” and validated with appropriate stakeholders. Thus, by continuously conducting these efforts and continuously generating the concept designs that feed them, the timelines for pre-Milestone A can theoretically shrink to zero. But whether the process reaches its theoretical limit or not, the practice will train a workforce prepared to execute those activities more efficiently, especially with the learning gained from continuously executing them. Thus, 12 months is a reasonable estimate for the timeline under these circumstances. These efficiencies carry forward into PD and CD since the knowledge created in a set-based method for the concepts carries forward into those phases. Further, tool and workforce development can organically bolster these phases with ship specification updates and other baseline transition work. Therefore, the PD and CD phases should also shorten because of the analytic engine and COLLECT efforts. A 33% reduction in those phases seems reasonable and cleanly estimates each phase pre-Milestone B as about 12 months. This could create a scenario in which an idea could be ready for detail design within 36 months, on average, instead of 78, cutting this time more than half.

With shipyard involvement in these phases, including establishing digital threads, there are potential schedule savings in detail design, but those effects are much more difficult to predict.

Second, the analytic engine and COLLECT address the cost metric. It is pre-decisional to release actual numbers, but they are less than the average cost the Navy incurs today—per ship class—for these efforts, representing a fiscal return on investment in the long run. This steady funding creates steady work for the ecosystem of naval engineering, though, which is an added return on investment, one that is less easy to quantify.

Further, the efforts address the other stated issues with pre-Milestone A activities. An organization dedicated to these activities allows for institutional learning. That organization can also assume responsibilities for engaging the entire ecosystem of naval engineers, from shipyards and combat system vendors to the science and technology enterprise and academia. Using SBD for the concepts makes them more robust to change and can also make them more flexible to it.

Summary

Set-based design, as executed at a system of systems scale on DDG(X), provides a framework for continuous concept development of naval vessels. The concept of set-based design for an enterprise requires its continuous employment. This paper proposes that construct and offers potential benefits achieved from its implementation. The Navy can also extend the framework beyond concept design work to CBA and AoA work to continuously create reusable knowledge in those activities. Collectively, this construct can reduce the cycle time of the development of our ships, helping to ensure they stay relevant and better accommodate the rapidly changing world in an era of Strategic Competition.

References

Burrow, J., Doerry, N., Earnesty, M., Was, J., Myers, J., Banko, J., McConnell, J., Pepper, J., & Tafolla, T. (2014). Concept exploration of the amphibious combat vehicle. *Day 1 Wed, October 22, 2014*, D011S001R007. https://doi.org/10.5957/SMC-2014-T19

Commander Naval Surface Forces. (2021). *Surface warfare: The competitive edge* (p. 22) [Commander's Intent]. Department of the Navy. https://www.surfpac.navy.mil/Portals/54/Documents/CNSP/SNA/SNA-2022/Competitive-Edge-Paper-Approved-Dec-20th.pdf

Dodaro, G. (Ed.). (2021). *Weapon system annual assessment*. Government Accountability Office.

Frye, M. C. (2010). *Applying set based methodology in submarine concept design* [Thesis, Massachusetts Institute of Technology]. http://dspace.mit.edu/handle/1721.1/69214

Garner, M., Doerry, D. N., MacKenna, A., Pearce, F., Bassler, D. C., Hannapel, D. S., & McCauley, P. (2015). *Concept exploration methods for the small surface combatant*. 10.

Gray, A. W. (2011). *Enhancement of set-based design practices via introduction of uncertainty through the use of interval type-2 modeling and general type-2 fuzzy logic agent based methods* [PhD, University of Michigan]. https://www.proquest.com/docview/896357950/abstract/2532E937DE1946D4PQ/19

Hannapel, S. E. (2012). *Development of multidisciplinary design optimization algorithms for ship design under uncertainty* [PhD, University of Michigan]. https://www.proquest.com/docview/1268742764/abstract/9A3C2528509442F9PQ/3

Kitchener, R., Cooper, B., & Schlise, P. (2021, January 6). *What got us here won't get us there*. U.S. Naval Institute. https://www.usni.org/magazines/proceedings/2021/january/what-got-us-here-wont-get-us-there

McKenney, T. A. (2013). *An early-stage set-based design reduction decision support framework utilizing design space mapping and a graph theoretic Markov decision process formulation* [PhD, University of Michigan]. https://www.proquest.com/docview/1499244175/abstract/190F38E60D564EE2PQ/1

Mebane, W. L., Carlson, C. M., Dowd, C., Singer, D. J., & Buckley, M. E. (2011). Set-based design and the ship to shore connector: Set-based design. *Naval Engineers Journal*, *123*(3), 79–92. https://doi.org/10.1111/j.1559-3584.2011.00332.x

Naval Sea Systems Command. (2008). *Ship design and analysis tool goals*.

Navy League 2022: Carrier Ford reaches IOC while keel is laid for Enterprise. (2022, April 6). Janes.com. https://www.janes.com/defence-news/news-detail/navy-league-2022-carrier-ford-reaches-ioc-while-keel-is-laid-for-enterprise

Office of the Chief of Naval Operations. (2018). *A design for maintaining maritime superiority* (2.0). Department of Navy. https://media.defense.gov/2020/May/18/2002301999/-1/-1/1/DESIGN_2.0.PDF

Office of the Chief of Naval Operations. (2020). *Report to Congress on the annual long-range plan for construction of Naval vessels* (No. 2-295B307; p. 23). Department of the Navy.

Office of the Secretary of the Navy. (2019). *Defense acquisition system and joint capabilities integration and development system implementation* (2F ed.). Department of Navy.

Office of the Secretary of the Navy. (2020). *Advantage at sea prevailing with integrated all-domain Naval power* (p. 36). Department of the Navy. https://apps.dtic.mil/sti/citations/AD1118532

Office of the Secretary of the Navy. (2021). *One Navy–Marine Corps team: Strategic guidance from the Secretary of the Navy* (Strategic Guidance No. 100721; p. 8). Department of the Navy. https://www.navy.mil/Press-Office/Press-Releases/display-pressreleases/Article/2805409/secnav-del-toro-outlines-top-priorities-on-maritime-dominance-people-strategic/

Singer, D. J. (2003). *A hybrid agent approach for set-based conceptual ship design through the use of a fuzzy logic agent to facilitate communications and negotiation*. ProQuest Dissertations Publishing.

Singer, D. J., Doerry, N., & Buckley, M. E. (2009). What is set-based design? *Naval Engineers Journal*, *121*(4), 31–43. https://doi.org/10.1111/j.1559-3584.2009.00226.x

Singer, D., Strickland, J., Doerry, N., McKenney, T., & Whitcomb, C. (2017). *SNAME T&R bulletin 7-12 set-based design*. The Society of Naval Architects and Marine Engineers.

Sobek II, D. K., Ward, A. C., & Liker, J. K. (1999). Toyota's principles of set-based concurrent engineering. *Sloan Management Review*, *40*(2), 67–83.

Toche, B., Pellerin, R., & Fortin, C. (2020). Set-based design: A review and new directions. *Design Science*, *6*, e18. https://doi.org/10.1017/dsj.2020.16

Walden, D. D., Roedler, G. J., Forsberg, K., Hamelin, R. D., Shortell, T. M., & International Council on Systems Engineering (Eds.). (2015). *Systems engineering handbook: A guide for system life cycle processes and activities* (4th edition). Wiley.

Ward, A. C. (1989). *A theory of quantitative inference applied to a mechanical design compiler*. https://dspace.mit.edu/handle/1721.1/6977

Ward, A. C., Liker, J. K., Cristiano, J. J., & Sobek II, D. K. (1995). The second Toyota paradox: How delaying decisions can make better cars faster. *Sloan Management Review*, *36*(3). https://doi.org/10.1016/0024-6301(95)94310-U

Labor Market Impacts on Navy Shipbuilding & Fleet Efficiency

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Abstract

The Department of Defense relies on a range of highly specialized—and in many cases, dwindling—skill sets in order to deliver critically needed military capabilities and weapons systems. In order to achieve its long-term shipbuilding plan, the Navy requires a data-driven understanding of the labor economics associated with commercial shipyards and relevant labor categories. In this decision science analysis, Govini conducts a labor market analysis that assesses the current and future balance between the supply of and demand for labor in the specific, critical trades that are requirements of shipbuilding.

Introduction

Seapower has always been vital to the political influence, military might, and economic prosperity of the United States. With strategic competition between the United States and the People's Republic of China intensifying and Russia remaining an acute threat, the U.S. military must defend far-flung interests in the Indo-Pacific and Europe. As a result, seapower remains as vital as ever.

Since the first six U.S. Navy frigates were laid down at the dawn of the republic, U.S. seapower has been underpinned by a strong and innovative shipbuilding industrial base. Prevailing over China in the Indo-Pacific and beyond depends on the continued health of that base. Accordingly, the Department of the Navy is undertaking a comprehensive evaluation of national shipbuilding capacity

The lifeblood of the shipbuilding industry has always been the skilled tradespeople that make up its labor force. Over the last few decades, however, changing patterns in U.S. military ship buying, new trends in the domestic and global commercial ship market, social and cultural perceptions favoring non-vocational training, and economic downturns have combined to exert significant strain on the shipbuilding industrial base labor force. Conditions have been further exacerbated over the last two years due to the damage wrought by the COVID-19 pandemic.

As part of the comprehensive evaluation of national shipbuilding capacity, the Navy's Shipbuilding Industrial Base Task Force (SIB-TF), sponsored by the Office of Secretary of Defense (OSD) Industrial Base Analysis and Sustainment (IBAS) office, tasked Govini to analyze and assess the macro- and micro-economic dynamics that shape the current and future labor market for critical trades relevant to Navy shipbuilding. To conduct the study, Govini employed decision science—the targeted application of machine learning and data at scale—to fuse disparate data sources, analyze historical trends, and forecast future labor market conditions. The study focused on labor force dynamics in the Gulf Coast region for four trades critical to the shipbuilding industrial base: Electricians, Metal Fabricators and Fitters, Inside Machinists, and Riggers. This focus was selected both to produce immediate insights for a region vital to U.S. shipbuilding and to build a rigorous and generalizable analytical model that could be used to assess other regional and/or national labor market dynamics. The study addressed two key questions:

1) Is there an adequate supply of skilled labor in select critical trades to meet current and projected demand for Navy ship construction in the U.S. Gulf Coast?
2) What drives supply and demand for select critical trades in the U.S. Gulf Coast?

The insights illuminated by the study can aid decision-makers in the Department of the Navy, Defense Department, the U.S. Coast Guard, Maritime Administration, and broader U.S. Government as they grapple with the challenges of maintaining a healthy shipbuilding labor force.

Key Findings

- **Demand for workers in the four critical trades is increasing—but not from Navy shipbuilding**. Wage trends and job vacancy data suggest current demand for workers on the Gulf Coast in the four critical trades analyzed is increasing. However, Navy shipbuilding does not appear to be driving this trend. In fact, demand for workers generated by Navy shipbuilding has declined 38% from its peak in 2016.
- **The supply of workers in the four critical trades is largely flat.** The assessed labor force in the Gulf Coast region for the four critical trades analyzed has not grown significantly from 2015 levels. Moreover, the labor force of riggers and metal fabricators and fitters in non-Gulf Coast regions of AL, FL, LA, and MS has declined significantly since 2018, reducing the potential pool of workers in the southeast region that could be enticed into shipbuilding.
- **Navy shipbuilders can expect sufficient labor capacity for electricians and riggers, but insufficient capacity for inside machinists and metal fabricators and fitters.** The supply and demand for electricians and riggers is expected to be balanced from 2022–2026. But there is projected to be an imbalance in the supply and demand of inside machinists and metal fabricators and fitters in the Gulf Coast region over the same period.

Methodology

The study analyzed historical data to forecast future supply and demand trends in the Gulf Coast region for four trades critical to the shipbuilding industry: Electricians, Metal Fabricators and Fitters, Inside Machinists, and Riggers. Govini conducted this study in two phases, each consisting of eight steps. The eight steps undertaken in each phase are depicted in Figure 1.

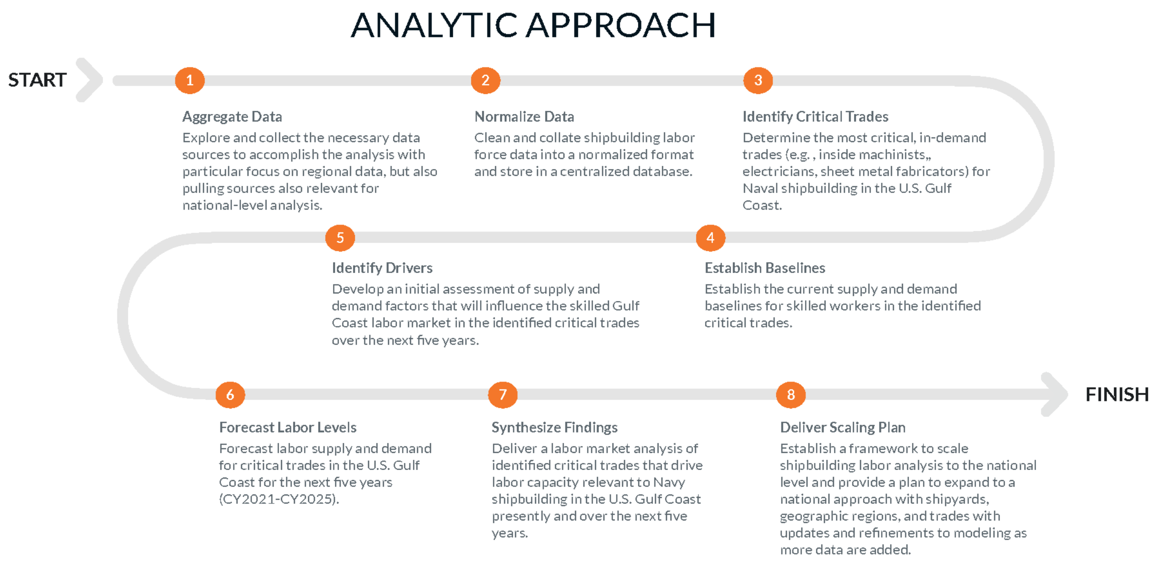


Figure 1. Analytic Approach

In the first phase, the study fused disparate U.S. Government and commercial market data to establish a baseline of historical supply and demand for the four critical trades from 2015 to the present. The study then leveraged this historical baseline to build a model to forecast future supply and demand trends. The forecasting model enabled Govini to assess future labor conditions and produce a series of initial insights.

In the second phase, the study incorporated additional data sources, such as data on workload by ship class, job vacancy postings, and adjacent occupations with common skills. This enriched data enhanced the robustness of the historical supply and demand baseline and enabled Govini to further refine the forecasting model. The study then used the refined forecasting model to generate insight on future labor market conditions to inform the SIB-TF's deliberations.

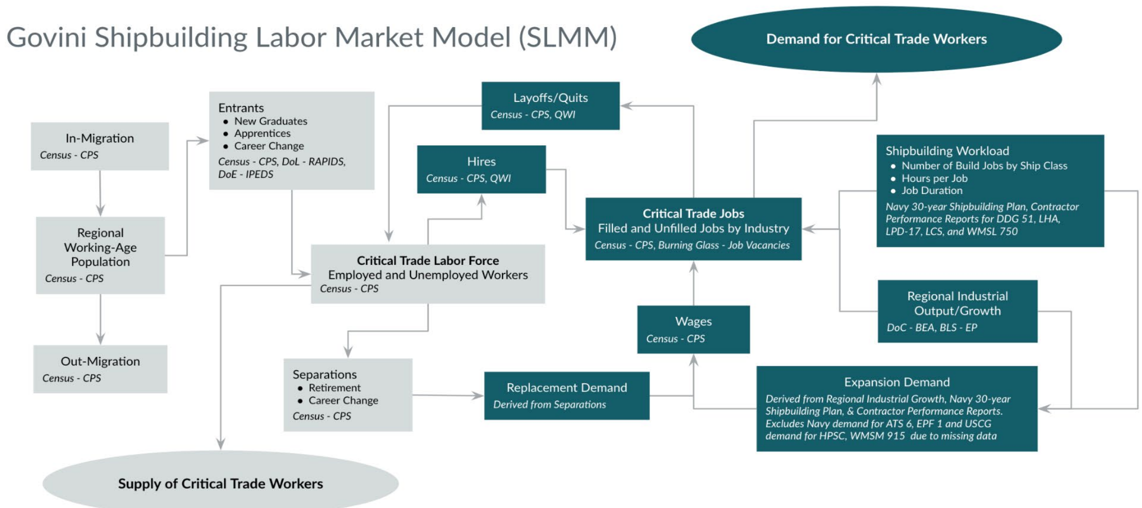


Figure 2. Giovani Shipbuilding Labor Market Model (SLMM)

At the heart of the methodology is Govini's Shipbuilding Labor Market Model (SLMM), which is depicted in Figure 2. The SLMM is built from an informed set of predictors that enable a data-driven approach to labor forecasting. The outputs of this model are ultimately designed to help the Navy, Congress, shipyards, and all other stakeholders to prepare the workforce and secure the shipbuilding industrial base for the future.

To identify factors that affect the market for skilled labor, Govini completed a thorough review of the academic and professional literature on labor economics and labor forecasting, as well as shipbuilding and repair. This review also informed data collection efforts as well as the statistical and analytic approaches used to calculate labor baselines and model future labor capacity. The model architecture is designed to be modular, generalizable, and therefore capable of being applied to additional geographies and/or trades.

Govini applied the SLMM to capture regional trends within the Gulf Coast shipbuilding industry and assess labor supply and demand around selected critical trade occupations and skills. The demand-side model encompasses Navy shipbuilding projects, repair workloads, wages, job vacancies, and growth in adjacent industries that employ workers with the same skill sets and compete with each other for the same workers.

The supply-side model encompasses employment, unemployment, wages, training programs, career changers, retirements, new graduates, apprenticeships, working-age population, and net migration. The labor market analysis also identified other industries in the region that employ workers with similar skill sets. The study then used these models to forecast five-year trends and assess future labor supply conditions in the context of the Navy's shipbuilding and repair plans.

Analysis

U.S. Navy shipbuilding workload for the four critical trades in the Gulf Coast region has been decreasing since late 2016 and is projected to continue trending downward until 2025 when it is forecasted to begin rebounding slightly. As illustrated by Figures 3 and 4, which depict the combined shipbuilding workload by ship class and trade over time, workload peaked in Q3 2016 when 20 distinct hulls were under construction. Beginning in 2017, however, workload began to decrease, declining by 38% from the 2016 peak by the end of 2021. The projected workload is forecasted to decline into early 2025, then begin to rebound as LPD 31, LPD 32, LHA 9, DDG 133, DDG 135, and DDG 137 begin to ramp up production. This rebounding, however, is not expected to reach 2016 peak levels during the period assessed.

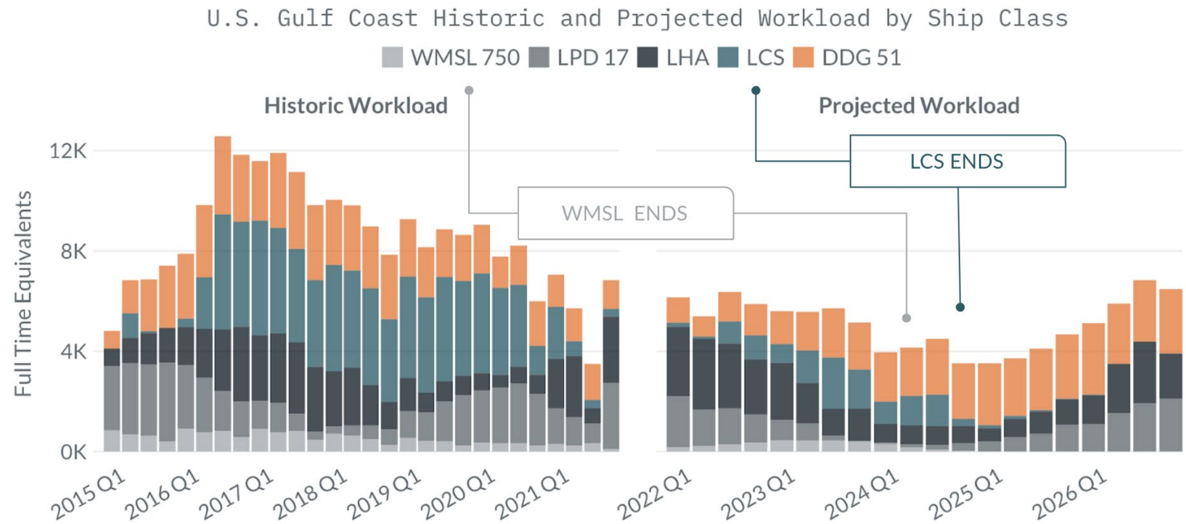


Figure 3. U.S. Gulf Cost Historic and Projected Workload by Ship Class

At the same time, the overall demand for labor in the four critical trades is increasing in the Gulf Coast region. Wage trends and job vacancy data suggest current demand for workers in these trades on the Gulf Coast is increasing. With the exception of riggers, wages for the trades in AL, FL, LA, and MS have increased since 2015. Wages in the Gulf Coast region are also relatively higher than wages in non-Gulf Coast regions of AL, FL, LA, and MS, signaling a tighter labor market in shipbuilding areas. Job vacancies in both the Gulf Coast and non-Gulf Coast regions of AL, FL, LA, and MS have increased upward of 40% since the second quarter of 2020, signaling a rapid increase in worker demand post-pandemic. Critically, not only has this increase in demand not been driven by U.S. Navy shipbuilding, but it has also largely not been due to commercial shipbuilding either. Rather, other industries—such as construction and oil and gas extraction—have been responsible for the increase in demand for these trades in the Gulf Coast region.

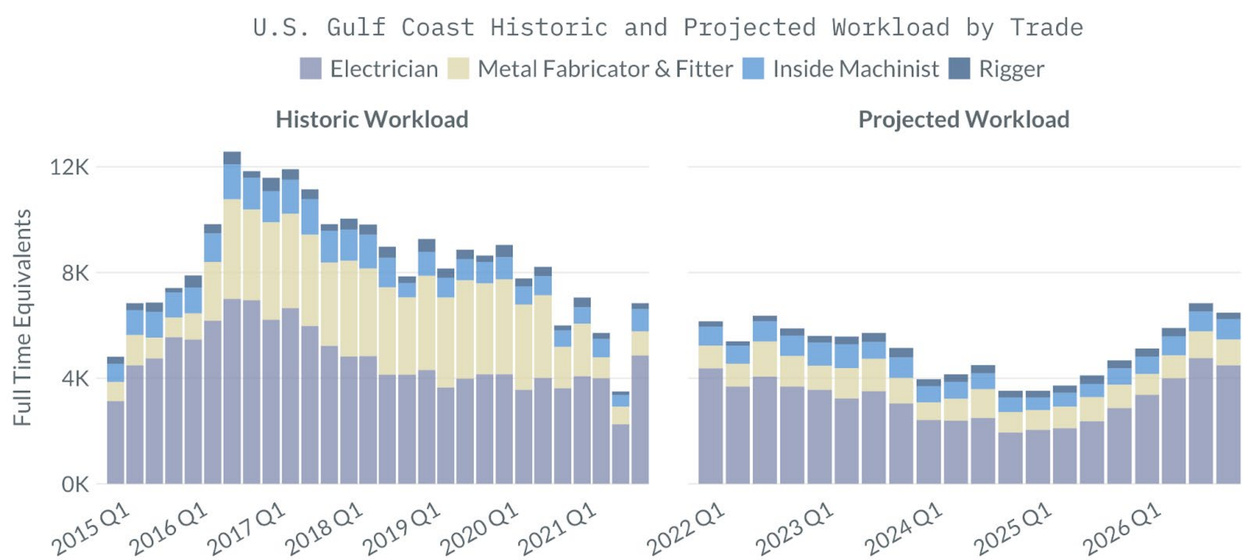


Figure 4. U.S. Gulf Coast Historic and Projected Workload by Trade

Although demand for these trades has been increasing, the supply of workers has remained largely flat since 2015. Moreover, the labor force of riggers and metal fabricators and fitters in non-Gulf Coast regions of AL, FL, LA, and MS has declined significantly since 2018, reducing the potential pool of experienced workers in the southeastern United States that could be enticed into shipbuilding. This imbalance between surging commercial demand outside the shipbuilding industry and flat supply for workers in these critical trades could have significant implications for the future health of the shipbuilding industrial base.

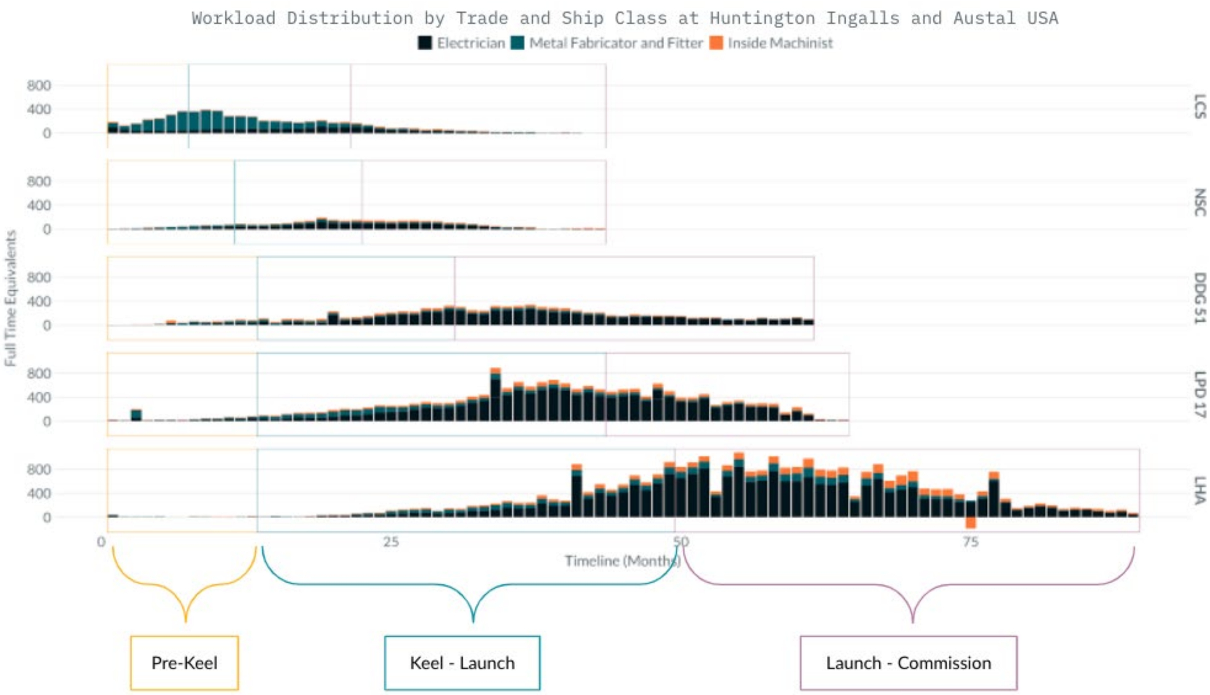
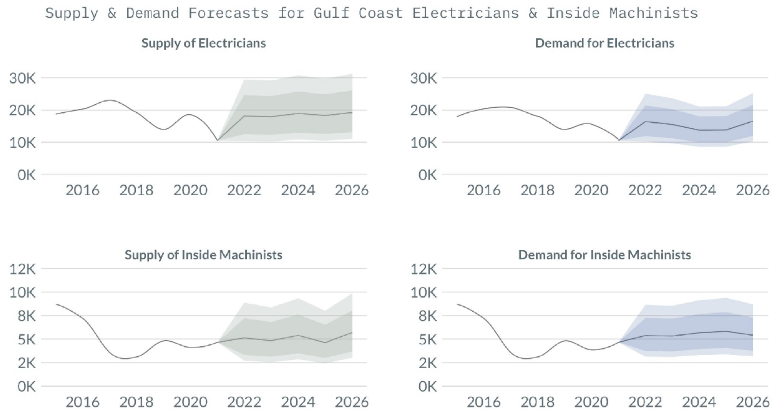


Figure 5. Workload Distribution by Trade and Ship Class at Huntington Ingalls and Austal USA

Given the increasing imbalances between labor supply and demand of the four critical trades in the Gulf Coast region—and the potential implications of these imbalances for the health of the shipbuilding industrial base—the study utilized the SLMM to forecast future labor conditions. The forecasts indicate that there should be sufficient labor capacity in the Gulf Coast region for electricians and riggers through 2026. The supply of inside machinists and metal fabricators and fitters, however, will likely face labor shortfalls through 2026.

Because all forecasts are associated with uncertainty, Govini captured a range of possible scenarios that the model predicts within a specified probability for each of the four trades, the outcomes of which are depicted in Figures 6 and 7:

- **Average:** Average predicted supply minus average predicted demand (represented by forecast trendlines)
- **Best:** Highest predicted supply value minus lowest predicted demand value (95% probability)
- **Worst:** Lowest predicted supply value minus highest predicted demand value (95% probability)



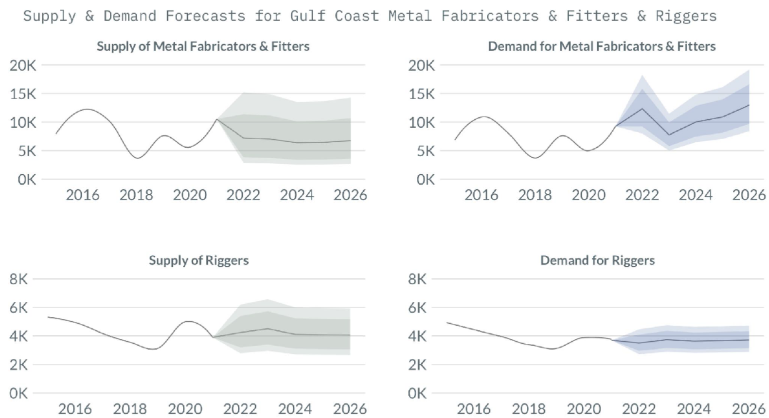
ELECTRICIANS

	Average Case	Best Case	Worst Case
2022	+1,760	+19,310	-14,613
2023	+2,425	+19,486	-13,372
2024	+5,136	+22,182	-10,190
2025	+4,433	+21,108	-10,660
2026	+2,664	+20,922	-14,230

Inside Machinists

	Average Case	Best Case	Worst Case
2022	-250	+5,742	-5,934
2023	-487	+5,269	-5,999
2024	-289	+6,024	-6,282
2025	-1,207	+4,612	-6,934
2026	+282	+6,704	-5,691

Figure 6. Supply and Demand Forecasts for Gulf Coast Electricians and Inside Machinists



Metal Fabricators & Fitters

	Average Case	Best Case	Worst Case
2022	-5,153	+7,237	-15,408
2023	-723	+9,854	-8,672
2024	-3,640	+7,015	-12,285
2025	-4,451	+6,595	-13,562
2026	-6,240	+5,880	-16,536

Riggers

	Average Case	Best Case	Worst Case
2022	+735	+3,479	-1,672
2023	+767	+3,682	-1,791
2024	+472	+3,187	-1,927
2025	+409	+3,116	-1,988
2026	+346	+3,055	-2,057

Figure 7. Supply and Demand Forecasts for Gulf Coast Metal Fabricators and Fitters and Riggers

The forecasts for metal fabricators and fitters predict both near and long-term shortfalls in capacity through 2026. The supply of workers is projected to decline and then flatten over the period, while demand is projected to grow. As a result, demand is expected to be sizably higher than supply every year in all cases but the best-case forecast. This decline in supply is largely driven by a decreasing number of new entrants into the trade.

The forecasts for inside machinists are less dire, with slight imbalances projected in the average-case forecast until 2026. The worst-case forecast projects greater imbalances through 2026, but still not as substantial in magnitude as those for metal fabricators and fitters. While demand is likely to remain relatively flat, the supply of inside machinists is likely to contract periodically over the next five years largely due to career changes and retirements, which drive the projected imbalances.

Implications for the Navy

The potential imbalance in labor supply and demand projected over the next five years for two of the four trades assessed could result in construction delays for ship classes built on the Gulf Coast. The impact of these labor supply shortfalls could fall disproportionately on smaller subcontractors that lack the resources to compete with larger companies in tight labor markets. If these subcontractors perform critical and difficult to substitute functions in the construction process, the effects of the labor shortfalls could create bottlenecks that have cascading consequences for cost and schedule, driving outsized delays and disruptions.

Moreover, two emerging trends could further exacerbate the labor supply and demand imbalance, potentially pushing future labor market conditions closer to or even beyond the worst-case forecasts in the short to medium terms. First, increased defense budgets in the wake of the Russian invasion of Ukraine, if sustained for several years, will likely result in greater U.S. Navy ship procurement than originally planned over the future years defense plan. Second, surging energy prices and the push to cut off Russia from global oil and natural gas markets could lead to higher demand and wages for workers in these trades in the oil and gas extraction industry in the Gulf Coast region, particularly for metal fabricators and fitters.

Given the potential disruptions that imbalances in labor supply and demand could create for Navy shipbuilding plans, there are a couple of mitigation measures that the Department of the Navy, Department of Defense, the U.S. Coast Guard, Maritime Administration (MARAD), and broader U.S. Government should consider implementing. First, efforts to stabilize order quantities across the Navy, Coast Guard, MARAD, and other U.S. Government agencies—coupled with federal government assistance—could enable shipyards and their suppliers to make greater investments in their labor force, including incentivizing retention to deter potential career changers and increasing wages to entice more new entrants and/or career changers. Stabilizing total orders over time will always be a challenge given uncertain future fiscal environments. But as noted in Figure 5, demand for each trade over time differs by ship class. As such, the Navy, Coast Guard, MARAD, and other agencies could seek to stagger class procurement to smooth labor demand over time.

Second, the Navy could forge partnerships with state and federal agencies to increase outreach and incentives for younger cohorts to enter training programs and apprenticeships. These measures could help to both expand the total pool of workers in the critical trades while infusing it with younger workers that will help lessen the risk of future shortages due to mass retirements. Interestingly, high demand in industries outside of Navy shipbuilding are drivers of acute labor imbalances, they may serve both to increase the pool of workers in the four critical trades while lowering the average age of workers in that pool in the longer term. Sustained high demand in industries like oil and gas extraction could lead to higher wages and steady work that attract new entrants to the trades. As a result, the Navy should consider how it can leverage these trends to funnel more new entrants into training programs to increase the pool of skilled tradespeople, thereby increasing the health of the shipbuilding industrial base and its resilience to future negative shocks.

Next Steps

In order to further refine the SLMM and use it to expand the assessment of the health of the shipbuilding industrial base, initial discussions with Navy and IBAS sponsors have explored the potential of applying the SLMM to new shipbuilding trades and to a new shipbuilding region, such as New England. This would allow for validation of the SLMM and relevant comparison of data between the unique labor dynamics of the Gulf Coast and New England. Additionally, as mentioned above, the team identified that the supplier ecosystem that supports the shipyards may have more critical labor risks than the yards themselves because of their business size and location. The shipbuilding and submarine industrial base supplier networks are geographically dispersed across the country making mapping by place of performance, categorizing by sub-industry, and prioritizing by systems across the supplier base a recommended and necessary step. The team can then quickly assess industry-level labor trends and risks for the shipbuilding industrial base by market sector and location.

Appendix: Deep Dives into Critical Trades

This appendix provides more detailed information on each of the four critical trades analyzed in the study. It focuses on four areas: proportion of labor demand for each trade from U.S. Navy shipbuilding versus other industries, including commercial shipbuilding; primary industries outside of U.S. Navy shipbuilding driving labor demand for the trade; annual rates of new entrants from educational programs and net career changers in the labor supply for the trade; and age distribution of workers within the labor supply for the trade.

Electricians

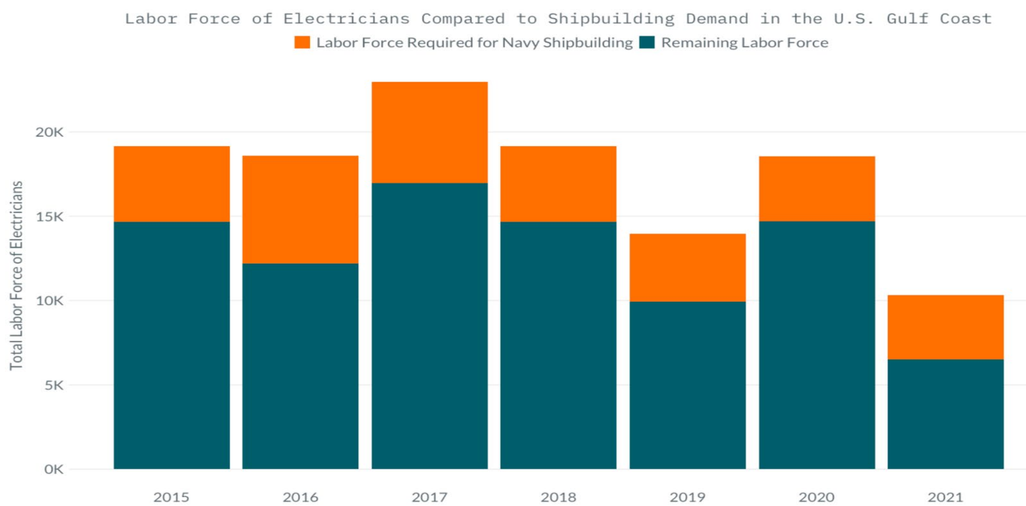


Figure 8. Labor Force of Electricians Compared to Shipbuilding Demand in the U.S. Gulf Coast

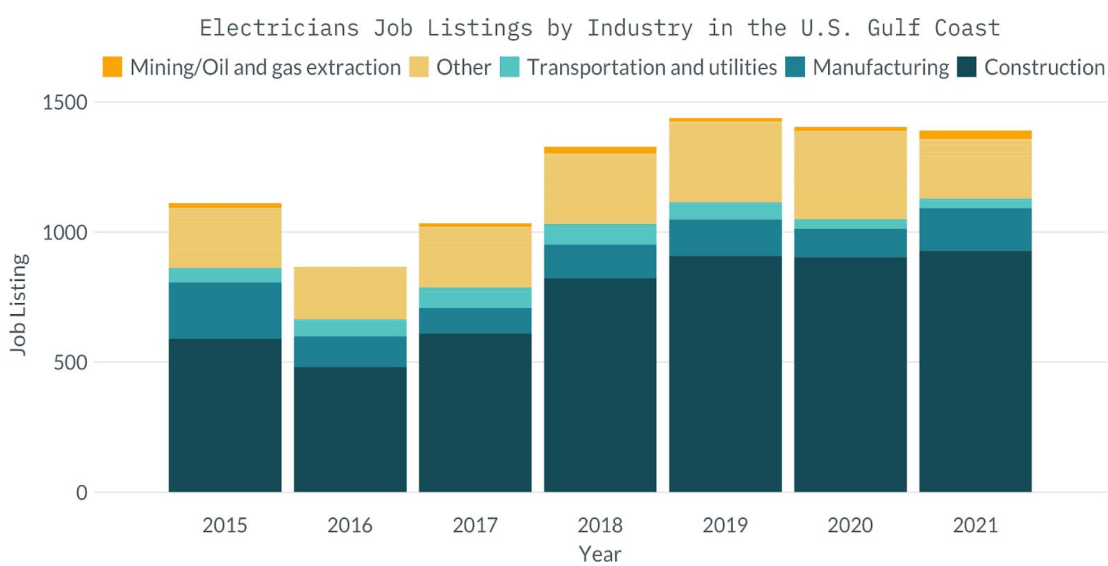


Figure 9. Electricians Job Listings by Industry in the U.S. Gulf Coast

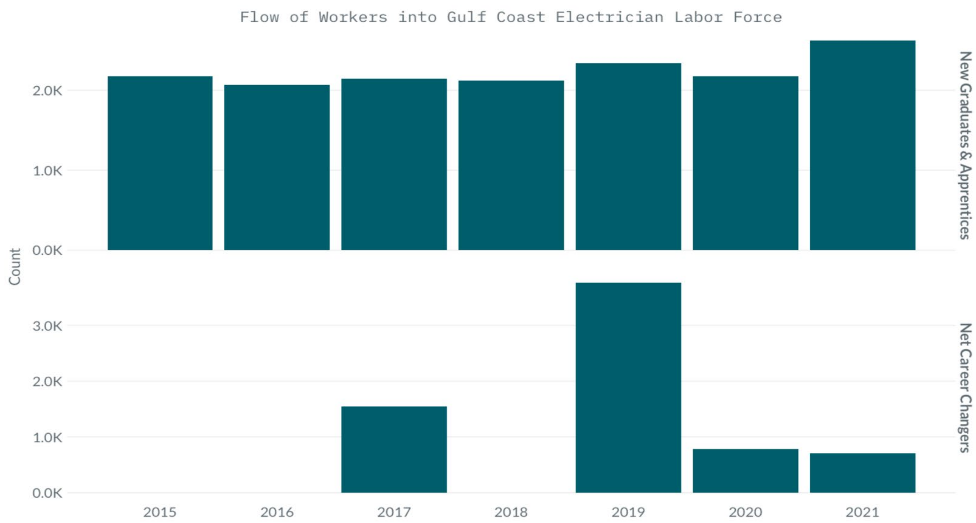


Figure 10. Flow of Workers into Gulf Coast Electrician Labor Force

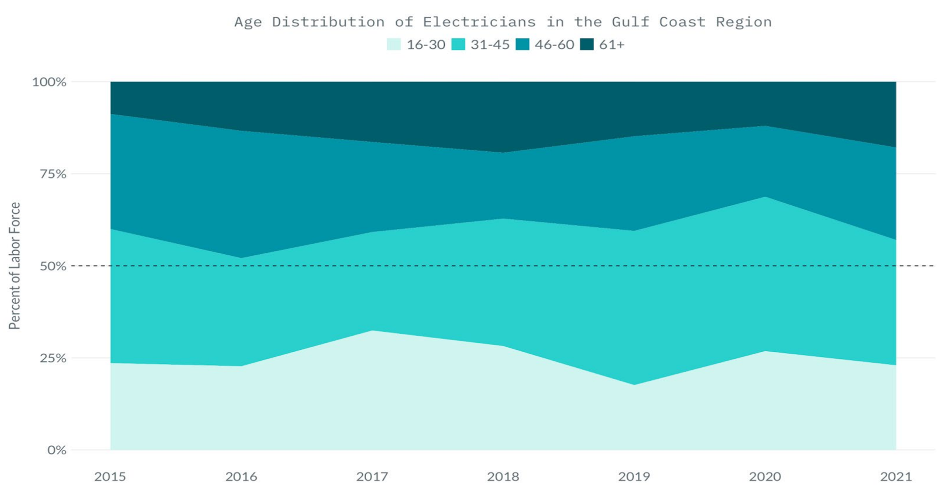


Figure 11. Age Distribution of Electricians in the Gulf Coast Region

Labor Demand Proportions: Electricians working in Navy shipbuilding comprise a minority of the total labor force of electricians in the Gulf Coast region, representing less than one-third of total labor demand for the trade. Despite periodic fluctuations, the proportion of the labor force required for Navy shipbuilding has remained steady since 2015, averaging around 28% of the total Gulf Coast electrician labor force from 2016–2021.

Industries Driving Demand: Outside of shipbuilding, the majority of job listings for electricians are in construction indicating high demand in this industry. From 2015 to 2021, 61% of job vacancies for electricians were in construction. The demand for electricians in the construction industry grew at an 8% compounded annual growth rate (CAGR), with the largest change occurring between 2017 and 2018, which saw a 35% increase in job posts. From 2015 to 2021, job vacancies in the manufacturing industry dropped by 4% CAGR. Although job vacancies in the mining/oil and gas extraction industry account for only 1.4% of all vacancies, the number of job posts in this industry experienced the largest growth at 10% CAGR between 2015 and 2021.

New Entrants and Net Career Changers: There was marginal growth in the electrician labor force in the region from new graduates, apprentices and net career changers. From 2015 through 2021, the number of new electrician graduates and apprenticeship completers in the Gulf Coast region grew at 3.2% CAGR. On average, 2,200 electricians enter the labor force from postsecondary institutions, including community colleges, as well as apprenticeship programs. Electricians do not appear to be prolific career changers with, on average, only a couple hundred workers switching into the trade each year. Still, from 2015 to 2021, more workers changed careers *in* the electrician trade than *out*.

Age Distribution in the Labor Supply: The majority of electricians in the Gulf Coast region are 45 or younger, signaling a low risk of mass retirement. The age distribution of electricians in the Gulf Coast region is stable and healthy. The age distribution of electricians in the non-Gulf Coast region mirrors that of electricians in the Gulf Coast region. In 2021, 42% of the non-Gulf Coast region labor force was 45 or older whereas 44% of the Gulf Coast region labor force was 45 or older.

Inside Machinists

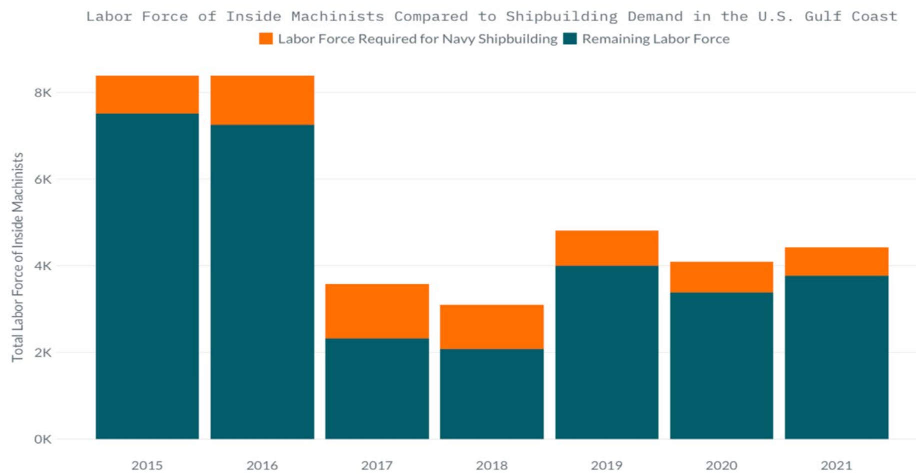


Figure 12. Labor Force of Inside Machinists Compared to Shipbuilding Demand in the U.S. Gulf Coast

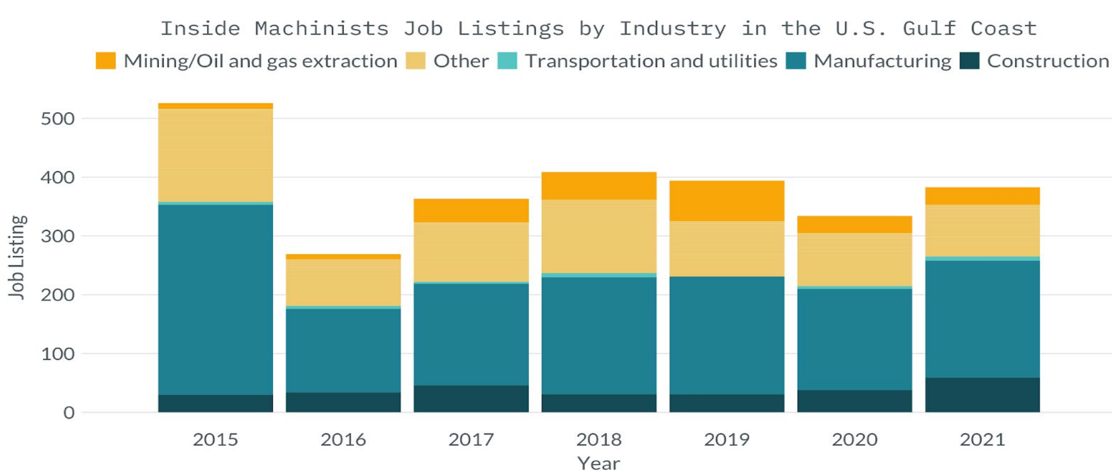


Figure 13. Inside Machinists Job Listings by Industry in the U.S. Gulf Coast

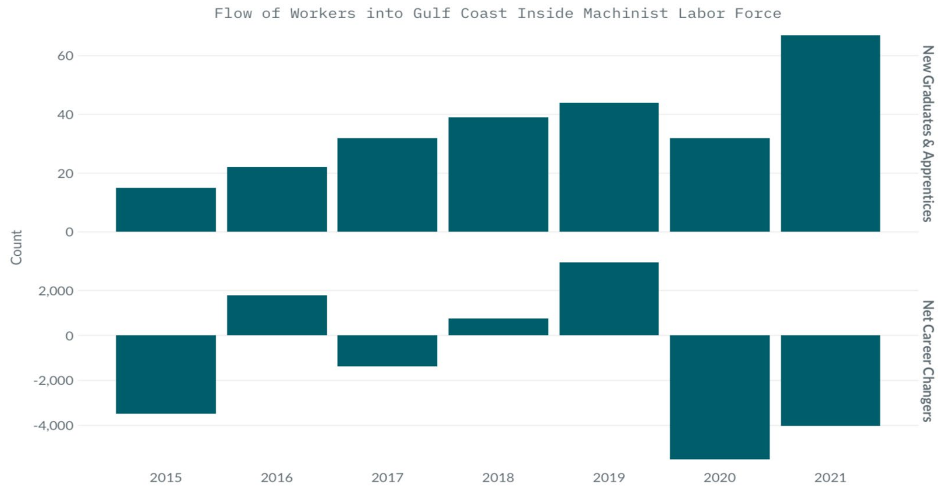


Figure 14. Flow of Workers into the Gulf Coast Inside Machinist Labor Force

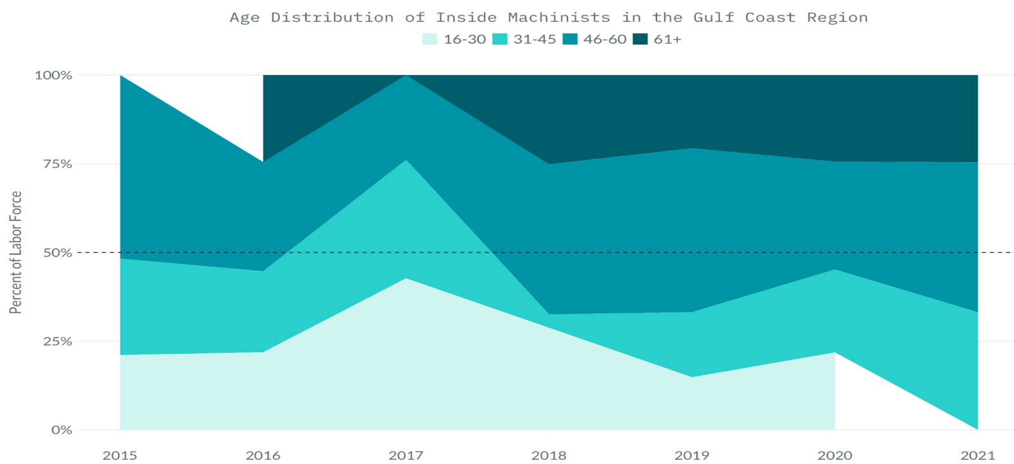


Figure 15. Age Distribution of Inside Machinists in the Gulf Coast Region

Labor Demand Proportions: Since 2019, the Navy has accounted for only a sixth of the demand for inside machinists in the Gulf Coast region. From 2015 to 2016, only 12% of the Gulf Coast inside machinist labor force was required for Navy shipbuilding, on average. The proportion of the labor force required grew dramatically to 34% from 2017 to 2018, corresponding to an increase in the Navy's demand for shipbuilding during this time. Since 2018, demand for inside machinists has declined. On average, only 16% of the inside machinist labor force was required for Navy shipbuilding between 2019 and 2021. This indicates that the majority of inside machinists in the Gulf Coast region are engaged in work not affiliated with Navy shipbuilding

Industries Driving Demand: Vacancies for inside machinists in mining/oil and gas extraction surpass construction in 2018–2019. In 2015 and 2016, more than half of the job vacancies for inside machinists were in the manufacturing industry. Job vacancies across all industries in 2016 dropped 49% from 2015 levels and then increased at an average rate of 24% from 2016–2018, until dropping again slightly by 4% in 2019. From 2016–2019, job vacancies in manufacturing increased by 9% CAGR while vacancies in mining/oil and gas extraction increased by 66% CAGR.

New Entrants and Net Career Changers: Growth in machinist labor force from new graduates, and apprentices were offset by net career changers. From 2015–2021, the number of new inside machinist graduates and apprenticeship completers grew at 28% CAGR. Since 2019, 48 inside machinists, on average, enter the labor force from postsecondary institutions, including community colleges, as well as apprenticeship programs. However, this is complicated by the number of inside machinists leaving the trade for another profession. Since 2015, more workers changed careers *out of* the inside machinist trade than in the inside machinists's trade, particularly in the past two years. On average, 1,200 inside machinists are lost every year due to career changers.

Age Distribution in the Labor Supply: An aging labor force of inside machinists poses the risk of mass retirement. Since 2015, a majority of workers have been over the age of 45, with the exception of 2016–2017, indicating that younger workers are not replacing older workers at the same rate. Of particular concern, the number of older workers is increasing while the number of younger workers is decreasing. Since 2018, 18% of inside machinists in the Gulf Coast region are 30 years or younger whereas 24% are 61 years or older. This increases the likelihood that waves of retirement will negatively affect the size of the inside machinist labor force in the coming years.

Metal Fabricators and Fitters

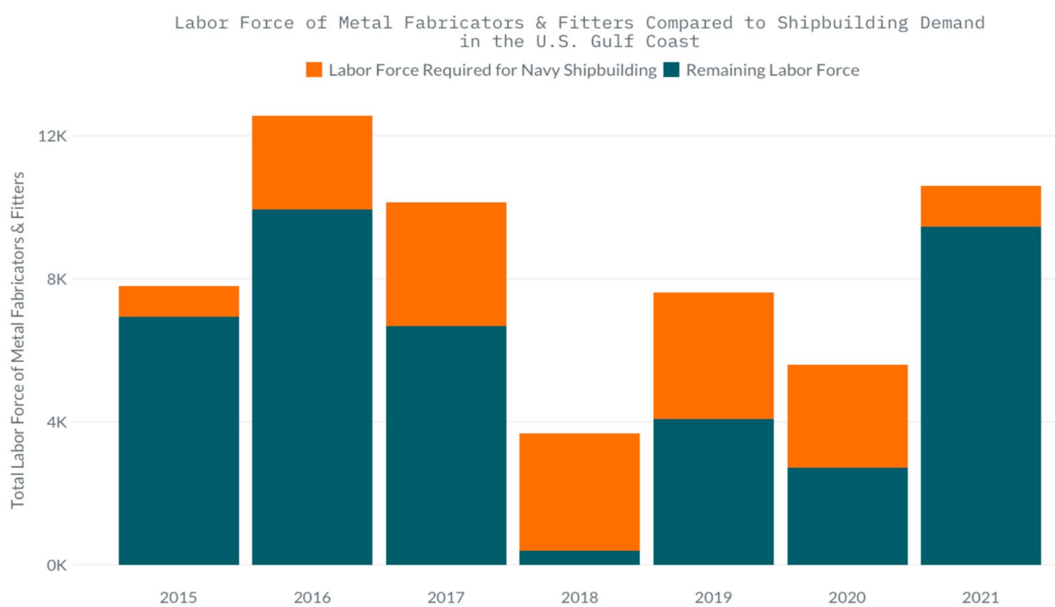


Figure 16. Labor Force of Metal Fabricators and Fitters Compared to Shipbuilding Demand in the U.S. Gulf Coast

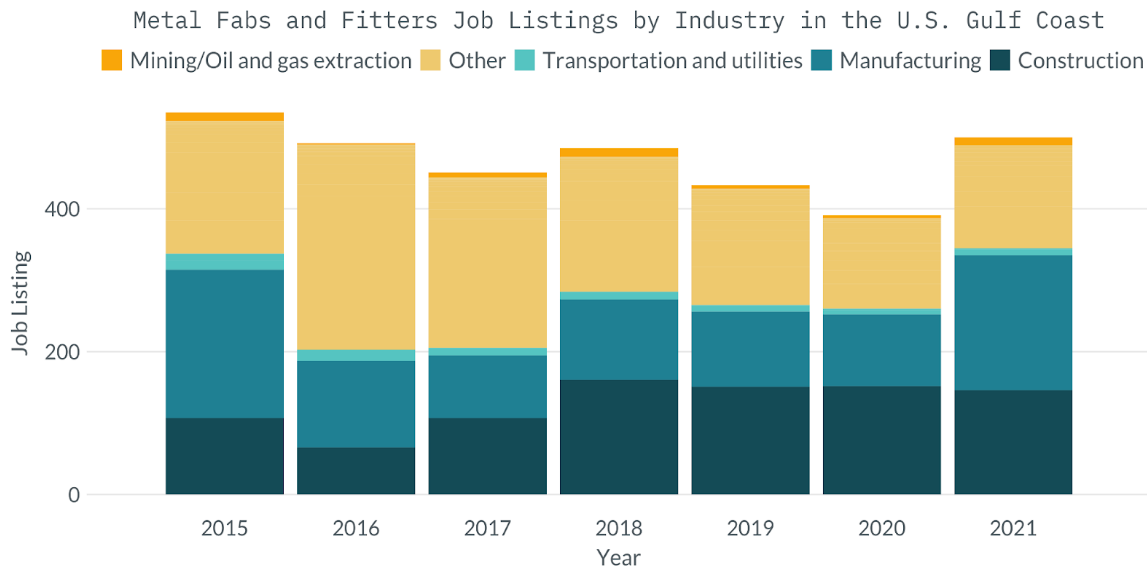


Figure 17. Metal Fabricators and Fitters Job Listings by Industry in the U.S. Gulf Coast

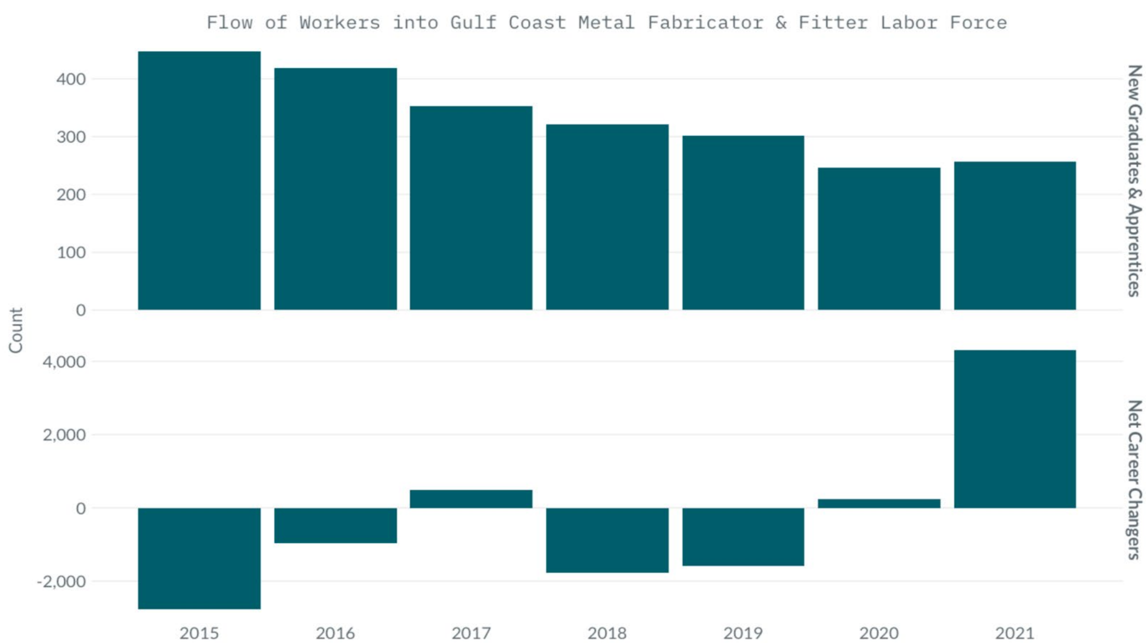


Figure 18. Flow of Workers into Gulf Coast Metal Fabricator and Fitter Labor Force

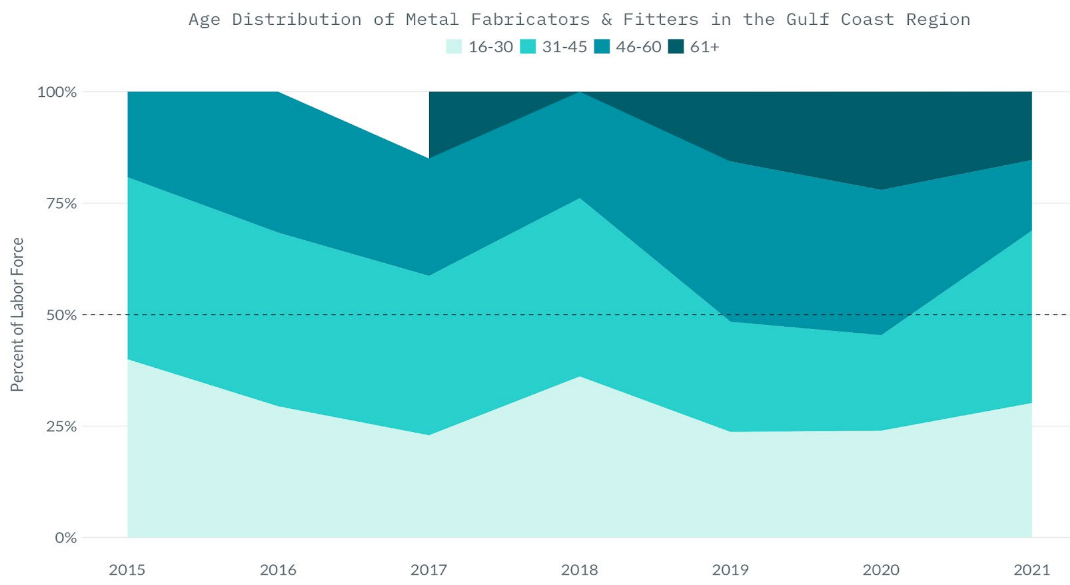


Figure 19. Age Distribution of Metal Fabricators and Fitters in the Gulf Coast Region

Labor Demand Proportions: U.S. Navy shipbuilding accounted for two-fifths of the demand for metal fabricators and fitters in the Gulf Coast region since 2015. But that proportion of demand has increased in recent years, rising 62% from 2018–2020.

Industries Driving Demand: At the same time, demand for metal fabricators and fitters vacancies have remained relatively stagnant in the last four years. From 2015–2017, job listings for metal fabricators and fitters gradually dropped by 6% CAGR. From 2017–2018, job vacancies in the manufacturing industry grew by 27% but then flattened out until 2020, before increasing by 89% in 2021. While vacancies in the manufacturing industry grew in 2021, demand in construction barely changed, even dropping slightly by 4%. Job vacancies in the construction industry dropped from a yearly proportion of 20% in 2015 to 13.41% in 2016, where it began to increase at an average rate of 6.37% year-over-year until 2020.

New Entrants and Net Career Changers: Recent years have seen a steady decline in metal fabricators and fitter graduates and apprentices. From 2015–2021, the number of new metal fabricator and fitters graduates and apprenticeship completers in the Gulf Coast region declined at 8.9% CAGR. Since 2019, on average, 268 metal fabricators and fitters entered the labor force from postsecondary institutions, including community colleges, as well as apprenticeship programs. Since 2015, more workers have changed careers *in* the trade than out, particularly in recent years. This net-positive change, however, was driven primarily by a massive spike in 2021 when 4,500 metal fabricators and fitters were added to the labor force from career changers.

Age Distribution in the Labor Supply: A recent influx of metal fabricators and fitters 45 or younger assuages concerns of an aging labor force. The age distribution of metal fabricators and fitters in the Gulf Coast region is generally stable and healthy, with a majority of workers aged 45 or younger every year except 2019 and 2020. In 2019–2020, the labor force for metal fabricators and fitters was rapidly aging due to an influx of workers under the age of 46, particularly those aged 31–45 indicating that younger workers are generally replacing older workers at a consistent rate, which decreases the likelihood that waves of retirements will negatively affect the size of the labor force in the coming years.

Riggers

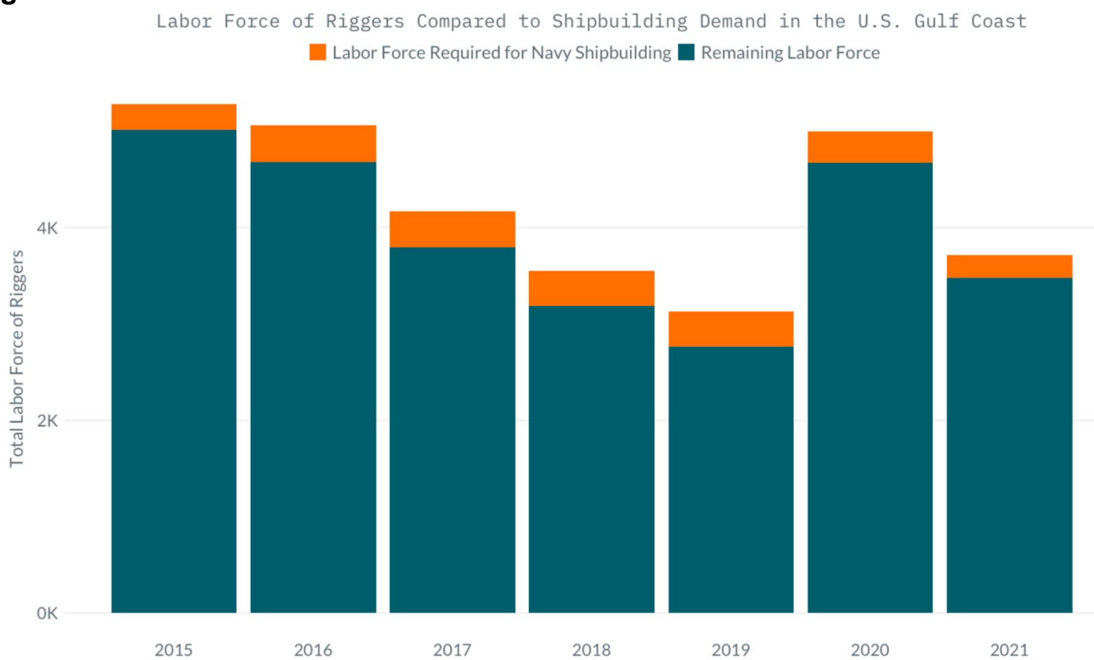


Figure 20. Labor Force of Riggers Compared to Shipbuilding Demand in the U.S. Gulf Coast

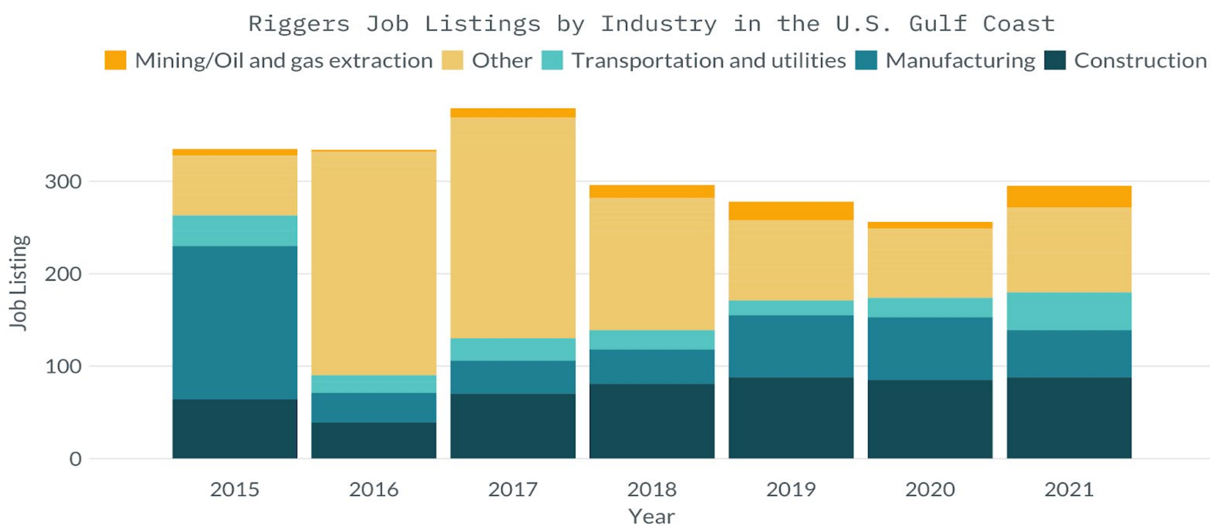


Figure 21. Riggers Job Listings by Industry in the U.S. Gulf Coast

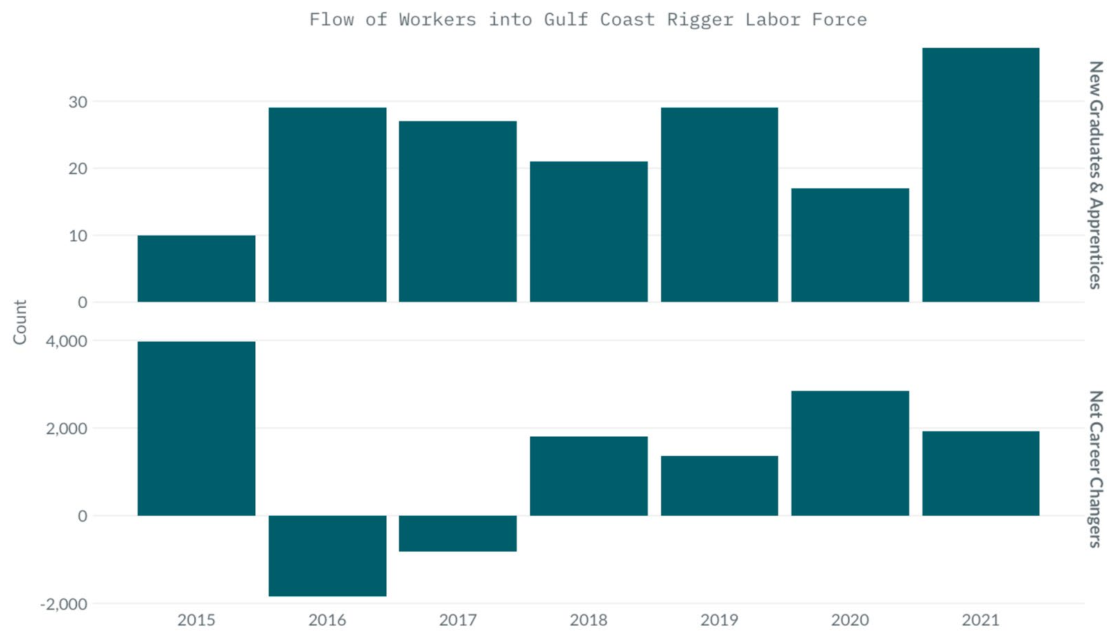


Figure 22. Flow of Workers into Gulf Coast Labor Force

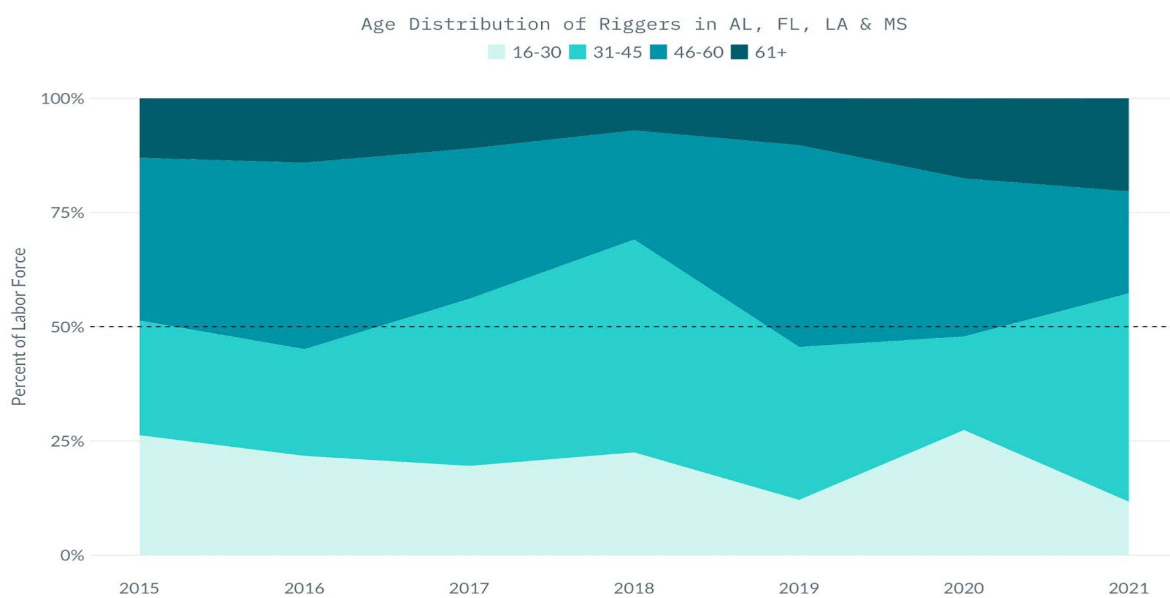


Figure 23. Age Distribution of Riggers in AL, FL, LA, and MS

Labor Demand Proportions: There has been a steady decrease in demand for riggers in Navy shipbuilding since 2015, with riggers working in Navy shipbuilding comprising a minority of the total labor force of riggers in the Gulf Coast region. At the same time, the proportion of the labor force required for Navy shipbuilding has been relatively stable, averaging around 8% of the total Gulf Coast rigger labor force between 2015 and 2021. Navy demand for riggers is consistent across years regardless of changes to the overall size of the rigger labor force.

Industries Driving Demand: From 2015 to 2016, job vacancies dropped by 81% in the manufacturing industry and 39% in the construction industry, while growing by 68% in the professional, scientific, and technical services industry. However, manufacturing and construction rebounded after 2016. From 2016–2019, job vacancies in the construction industry increased by 20% CAGR before flattening in 2019–2021 at an average of 62 job listings. Job vacancies in the manufacturing industry nearly doubled from 2018 to 2019 with an 81% increase in job listings but drops by 25% in 2020–2021.

New Entrants and Net Career Changers: The rigger labor force has been stabilized by a steady number of new graduates, apprentices and net career changers. From 2015 to 2021, the number of new rigger graduates and apprenticeship completers in the Gulf Coast region grew at 25% CAGR. On average, 24 riggers enter the labor force from postsecondary institutions, including community colleges, as well as apprenticeship programs. Moreover, more workers changed careers *in* the rigger trade than out of the rigger trade with an average of 1,300 riggers entering the labor force from career changers each year

Age Distribution in the Labor Supply: The age distribution of riggers in the Gulf Coast region shows a balanced labor force between older and younger workers. But the steady decline in the number of riggers 30 years or younger risks the ability to replace older generations of riggers. Starting in 2019, the number of riggers aged 61 or older grew from 7% to 21% of the overall labor force. The influx of workers aged 31–45, however, mitigates to some extent the risk that waves of retirements will negatively affect the size of the labor force in the coming years.

PANEL 5. SUPPORTING THE CURRENT & FUTURE WORKFORCE

Wednesday, May 11, 2022	
11:05 a.m. – 12:20 p.m.	**Chair: James Woolsey,** President, Defense Acquisition University ***Program Management Versus Portfolio Management in Defense Acquisition*** Robert Mortlock, Naval Postgraduate School Raymond D. Jones, Naval Postgraduate School Major Conor W. Stewart, United States Marine Corps Major Adam T. Deitrich, United States Marine Corps Major Jordan M. Reid, United States Marine Corps ***A CMS - Based Competency Assessment of the DoD Contracting Workforce*** Rene Rendon, Naval Postgraduate School ***Predictability and Forecasting of Acquisition Careers in the Army*** Eduardo Lopez, George Mason University Frank B. Webb, George Mason University

James P. Woolsey—is President of the Defense Acquisition University (DAU), a position he has held since January 2014. In that role, he is responsible for delivery of learning products through the DAU regions, the Defense Systems Management College, and the College of Contract Management; curriculum development; online learning programs; learning technology; and library services for a major Department of Defense corporate university. DAU is strategically located within five geographical regions across the country and provides a global learning environment to develop qualified acquisition, requirements, and contingency professionals who deliver and sustain effective and affordable warfighting capabilities.

He previously served as the first Deputy Director for Performance Assessments (PA) in the office of Performance Assessments and Root Cause Analyses (PARCA). In standing up the PA organization, he created the processes and practices that allowed it to perform its statutory responsibility of assessing the progress of all Major Defense Acquisition Programs. The new office also made a substantial contribution to re-invigorating the Defense Acquisition Executive Summary process and provided the Under Secretary of Defense for Acquisition, Technology and Logistics with unique analyses to give him improved visibility into the status of the MDAP portfolio.

Mr. Woolsey was previously an Assistant Director in the Cost Analysis and Research Division of the Institute for Defense Analyses. His responsibilities included management of the division's cost analysis and research, and leadership of a wide range of cost and acquisition studies. His work included a congressionally-directed cost benefit analysis of the F-35 alternate engine, an evaluation of KC 767A lease prices, C-5 re-engineering costs and benefits, F-22 production readiness, Joint Air-to-Surface Standoff Missile costs, and space launch alternatives. Mr. Woolsey also served on a Defense Science Board Task Force on long-range strike.

Mr. Woolsey's other previous positions include service as a structures engineer for F/A-18 aircraft at Naval Air Systems Command, and work as an engineer for Lockheed Martin airlift programs in Marietta, GA.

Program Management Versus Portfolio Management in Defense Acquisition

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Abstract

This research performed a gap analysis on the existing Department of Defense (DoD) program management competency standards to determine if changes are required to fully adopt product portfolio management (PPM) strategies in defense acquisition. Current DoD program management standards are compared to the Project Management Institute's Portfolio Management Professional certification standards to analyze alignment and gaps between the standards. Barrier to Implementation (BTI) scores are assigned to address the identified gaps in the DoD standard. The study found that the DoD program management competencies are on average 41% aligned with portfolio management industry standards. The DoD program management competencies are least aligned with the portfolio management domains of governance and strategic alignment. The composite BTI score indicates low to medium level of implementation barriers for most of the gaps. Results indicate that the DoD is capable of conducting PPM, and further research is needed to fully align the current competency standards with industry best practices. Defense acquisition senior leaders should consider formulating DoD portfolio management career field functional competencies to address congressional mandates for portfolio management implementation within the DoD.

Keywords: portfolio management, program management, gap analysis, NDAA acquisition guidance, acquisition reform and innovation

Introduction

The National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2021 recently established portfolio management as the required management process for the acquisition of defense weapons systems to reduce cost and increase acquisitions efficiency (National Defense Authorization Act [NDAA], 2021). This is a significant shift from the current strategy of program management (PM) within Defense acquisitions and necessitates study of the alignment between existing PM competency standards with product portfolio management (PPM) and the overall construct of corporate portfolio management (CPM). The research performs a gap analysis on the existing Department of Defense (DoD) PM competency standards to determine if changes are required to fully adopt PPM strategies as outlined by the NDAA.

The FY2021 NDAA establishes portfolio management as a requirement for DoD acquisitions, with full implementation expected by 2023. Additionally, the FY2021 NDAA orders the secretary of defense to implement a "third-party accredited [certification] program based on national or international recognized standards" (NDAA, 2021, p. 318) for all acquisition career fields. Currently, acquisition career fields established by Defense Acquisition Workforce Improvement Act (DAWIA) and managed by the Services' Directors of Acquisition Career Management (DACMs) do not formally recognize portfolio manager as a career field separate and distinct from PM, creating a potential gap between the competency standards and the requirement for portfolio management.

While organizations such as the Section 809 Panel, the Office of Management and Budget (OMB), and the Government Accountability Office (GAO) have been advocating for PPM for 20 years, change has been slow to come (Ahern & Driessnack, 2019; GAO, 2015). In the corporate world, when an organization shifts from a program-centric acquisitions strategy to a PPM strategy, it stems from two drivers: the need to make rational investment decisions that deliver organizational benefits and the need to optimize resources to ensure the efficient delivery of those benefits (Young & Conboy, 2013). PPM achieves these benefits by pooling resources and analyzing how decisions made about one product affect the other products in the portfolio and portfolio priorities writ large. Additionally, the defense acquisitions enterprise comprises numerous commands with their own goals, agendas, and interpretations of policies (GAO, 2020). These organizations change leaders and priorities every 3 or 4 years. This "fragmented adhocracy" makes implementing change difficult (Young & Conboy, 2013, p. 1090). Last, implementing PPM will require competent professionals. According to Young and Conboy (2013), competence is "the ability to do something well" (p. 1091). PPM requires a common competency standard as the metric to train and evaluate acquisition professionals. Identifying gaps in the competency standards will assist in updating and codifying a standard that can be used as a common thread to synchronize PPM efforts across the Defense acquisitions enterprise.

Within the DoD, significant knowledge gaps are preventing the full implementation of PPM. One reason for the absence of standards related to PPM is a lack of clarity. In the academic community and industry, there has been confusion as to what constitutes PPM. The term often gets used interchangeably with PM, project management, and multi-project management (Young & Conboy, 2013). In part, DoD PPM standards have not been created or implemented because of a lack of theoretical glue. A similar situation exists in the private sector where CPM practices and procedures have been undervalued and under-researched, leading to an identified gap between the direction and means available to implement CPM. Despite many medium and large corporations applying CPM principles and tools to make strategic decisions, "Academic research has not kept up with the realities and needs of the corporate world" (Nippa et al., 2011, p. 64). The lack of CPM-focused research, combined with the statutory requirement to implement portfolio management, presents a need to conduct focused CPM research to recognize and improve CPM's value. While related topics have been researched, CPM has been neglected in part due to the emergence of, and focus on, value-based models and criticisms of CPM practices and tools (Nippa et al., 2011). Much of the body of previous research underestimates the importance of corporate diversification, oversimplifies CPM, and criticizes its application without consideration of empirical evidence to the contrary (Nippa et al., 2011).

The research questions included the following:

- Are there gaps in the DoD PM competency standards that must be addressed before the DoD can fully implement PPM as directed in the NDAA of 2021?
- Where are the DoD and Project Management Institute (PMI) aligned regarding competency standards?
- What barriers exist regarding the implementation of PPM standards for Defense acquisitions?

The research study benefits the defense acquisition community in a multitude of ways. First, the study assesses the current alignment of DoD standards to PMI standards and highlights the most significant gaps in DoD competency standards. Next, it highlights areas that have the lowest barriers for PMI standard implementation. Lastly, it serves as a foundation for developing updated professional standards for use in the DoD based on accredited national and international standards as mandated in the FY2020 and FY2021 NDAAs (NDAA, 2019, 2021).

The scope of this research was narrowed to the analysis of the competency standards required for acquisitions professionals and the potential application of new standards to encompass portfolio management. The study of current internationally accepted industry standards is included for determining their applicability to the DoD acquisitions process and associated competency standards. Structural, budgetary, statutory, and design implications may exist in implementing the shift from program-centric to portfolio management that require further research.

The shift from program to portfolio management is a significant endeavor for the DoD that requires analysis of existing competency standards to determine the applicability of the existing standards and the requirement for developing new standards. Applying nationally accepted industry standards to portfolio management competencies in the DoD may be a vital component to improving the acquisition system and meeting the FY2021 NDAA requirements.

Background and Literature Review

Product Portfolio Management

Portfolio management is an approach that commercial companies use to optimize investments (GAO, 2015). It starts with understanding customers' needs and desires and then prioritizes acquisition opportunities while accounting for resource constraints. Once the opportunities are prioritized, business cases are created, reviewed and "assessed against others in the portfolio" (GAO, 2015, p. 5). Resources, established criteria, competing products, and the organization's strategic goals are all considered during the assessment. This process continues "until only those alternatives with the greatest potential to succeed" are added to the product portfolio (GAO, 2015, p. 5). Therefore, the DoD would only create new programs through a holistic portfolio analysis process (GAO, 2015).

A portfolio management strategy improves the defense acquisitions procedure in three significant ways. First, it requires acquisition professionals to assess investments collectively at the enterprise and component level rather than as independent initiatives at the service level. Second, it uses "an integrated approach to prioritize needs and allocate resources" to align with strategic goals (GAO, 2015, p. 7). Last, it empowers leaders to make investment decisions and provides a mechanism to hold them accountable for the outcome (Section 809 Panel, 2019a). Under this construct, program executive officers (PEOs) would be replaced with portfolio acquisition executives (PAEs). These PAEs would be delegated milestone decision authority (MDA) in most cases. Instead of being funded to manage a single program, they would create a road map, draft a budget, and receive funding for their portfolio. Using the gated process to receive guidance from strategic decision-makers, the PAE would shift funding, timelines, and other priorities within their portfolio to meet customer needs and strategic goals. They would also be responsible for ensuring interoperability, managing the entire life cycle, and working with the research and development (R&D) community regarding prototyping and experimentation (Section 809 Panel, 2019a).

Current defense acquisitions procedures measure success through cost, schedule, and performance metrics for individual programs with acquisition program baselines. However, these measurements do not allow program managers to develop optimal solutions across a range of capabilities and customer needs. Therefore, at times they can be detrimental to the larger, strategic mission. Additionally, they provide little insight into the value the program offers to the customer. Last, they do not allow flexibility because they incentivize stability and avoiding new requirements. Instead, PAEs and portfolios should be judged on things such as “customer satisfaction, user acceptance or reject rates, user productivity improvements, mission effectiveness enhancements, and many others that relate to value and return on investment” (Shultz, 2020, p. 47). Additionally, there must be a mechanism to measure the success of things such as rapid prototyping. These may include metrics such as “time to deliver knowledge points, cycle time to build virtual prototypes, number of failures and lessons learned, and time to mature prototypes into fieldable capabilities” (Shultz, 2020, p. 47).

Defining what PPM is and what it is not, is of particular importance in the DoD because the terms program, portfolio, and project are often used interchangeably by defense acquisition professionals at all levels. PMI defines a portfolio as “a collection of projects, programs, subsidiary portfolios, and operations managed as a group to achieve strategic objectives” (Project Management Institute [PMI], 2017b, p. 6). While the first part of this definition is easily understood, the second half can generate confusion. A portfolio is a way to hedge against risk by pooling resources. Hence, a portfolio must be made with a clear strategy and priorities that the manager can use to make decisions. If portfolio managers are given a set of missions or capabilities they must meet, they can then analyze the assets and programs within the portfolio available to fulfill that mission. The manager can then identify gaps in the portfolio where the DoD must allocate resources. These gaps inform how funding, personnel, and R&D should be allocated, all while keeping within the overarching strategy of the portfolio. Portfolio managers are not overly invested in the success or failure of any particular project or program but instead focus on how individual programs are performing holistically within the portfolio (PMI, 2017b). Success is determined based on “aggregate investment performance and benefits realization of the portfolio” (PMI, 2017b, p. 6). While in business, a company may have just one portfolio, such as Ford’s portfolio of vehicles or Coca-Cola’s portfolio of soft drinks, but the DoD is too large and its mission too robust and diverse for only one portfolio.

As displayed in Table 1, projects, programs, and portfolios are not interchangeable, as they are separately defined, structured, and executed. These concepts build on each other, as a project is the most narrowly scoped item, a program is a “group of related projects … that are managed in a coordinated manner,” and portfolios are “a collection of projects, programs, subsidiary portfolios, and operations managed to achieve strategic objectives” (PMI, 2017b, p. 3). One of the critical elements of the portfolio versus a program or project is the aggregation highlights in Table 1. While programs consist of projects, or program components, that require “coordinated and complimentary” scope, planning, and management, portfolios require a higher coordination threshold, evidenced in the focus on the coordination in aggregate (PMI, 2017b). Additionally, the monitoring and success elements further highlight the differences in scope and focus of programs and portfolios. Program monitoring is focused “to ensure the overall goals, schedules, budget, and benefits of the program will be met” (PMI, 2017b, p. 6). The cost, schedule, and performance metrics currently used meet the standards of monitoring for programs. However, for a portfolio, monitoring requires analyzing the projects and programs within the portfolio in aggregate to determine overall “resource allocation, performance results, and risk of the portfolio” (PMI, 2017b, p. 6). Rather than monitor an individual project or program, the portfolio considers all aspects of those nested projects and programs to provide an organizational view versus narrowly considering individual projects or programs. Measures of success for programs include cost, schedule, and performance metrics compared to success in a portfolio, which is “measured in terms of the aggregate investment performance and benefit realization” (PMI, 2017b, p. 6) of the portfolio at large. These comparisons highlight the differences and the hierarchy of projects, programs, and portfolios.

Table 1. Comparative Overview of Portfolio, Program, and Project Management.
(PMI, 2017b, p. 6).

Organizational Project Management			
	Projects	**Programs**	**Portfolios**
Definition	A project is a temporary endeavor undertaken to create a unique product, service, or result.	A program is a group of related projects, subsidiary programs, and program activities that are managed in a coordinated manner to obtain benefits not available from managing them individually.	A portfolio is a collection of projects, programs, subsidiary portfolios, and operations managed as a group to achieve strategic objectives.
Scope	Projects have defined objectives. Scope is progressively elaborated throughout the project life cycle.	Programs have a scope that encompasses the scopes of its program components. Programs produce benefits to an organization by ensuring that the outputs and outcomes of program components are delivered in a coordinated and complementary manner.	Portfolios have an organizational scope that changes with the strategic objectives of the organization.
Change	Project managers expect change and implement processes to keep change managed and controlled.	Programs are managed in a manner that accepts and adapts to change as necessary to optimize the delivery of benefits as the program's components deliver outcomes and/or outputs.	Portfolio managers continuously monitor changes in the broader internal and external environments.
Planning	Project managers progressively elaborate high-level information into detailed plans throughout the project life cycle.	Programs are managed using high-level plans that track the interdependencies and progress of program components. Program plans are also used to guide planning at the component level.	Portfolio managers create and maintain necessary processes and communication relative to the aggregate portfolio.
Management	Project managers manage the project team to meet the project objectives.	Programs are managed by program managers who ensure that program benefits are delivered as expected, by coordinating the activities of a program's components.	Portfolio managers may manage or coordinate portfolio management staff, or program and project staff that may have reporting responsibilities into the aggregate portfolio.
Monitoring	Project managers monitor and control the work of producing the products, services, or results that the project was undertaken to produce.	Program managers monitor the progress of program components to ensure the overall goals, schedules, budget, and benefits of the program will be met.	Portfolio managers monitor strategic changes and aggregate resource allocation, performance results, and risk of the portfolio.
Success	Success is measured by product and project quality, timeliness, budget compliance, and degree of customer satisfaction.	A program's success is measured by the program's ability to deliver its intended benefits to an organization, and by the program's efficiency and effectiveness in delivering those benefits.	Success is measured in terms of the aggregate investment performance and benefit realization of the portfolio.

Within Defense acquisitions, portfolio management has technically been required since 2008 with the establishment of DoD Directive 7045.20, Capability Portfolio Management, and the framework for portfolio management has been in place since the establishment of PEOs in the 1990s. However, "no substantial changes to the program approach have materialized," as the majority of projects maintained the program-centric model because the overall structure of the defense acquisitions system "is not well suited for portfolio-based management" (Section 809 Panel, 2019a, p. 77). Despite the creation of PEOs in the 1990s and the direction for portfolio management, "PEOs were not assigned any additional duties in statute or DoDD 5000.01 to accomplish portfolio management … instead, they are midlevel managers," without being responsible for or held accountable for a portfolio management baseline (Section 809 Panel, 2019a, p. 77).

Over the last several decades, the U.S. government sponsored numerous efforts, studies, panels, and reports regarding the requirement for DoD acquisitions to undergo significant reform, depart from the historical PM approach, and manage acquisitions in a portfolio-centric model. These efforts were codified by the Section 809 Panel on Streamlining and Codifying Acquisition Regulations as established by the direction contained in the FY2016 NDAA. The purpose of the Section 809 Panel was to "review the acquisition regulations … with a view toward streamlining and improving the efficiency and effectiveness of the Defense acquisition process” (Section 809 Panel, 2017, p. 5). The panel was also charged with making recommendations for changes necessary to improve the process, preserve the integrity of the process, and remove any hindrances to the process. The panel released multiple reports from 2016 to 2019. They produced 98 recommendations for changes and improvements to the defense acquisitions system, with many of the recommendations focusing on the requirement for actual portfolio management. The Section 809 Panel “identified portfolio management as a priority for reform, recommending not only a change in investment processes but a shift away from the decades-old program-centric acquisition model” (Shultz, 2020, p. 44). Specifically, the Section 809 Panel’s (2019a, p. 17) Recommendation 38 is to “implement best practices for portfolio management” and includes the following language:

> Moving defense acquisition from a highly centralized, program-centric model with stovepipe-driven requirements, budget, and acquisition processes to a collaborative, decentralized, portfolio-centric framework entails nothing more than implementing management best practices. The move would yield timely, flexible, agile, cost-effective, and technologically innovative weapon systems acquisition and sustainment. Portfolio management is no longer in its infancy; there are standards and best practices that DoD can use while implementing the recommended multitiered capability portfolio framework. (Section 809 Panel, 2019a, p. 84)

While some acquisitions professionals argue that portfolio management already occurs due to the previous instructions and directives, “each program navigates the acquisition life cycle independently [and] programs design, develop, test, and produce individual systems that meet a defined set of requirements within an allocated budget” (Janiga & Modigliani, 2014, p. 13) regardless of classification under a portfolio.

DoD Competency Model

According to DoD Instruction 5000.66, Defense Acquisition Workforce Education, Training, and Career Development Program, a competency is a “measurable pattern of knowledge, skills, abilities, behaviors, and other characteristics that an individual needs to perform work roles or occupational functions successfully. Competencies are used to develop acquisition training and education standards” (Office of the Under Secretary of Defense for Acquisition and Sustainment [OUSD(A&S)], 2019, p. 34). DoD policy requires that functional community competency models be established and maintained by functional leaders (FL)—civilians within the OUSD(A&S). FLs coordinate with component DACMs; the executive director, Human Capital Initiatives (HCI); the president of the DAU; and the functional integrated product team (FIPT) on all aspects regarding competency models and requisite certifications. The policy requires the standards to be reviewed and updated annually (OUSD[A&S], 2019).

The DoD PM Career Field Functional Competencies (DAU, 2020) fall under Tier 2, Primary Occupational Competencies within the DoD Competency Management Framework (OUSD[A&S], 2019). They define “the needed skills, abilities and knowledge for three levels of [DoD PM] employees as discerned by the PM Working Groups” (MacStravic, 2016, p. 2). The purpose of these standards is to ensure that program managers are trained and can be adequately evaluated on the requisite skills that provide critical warfighting capabilities to the DoD. The DoD further breaks down the structure of competencies and their interaction with the education realm from this overarching framework. In the Acquisition Education and Training Competency Model Framework, competency standards are divided into units of competency, competency topics, and sub-competencies (OUSD[A&S], 2019, p. 18). As a result of DAWIA, the government created the DAU and assigned it to provide training for acquisition professionals.

Portfolio manager is neither listed as a "career path" nor a "career field." This is because DoD policy states, "Neither the career field nor the career path competency models should contain [DoD] Component-specific or position-specific competencies" (OUSD[A&S], 2019, p. 18). Instead of being listed as a particular career path, the DoD associates portfolio management with the position of PEOs, PMs and deputy PMs of Major Defense Acquisitions Programs (MDAP) and Major Automated Information Systems (MAIS), and PMs and deputy PMs of "significant nonmajor programs" (DAU, n.d.). This is reflected in the Unique Position Training Standards listed under DAU's PM certification guide. This section has two required courses for these critical positions: PMT 4010, Program Management Course, and PMT 4020, Executive Program Manager's Course (DAU, n.d.). Within the course description and learning objectives for PMT 4020, portfolio-centric outcomes, impacts, and learning objectives are described and associated with topics such as portfolio strategy, governance, capabilities integration, risk, portfolio performance, and stakeholder management (DAU, 2021). This indicates that the DAU has established a training and education pathway for portfolio management to some degree. However, these outcomes, impacts, and learning objectives are only resident in this two-week training course. They are not currently linked to any particular competency or sub-competency standards as outlined in the Acquisition Education and Training Competency Model Framework.

Project Management Institute

The American National Standards Institute (ANSI) recognizes the PMI as the consensus national standard for program, project, and portfolio management certification (Karnes, 2020). Figure 1 shows the relationship between the disciplines of project, program, and portfolio management. The PMI Project Management Professional (PMP) and Program Management Professional (PgMP) certifications are widely recognized and feed into the PMI Portfolio Management Professional (PfMP) certification.

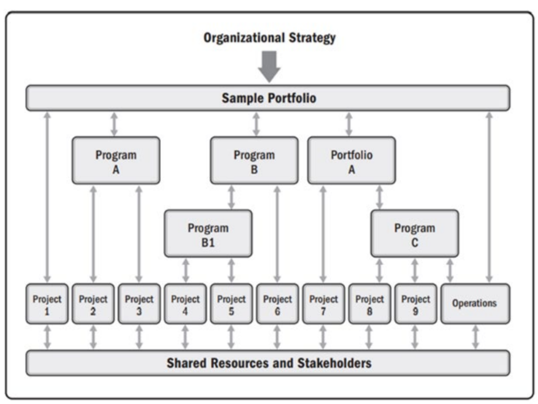

Figure 1. Portfolios, Programs, and Projects: High-Level View.
(PMI, 2017b, p. 4).

The PfMP certification is one of the most rigorous offered and requires an extensive amount of experience. PfMP applicants must have a minimum of eight years of professional business experience and four to seven years of unique nonoverlapping professional portfolio management experience. This does not mean that the applicant must be the senior portfolio manager but, instead, must just have worked in an organization that uses the portfolio management construct. Applicants must also complete a 500-word summary detailing their portfolio management experience (PMI, 2017a). Once the application is complete, a panel of volunteer portfolio managers worldwide review the application and make the accession decision. If accepted, the candidate has one year to study for and pass the PfMP exam. Once a candidate has achieved PfMP certification, they must report 60 professional development units (PDUs) every three years.

PMI delineates the PfMP certification from the others it offers by chartering an independent third-party study every five to seven years (PMI, 2017a). This study is conducted by professionals from around the world and analyzes specific roles associated with the duties of a portfolio manager. PMI competency standards for portfolio management are validated and updated as required to reflect the current best practices of industry professionals. Once the study is complete, PMI sends a survey out to thousands of portfolio managers worldwide requesting feedback on the updated standards. Once the responses are analyzed, a final competency standard is published and used to develop curriculum and testing (PMI, 2017a). *The Standard for Portfolio Management,* 4th edition, explains various tasks related to the six recognized performance domains shown in Figure 2 (PMI, 2017b). However, for certification purposes, PMI only tests on five domains—including Strategic Alignment, Governance, Portfolio Performance, Portfolio Risk, and Communication (as shown in Figure 2). These five domains and their numerous competencies form the basis of our analysis and research.

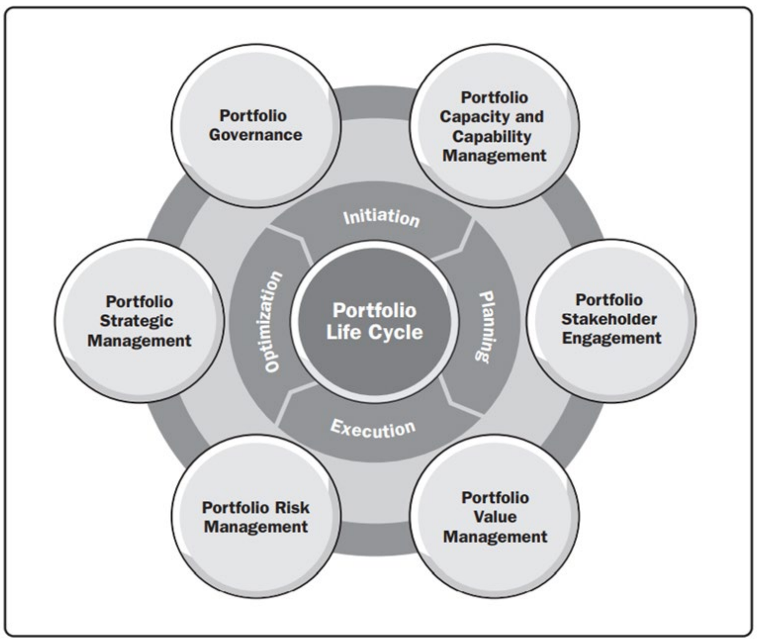

Figure 2. Portfolio Management Performance Domains.
(PMI, 2017b, p. 10).

Methodology

This research used mixed quantitative and qualitative methods. Specifically, a competency gap analysis was conducted by mapping the current DoD PM Career Field Functional Competencies (DAU, 2020) to the PMI (2013) PfMP Examination Content Outline domains and tasks to answer first two research questions:

- Are there gaps in the DoD PM competency standards that must be addressed before the DOD can fully implement PPM as directed in the NDAA of 2021?

- Where are the DoD and Project Management Institute (PMI) aligned regarding competency standards?

To answer the third research question—What barriers exist regarding the implementation of PPM standards for Defense acquisitions?—the assessed gaps were assessed into three qualitative categories based on perceived barriers to implementation (BTI), and categorized the BTI as low, medium, or high. Low BTI indicate the gaps that are easiest to address immediately. Medium BTI show that the Defense acquisitions must alter either personnel or policy to address the gap adequately. Finally, barriers assessed as high indicate that Defense acquisitions must change both personnel structure and policy to address the gap adequately.

A gap analysis is the process of reviewing and comparing the current state of operations to a proposed ideal state, highlighting where the current state falls short of the ideal state, and describing the steps required to close the gap (Weller, 2018). We used the PMI (2013) PfMP Examination Content Outline domains and tasks as the ideal state for this analysis. To capture and assess the current state of operations, we used the DoD PM Career Field Functional Competencies (DAU, 2020). The use of the DoD PM Career Field Functional Competencies (DAU, 2020) provided opportunities for efficiency and a logical progression of competency standards from a program to a portfolio-centric model. By selecting existing competency standards and making the necessary adjustments to fit a new model, the DoD can gain efficiencies in training and education. Additionally, acquisitions professionals can progress within their career tracks more seamlessly by building upon common standards where common standards are warranted. Furthermore, the use of the PfMP Examination Content Outline (PMI, 2013) as the "ideal state" ensured that the DOD is basing the defense acquisitions education and training curriculum on the industry's leading competency content while meeting congressional mandates from NDAA requirements.

Data Sources

The primary data sources used for the quantitative and qualitative analyses were the DoD PM Career Field Functional Competencies (DAU, 2020) and the PMI (2013) PfMP Examination Content Outline domains and tasks.

The DoD Program Management Career Field Functional Competencies served as our primary data source for DoD competency standards (DAU, 2020). They consist of four competency units, including Acquisition Management (AM), Business Management (BM), Technical Management (TM), and Executive Leadership (EL; DAU, 2020). Within each of these competency units are distinct topics, and within each of the topics are specific competencies and their subordinate sub-competencies. Table 2 depicts the overarching structure of the DoD PM Career Field Functional Competencies (DAU, 2020). The competency units are depicted as colored headers. The topics within each competency unit are listed in bold, and their nested competencies are indented within each. The DoD PM Career Field Functional Competencies list breaks down each competency based on this framework, which aligns with the DOD's overall competency framework. The four competency units are further broken down into 18 units of competency (UOC)/topics, 69 competencies, and 184 competency elements/sub-competencies.

Table 2. Program Management Competency Units, Topics, and Competencies.
(MacStravic, 2016, p. 3).

Acquisition Management		**Technical Management**
Capability Integration Planning	**Program Execution**	**Engineering Management**
Requirements Management (Mgmt)	Risk/Opportunity Mgmt	Technical Planning
Acquisition Program Strategic Planning	Program Planning	Requirements Decomposition
Business Case Development	Teaming	Technical Assessment
Acquisition Law and Policy	Program Oversight	Decision Analysis
Acquisition Policy and Best Practice	Resource Mgmt	Configuration Mgmt
Contractual Laws, Regulations, and Obligations	Technology Mgmt	Technical Data Mgmt
Financial Mgmt Laws, Directives, and Policies	**Services Acquisition**	Interface Mgmt
Program Support Laws, Directives, and Policies	**Business Management**	**Defense Business Systems**
Technical and Engineering Laws, Directives and Policies	**Contract Management**	DBS Certification
Information Technology Laws, Policy, Best Practices	Market Research	DBS Acquisition Approach Preparation
International Acquisition and Exportability	Pre-Solicitation Planning and Execution	**Test and Evaluation Mgmt**
International Cooperative Programs	Source Selection and Negotiations	Test Planning
Sales and Transfers	Contract Administration	Test Execution
Technology Security and Foreign Disclosure	Contract Closeout	**Manufacturing Mgmt**
Defense Exportability Integration	**Financial Mgmt**	Manufacturing Planning and Transition
	Financial Planning	Manufacturing Shutdown
Stakeholder Mgmt	Programming	**Product Support Mgmt**
Political Savvy	Budget Formulation	Product Support Planning
External Situational Awareness	Budget Execution	Product Support Mgmt
Media Relationships	Cost estimates	Supply Chain Mgmt
Executive Leadership		
Foundational Competencies	**Leading Change**	**Results Driven**
Interpersonal Skills	Creativity & Innovation	Accountability
Integrity / Honesty	Vision	Decisiveness
Communicate Effectively	Flexibility	Entrepreneurship
Continual Learning	Resilience	Customer Service
Public Service Motivation	**Leading People**	Problem Solving
Technical Credibility	Conflict Management	
Building Coalitions	Leveraging Diversity	
Influencing / Negotiating	Developing Others	
Partnering	Team Building	

The PMI (2013) PfMP Examination Content Outline served as our primary data source for industry portfolio management competency standards. PMI designed the PfMP exam to reflect the required skills of portfolio management professionals (PMI, 2013). The PfMP exam "measures and evaluates appropriately the specific knowledge and skills required to function as a portfolio management professional" (PMI, 2013, p. 1). The purpose of the exam is to ensure that each required element of portfolio management is accurately measured to validate competency in the portfolio management profession. This purpose aligns with the goal of DoD PM Career Field Competency Standards (DAU, 2020). The exam outline lists five domains and weights each in terms of importance for assessment. This weight is depicted by the percentage of questions on the exam, as outlined in Table 3. The five assessed domains are Strategic Alignment, Governance, Portfolio Performance, Portfolio Risk Management, and Communications Management. Each of these domains includes subordinate tasks. PfMP domains are equivalent to DoD competency units. PfMP tasks are analogous to DoD competencies. Appendix A provides the detailed explanation of the tasks within the portfolio management domains.

Table 3. Portfolio Management Professional Examination Domains and Weights. (PMI, 2013, p. 3).

Domain	Percentage of Items on Exam
Strategic Alignment	25%
Governance	20%
Portfolio Performance	25%
Portfolio Risk Management	15%
Communications Management	15%

Qualitative Analysis of Data

A lexicographic analysis of keywords and the principal purpose of each DoD PM competency was matched to each of the PMI PfMP domains and tasks. Karnes's (2020) work on aligning PM competencies with PMI standards informed our approach; however, the goal of the gap analysis was to analyze the current state of operations (PM competency standards) to the ideal state (PMI PfMP domains and tasks). This research mapped as many applicable DoD PM standards as possible to the PMI standard. Meaning, if a DoD PM competency standard did not align with a PMI standard, it may not appear in the analysis. This approach ensured that we were not simply attempting to find alignment where no alignment existed or focus on maintaining competency standards that did not apply to a fundamentally different acquisitions strategy. However, it supported identifying commonalities and building upon existing DoD PM competency structures to minimize unnecessarily modified standards.

A competency alignment matrix with three classifications of alignment was created: No Discernible Alignment (color code: red), Partial Alignment (color code: yellow), or Full Alignment (color code: green). It is organized first by PMI PfMP domain and then by PfMP task. The task number and description match the task number and description from the PfMP Exam Content Outline (PMI, 2013). Each competency includes the UOC/topic number (e.g., AM1), the competency description listed in the DoD PM Career Field Functional Competencies (DAU, 2020), and a color-coded qualitative alignment assessment. The assessment of alignment was based on the following criteria:

- No Discernible Alignment indicated that no current DoD PM competency standard fit the description of a PMI-stated task.
- Partial Alignment indicated that one or more keywords or the general purpose of the DoD PM competency or sub-competencies related to the PMI stated task.
- Full Alignment indicated that an existing DoD PM competency standard matched the PMI stated task to the degree that included several exact word matches or clearly aligned descriptions, purposes, or applications.

After reviewing and matching all applicable DoD PM competency standards to the PMI domains and tasks, BTI scores were assessed. A shift from a PM-centric to a portfolio management-centric strategy will inherently require policy and operational changes. The assessed barriers signal to defense acquisitions decision-makers the areas where we perceive that implementation would be the most challenging. The color-coding of alignment guided an initial assessment, but a lexicographic alignment of competency standards may not correlate directly with ease of implementation. The coding approach used to analyze alignment included the following:

- No BTI as practices that already occur within the DoD.
- Low BTI as changes that the DoD could implement immediately with little to no change in personnel structure or additional policy concerns.
- Medium BTI as changes that would require either significant changes in policy or personnel structure.
- High BTI as changes that would require both significant personnel and policy changes.

Quantitative Analysis of Data

To assess a quantitative measure of alignment, the following Alignment Score scale was defined:

- No Discernible Alignment = 0
- Partial Alignment = 0.5
- Full Alignment = 1

Each PMI PfMP task was assessed an alignment score based on the qualitative assessment. Within each PfMP domain, average score were calculated (i.e., the total score of all tasks divided by the total number of tasks within the domain). The average scores indicate the degree to which the DoD is already postured to transition to train, educate, and assess portfolio management skills based on its current PM competency standards. To assess a quantitative measure of BTI, the following Barrier to Implementation Rating scale was defined:

- No BTI = 0
- Low BTI = 1
- Medium BTI = 2
- High BTI = 3

Each PMI PfMP task was assigned a BTI rating using this scale based on the qualitative assessment. Within each PfMP domain, the average score was calculated (i.e., the total score of all tasks divided by the total number of tasks within the domain), and rounded to the nearest one-hundredth of a point to provide a quantitative domain BTI rating. This rating indicated the assessed degree of difficulty in implementing portfolio management standards based on current DoD practices, personnel, and policy.

Results

Overall Alignment

Table 4 depicts the alignment between the PMI PfMP competency standards and the DOD competency standards broken down by PfMP domain. The overall average alignment of the two standards is 41%. However, within each domain, those alignment scores vary significantly. In the domains of Strategic Alignment and Governance, the DoD is very poorly aligned with PfMP standards, while in the domain of Communications Management, the two standards are aligned 100%. When evaluating the overall alignment score, it is critical to recognize the weights of each domain from the PfMP Examination Content Outline (PMI, 2013). The three most heavily weighted domains—Strategic Alignment, Portfolio Performance, and Governance—exhibit the three lowest alignment percentages of the five domains. The remaining two domains—Portfolio Risk Management and Communications Management—exhibit the highest alignment but are the least heavily weighted domains in the PfMP certification exam. This is significant because the weights from the exam represent the importance of the domain in evaluating competency. This is calculated by taking the weighted average—multiplying the PfMP exam weights by the assessed alignment percentages. For example, the Strategic Alignment domain is worth 25% of the PfMP exam. It is then multiplied by the assessed percentage—19%—for a total score of 4.75%. When each domain is weighted and summed, the assessed alignment drops to 36%.

Table 4. Raw and Weighted Alignment Scores

Domain	Alignment Score	Exam Weight
Strategic Alignment	19%	25%
Governance	0%	20%
Portfolio Performance	35%	25%
Portfolio Risk Management	50%	15%
Communications Management	100%	15%
Average Alignment	**41%**	**36%**

Detailed Alignment Analysis by Domain

Table 5 depicts the detailed view of the analysis in the Strategic Alignment domain. Partial alignment existed in such tasks as evaluating organizational strategic goals, gathering data, and identifying potential portfolio components through business plans, because those tasks must be done even in a program-centric model. There was no discernable alignment for five of the eight tasks because they spoke specifically to tasks carried out by an organization with the structure and policy to execute portfolio management.

Table 5. Strategic Alignment Domain Comparison

PMI Portfolio Management Professional (PfMP) Compentencies		DoD Program Management Career Field Functional Compentencies					
Domain 1: Strategic Alignment							
Task #	Task	UOC	Competency	Alignment Score	19%	Barrier to Implementation Rating	1.63
1	Evaluate organizational strategic goals and objectives using document reviews, interviewing, and other information gathering techniques in order to understand the strategic priorities.	AM1	Supervise the acquisition program strategic planning process to develop and document the organization's mission, vision of success, and fundamental values as they relate to achieving successful acquisition outcomes	0.5		1	
2	Identify prioritization criteria (e.g., legislative, dependencies, ROI, stakeholder expectations, strategic fit) using information gathering and analysis techniques in order to create a basis for decision making.		No Disernable Alignment	0		2	
3	Rank strategic priorities working with key stakeholders and using qualitative and quantitative analyses in order to provide a guiding framework to operationalize the organizational strategic goals and objectives.		No Disernable Alignment	0		2	
4	Identify existing and potential portfolio components by reviewing documentation such as business plans/proposals in order to create portfolio scenarios.	BM1	Plan and lead a market research effort to define the industry/ procurement environment and gather and apply relevant market research information to initiate and execute the program. Utilize PCO advice on source selection sensitive information in scenarios involving contractors to prevent future conflict of interest or potential competitive advantage.	0.5		2	
5	Create portfolio scenarios (what-if analysis) by reviewing components against prioritization criteria and using analysis techniques (e.g., options analysis, risk analysis, SWOT analysis, financial analysis) in order to evaluate and select viable options.		No Disernable Alignment	0		1	
6	Recommend portfolio scenario(s) and related components, based on prioritization analysis/criteria, in order to provide governance with a rationale for decision making.		No Disernable Alignment	0		1	
7	Determine the impact to portfolio and portfolio components due to changes in strategic goals and objectives, in order to sustain strategic alignment.		No Disernable Alignment	0		2	
8	Create high level portfolio roadmap working with key stakeholders using prioritization, interdependency analysis, and organizational constraints in order to confirm and communicate the portfolio components sequencing, dependencies, and strategic alignment.	AM3	Analyze an integrated master plan (IMP) confirming measures of effectiveness, measures of performance, technical performance measures and accomplishment criteria accurately define the program architecture consistent with the acquisition strategy, SEP and TEMP	0.5		2	

The most significant gaps in the DOD competency standard regarding portfolio management are related to the Governance domain. As shown in Table 6, 0% alignment in this domain was observed. The tasks in this domain include establishing policies, procedures, authorities, and management models that align with portfolio management practices. The current DoD standards do not speak to this. Moreover, in practice these governance models either do not exist or, at the very least, are not codified in writing.

Table 6. Governance Domain Comparison

Domain 2: Governance							
Task #	Task	UOC	Competency	Alignment Score	0%	Barrier to Implementation Rating	3
1	Define and establish a governance model including the structure (including but not limited to steering committees, governance boards), policies, and decision-making roles, responsibilities, rights and authorities in order to support effective decision-making and achieve strategic goals.		No Disernable Alignment	0		3	
2	Determine portfolio management standards, protocols, rules, and best practices, using organizational assets (such as information systems, subject[1]matter experts) and industry standards in order to establish consistent portfolio management practices.		No Disernable Alignment	0		3	
3	Define and/or modify portfolio processes and procedures including but not limited to benefits realization planning, information management, performance, communication, risk management, stakeholder engagement, resource management, and change management in order to manage the portfolio efficiently and effectively.		No Disernable Alignment	0		3	
4	Create the portfolio management plan including, but not limited to, roles and responsibilities, governance model, escalation procedures, risk tolerances, and governance thresholds, change control and management, key performance indicators, prioritization model, and communication procedures using standards, models, and other organizational assets in order to ensure effective and efficient portfolio management.		No Disernable Alignment	0		3	
5	Make recommendations and obtain approval regarding portfolio decisions (e.g, components, plans, budget, roadmap) through communication with key decision makers as defined by the governance model, in order to authorize the execution of the portfolio.		No Disernable Alignment	0		3	

In the domain of Portfolio Performance, the DoD competency standard was 35% aligned with the PfMP standard. Full alignment was observed in three of the 10 tasks and partial alignment in one. As shown in Table 7, the places where the standards align include monitoring performance and ensuring strategic alignment with organizational goals. Moreover, they align in training personnel to escalate issues to appropriate decision-makers, propose solutions, and determine the decision's impacts on the organization. However, the standards did not align in six of the 10 tasks related to Portfolio Performance. Specifically, the PfMP standard calls for training in creating and implementing a portfolio road map. Since the DoD only trains personnel at the program level, this structure and policy do not exist. Moreover, the DOD does not currently train or educate personnel on balancing, prioritizing, or optimizing funding across a portfolio, which is a central theme in portfolio management.

Table 7. Portfolio Performance Comparison

Domain 3: Portfolio Performance							
Task #	Task	UOC	Competency	Alignment Score	35%	Barrier to Implementation Rating	1.30
1	Initiate the portfolio using the portfolio roadmap and supporting artifacts in order to authorize the portfolio structure and activate the components.		No Disernable Alignment	0		2	
2	Collect and consolidate key performance metric data, as defined by portfolio governance and using various techniques, in order to measure the health of the portfolio.	EL4	(Entrepreneurship) Position the organization for future success by identifying new opportunities, improving products or services. Compose appropriate metrics to obtain feedback and implement process improvements. Execute process improvement methods to eliminate time, economic, and product waste.	0.5		1	
3	Monitor the portfolio performance on an ongoing basis, using reports, conversations, dashboards, and auditing techniques in order to ensure portfolio effectiveness and efficiency and maintain strategic alignment.	EL4	Hold self and others accountable for measurable high-quality, timely, and cost-effective results by monitoring progress and evaluates outcomes to improve organizational efficiency and effectiveness. Quality Management. Includes the processes for incorporating the organization's quality policy regarding planning, managing, and controlling project and product quality requirements, in order to meet stakeholders' expectations.	1		0	
4	Manage and escalate issues by communicating recommended actions to appropriate decision makers for timely approval and implementation of proposed solution(s).	EL4	Make well-informed, effective, and timely decisions, even when data are limited or solutions produce unpleasant consequences; perceive the impact and implications of decisions	1		1	
5	Manage portfolio changes using change management techniques, in order to improve portfolio performance and maintain strategic alignment.	EL4, EL5	EL4: See above. EL5: (Problem Solving) Conduct an evaluation of a program to identify, analyze, and create solutions for problems. Distinguish between relevant and irrelevant information to make logical judgments. Implement an appropriate corrective action plan within program resources	1		1	
6	Balance portfolio and prioritize portfolio components, using established criteria and methods in order to optimize resource utilization and achieve strategic portfolio objectives.		No Disernable Alignment	0		2	
7	Analyze and optimize the consolidated allocation/reallocation of capacity (e.g., people, tools, materials, technology, facilities, financial) using supply/demand management and scenario analysis techniques to ensure portfolio efficiency and effectiveness.		No Disernable Alignment	0		1	
8	Update and refine existing portfolio road maps, using change analysis in order to facilitate re-allocation of organizational resources to the portfolio.		No Disernable Alignment	0		2	
9	Measure the aggregated portfolio performance results against the defined business or strategic goals and objectives in order to demonstrate progress toward the achievement of business or strategic goals.		No Disernable Alignment	0		1	
10	Maintain records by capturing portfolio artifacts, such as approvals, prioritizations, and other decisions, in order to ensure compliance with organizational policies, regulatory requirements, and portfolio management standards		No Disernable Alignment	0		2	

As depicted in Table 8, 50% alignment was observed in the domain of Portfolio Risk Management. The DoD standard devotes significant time to outlining ways in which acquisitions personnel must identify and mitigate risk. However, in half of the tasks listed in the PfMP standard, the document speaks directly to processes and procedures unique to a portfolio management structure. These include tasks such as dependency analysis, portfolio-level risk registers, and analysis of portfolio management reserves. The DoD's program-centric training does not require similar practices.

Table 8. Portfolio Risk Management Comparison

Domain 4: Portfilio Risk Management							
Task #	Task	UOC	Competency	Alignment Score	50%	Barrier to Implementation Rating	1.33
1	Determine acceptable level of risk for the portfolio, based on organizational and stakeholder risk tolerances, in order to provide input to governance.	AM3	Establish, specify, and manage an integrated risk, issue and opportunity management process. Risk Management. Includes the processes of conducting risk management planning, identification, analysis, response planning, response implementation, and monitoring risk on a project.	1		1	
2	Develop the portfolio risk management plan, using governance risk guidelines, processes, and procedures and other organizational assets in order to capitalize on opportunities, and respond to risks.	AM3	Establish, specify, and manage an integrated risk, issue and opportunity management process. Includes the processes of conducting risk management planning, identification, analysis, response planning, response implementation, and monitoring risk on a project.	1		1	
3	Perform dependency analysis to identify and monitor risks related to the interdependencies and intradependencies within or across portfolios in order to support decision-making.		No Disernable Alignment	0		2	
4	Develop, monitor, and maintain portfolio-level risk register, including risks to strategic goals and objectives, to business value, and escalated from portfolio components, using risk management processes in order to support decision making.		No Disernable Alignment	0		1	
5	Promote common understanding and stakeholder ownership of portfolio risks, through communications with stakeholders, in order to facilitate risk response.	EL1	Plan for the dissemination of information both internally and externally with emphasis on ensuring all work groups, project oriented teams, IPPTs, PM Staff and several layers of contractor/sub-contractor employees have comprehensive macro view of the program priorities	1		1	
6	Provide recommendation and obtain approval for a portfolio management reserve, based on aggregate portfolio risk exposure, in order to optimize portfolio strategic goals and objectives		No Disernable Alignment	0		2	

Table 9 shows the alignment of the two standards in the domain of Communications Management. In this domain, 100% alignment was observed. The DoD standard goes to great lengths to describe the type of communication they expect from their acquisition professionals. This training is easily transferrable to a portfolio management format. Moreover, in this section of the PfMP standard, there is less portfolio-specific verbiage used. Instead, it is spelled out how portfolio managers should engage stakeholders and communicate up and down the chain of command.

Table 9. Communications Domain Comparison

Domain 5: Communications Management							
Task #	Task	UOC	Competency	Alignment Score	100%	Barrier to Implementation Rating	0
1	Analyze internal and external stakeholders using techniques such as meetings, interviews, surveys/questionnaires, in order to identify stakeholder expectations, interests, and influence on the success of the portfolio.	AM3	Organize, manage, coach, lead and evaluate program teams (working groups, IPTs, project-oriented teams, support contractor teams, system integrator/supplier teams) to maximize efficiency within the program/portfolio.	1		0	
2	Create the aggregate communication strategy and plan, including methods, recipients, vehicles, timelines and frequencies in order to enable effective communication to stakeholders.	AM4	Maintain awareness of the environment external to an acquisition program simultaneously from (including) historical, current, and future perspectives. Apply the media related policies contained in Agency directives/publications in addressing public affairs.	1		0	
3	Engage stakeholders, through oral and written communication, to ensure awareness, manage expectations, foster support, and build relationships and collaboration for the success of the portfolio roadmap.	EL1	(Communicate Effectively) Plan for the dissemination of information both internally and externally with emphasis on ensuring all work groups, project oriented teams, IPPTs, PM Staff and several layers of contractor/sub-contractor employees have comprehensive macro view of the program priorities.. 1. Write in a clear, concise, organized, and convincing manner for the intended audience. 2. Make clear and convincing oral presentations. Listen effectively; clarify information as needed. 4. Share & communicate lessons learned. Explain how process improvements at the macro level translate into improved operational effectiveness. 5. Pursue chances to stretch skills to further professional growth to include using challenges as opportunities to improve and become more effective.	1		0	
4	Maintain the communication strategy and plan by evaluating current communications capabilities, identifying gaps, and documenting communications plan to meet stakeholder requirements.			1		0	
5	Prepare and/or facilitate stakeholder understanding of portfolio management[1]related processes, procedures, and protocols using organizational assets (e.g., information systems, training delivery methods) in order to promote common understanding and application of the portfolio management process.			1		0	
6	Verify accuracy, consistency, and completeness of portfolio communication, utilizing governance guidelines, to maintain credibility and satisfaction with all stakeholders.			1		0	

Barriers to Implementation (BTI) Analysis

Figure 3 reflects the BTI rating for each domain of the PfMP standard. The overall BTI score is 1.45, reflecting a low to medium BTI level for most gaps observed in the DoD standard. This means that many of the skills trained in the DoD PM standards are transferrable to the portfolio management model with few modifications. However, one area where the transition will be difficult is in the domain of governance, where we assessed a BTI rating of 3.0—meaning all tasks in this domain classify as a high BTI. Currently, DoD personnel structures, policies, and procedures are set for a program-centric model of governance. The DoD will need to modify personnel structure, current governance policies, and associated procedures towards a portfolio-centric structure to transition to a portfolio management structure. Changes in the domain of governance will allow for changes across all domains analyzed in this research.

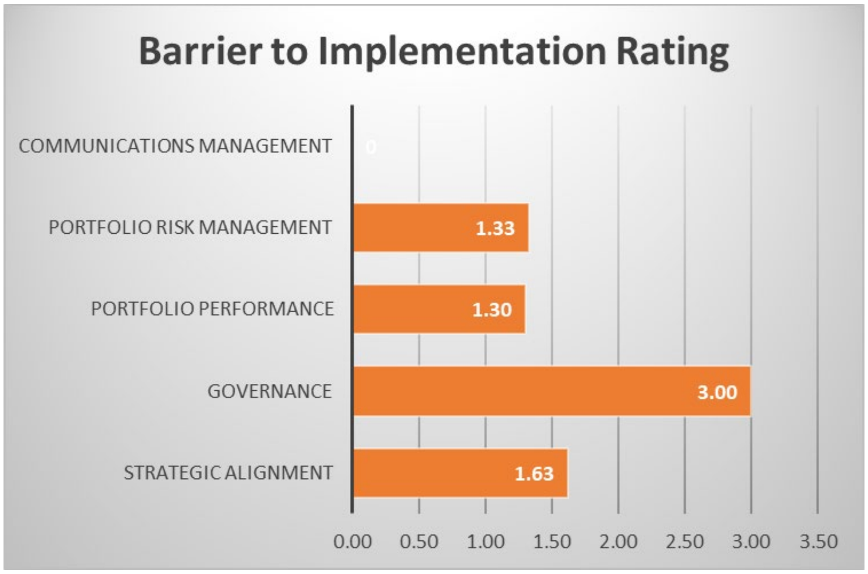

Figure 3. BTI Breakdown by PfMP Domain

Figure 4 shows the distribution of observed BTI task ratings. In four out of the five domains, the highest BTI rating was a 2. BTI ratings of low or medium were observed in 69% of the data, while a high BTI was recorded in 14%.

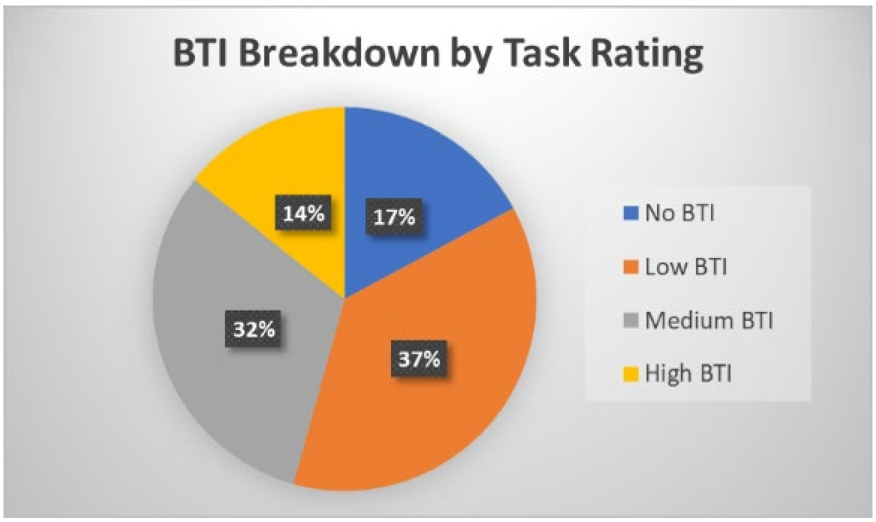

Figure 4. BTI Distribution

Table 10 depicts the breakdown of BTI ratings by individual task. It also shows the relationship between alignment score and BTI rating. While low alignment scores do not automatically mean medium or high BTI ratings, a -0.731 correlation between the data sets was observed. This means that, in general, as alignment scores decreased, BTI ratings increased and vice versa. These results further indicate significant gaps in the DoD standards related to governance, with low to medium barriers to entry across the remaining domains.

Table 10. BTI Rating by Domain and Task

BTI Rating by Domain and Task

Domain 1: Strategic Alignment		
Task #	Alignment Score	BTI Rating
1	50%	1
2	0%	2
3	0%	2
4	50%	2
5	0%	1
6	0%	1
7	0%	2
8	50%	2
Average BTI Rating		1.63

Domain 2: Governance		
Task #	Alignment Score	BTI Rating
1	0%	3
2	0%	3
3	0%	3
4	0%	3
5	0%	3
Average BTI Rating		3.00

Domain 3: Portfolio Performance		
Task #	Alignment Score	BTI Rating
1	0%	2
2	50%	1
3	100%	1
4	100%	1
5	100%	1
6	0%	2
7	0%	1
8	0%	2
9	0%	1
10	0%	2
Average BTI Rating		1.30

Domain 4: Risk Management		
Task #	Alignment Score	BTI Rating
1	100%	1
2	100%	1
3	0%	2
4	0%	1
5	100%	1
6	0%	2
Average BTI Rating		1.33

Domain 5:Communications		
Task #	Alignment Score	BTI Rating
1	100%	0
2	100%	0
3	100%	0
4	100%	0
5	100%	0
6	100%	0
Average BTI Rating		0.00

Summary and Conclusions

Summary Findings

Research Question #1: Are there gaps in the DoD project management competency standards that must be addressed before the DoD can fully implement PPM as directed in the 2021 NDAA?

The analysis indicates significant gaps in the DoD project management competency standards that must be addressed before the DoD can fully implement PPM as directed. The most significant gaps are in the domain of governance. These findings are consistent with the recommendations from the Section 809 panel and GAO reports. Currently, DoD acquisitions operates on a program-centric model that stovepipes funding into specific programs. Moreover, DoD PMs have little insight and influence into the acquisition program baselines of adjacent PMs within the same PEO or other PEOs (Shultz, 2020).

In the governance domain, the PfMP standard calls for personnel to “define and establish a governance model, policies, and decision-making roles” (PMI, 2013, p. 5). For the DoD, this would require significant restructuring and policy reform. Most importantly, portfolio managers’ authorities, roles, and responsibilities must be codified to incorporate the tasks outlined in the governance domain. Once the structure is in place, the PfMP standard outlines the need for each portfolio manager to enact a “portfolio management plan” (PMI, 2013, p. 5).

This includes authoritative thresholds, risk tolerance levels, key performance indicators, prioritization models, and escalation procedures within each portfolio. While similar considerations exist inside many programs, the infrastructure does not currently exist at the portfolio level within the DoD.

The second domain in which the DoD has significant gaps in project management standards is strategic alignment. This PfMP domain calls for leaders to make and evaluate organizational goals and marry them to portfolios (PMI, 2013). Without the structure, protocols, authorities, and procedures for effective PPM at the portfolio level within the DoD, a cohesive strategy cannot be developed. Once the goals align with portfolios, the PfMP standard calls for portfolio managers to set prioritization criteria using analytical decision-making tools, resulting in a portfolio road map used to budget, plan, and execute. The PfMP standard calls for impact analysis of shortfalls within the portfolio road map (PMI, 2013). Shultz (2020) discussed analyzing each program and project against the portfolio's road map.

Portfolio management requires a higher echelon of training and education, which partially covered in executive-level DAU training. However, to fully incorporate the domains of governance and strategic alignment, authorities and responsibilities will need to be decentralized to the PEO level. For PEOs to perform and be evaluated on these key domains properly, they must receive adequate training and education supported by clearly defined career field competency models. Establishing PfMP competency standards will not fully resolve these shortfalls due to the various other policy and structural changes that will require reform. However, educating, training, and evaluating acquisitions professionals on incorporating the proper aspects of governance and strategic alignment—based on PfMP competency standards—will be essential to moving forward with a portfolio-centric approach.

Research Question #2: Where are the DoD and PMI aligned regarding competency standards?

The DoD and PMI standards were fully aligned in the domain of communications management. The tasks in this domain center around leadership, developing leaders, and developing rapport with vendors. Communications management competency is the strength that can enable forward momentum for the DoD to overcome BTIs to make swift and efficient progress towards transition. This is an area within the PM competency standards that does not need to be duplicated within DoD PfMP standards.

Portfolio risk management was the next closest aligned domain at 50%. The current competency standards capture the understanding, planning, and mitigating of risk thoroughly. However, adding the higher lens from the portfolio level is essential for effective portfolio risk management. In this regard, the DoD needs to continue to develop standards that capture this increased awareness of risk and how changes in one program can increase or decrease risks in an adjacent program within a portfolio. Under the current model, stovepiped programs often lack the proper coordination and awareness of adjacent programs.

The final area in which some alignment was observed was in portfolio performance—specifically, in tasks dealing with accountability, maintaining high standards, and making well-informed and timely decisions. These competencies are central to basic military standards and culture and are currently trained to and evaluated in PM competency standards. These tasks will carry over well to the PPM construct in the future. Areas in which the DoD must improve include the creation of portfolio road maps, balancing and optimizing portfolio resources, and analyzing portfolio performance against strategic goals.

Research Question #3: What barriers exist regarding the implementation of national standards?

The results of our study suggest that the most significant BTIs reside in the governance domain. This is a result of the current program-centric construct called for by the Goldwater-Nichols Act that resulted in the basic governance construct still in place (Section 809 Panel, 2019a). It divides the acquisition governance into three decision support systems: requirements [Joint Capabilities Integration and Development System (JCIDS) for formal programs of record]; resourcing [Planning, Programming, Budgeting, and Execution (PPBE) system]; and the Adaptive Acquisition Framework. Each of these decision support systems is fundamentally driven by different and often contradictory goals:

- The requirements generation system is driven primarily by a combination of capability needs and an evolving threat—pointing toward the need for a responsive acquisition system.
- The resource allocation system is calendar-driven, with Congress writing an appropriations bill and the president signing the bill every fiscal year—providing control of funding to the Congress and transparency to the American public and media for taxpayer money.
- The Adaptive Acquisition Framework is event-driven by milestones—based on commercial industry best practices of knowledge points and off-ramps supported by the design, development and testing of the systems as technology, system design and manufacturing processes mature.

The disjointed nature of this construct will be the most significant barrier to implementation of PPM. These finding are consistent with the Section 809 Panel's (2019a) analysis.

This analysis does not indicate that the DoD is incapable of conducting portfolio management. Instead, in conducting portfolio management, the DoD relies on PM competency standards that do not align with industry best practices. Defense acquisitions are not currently structured to provide the appropriate training, education, evaluation, and feedback for proper job performance within a portfolio management-centric strategy. The establishment of PPM competencies remains a vital component to a successful implementation of congressional mandates to move towards a portfolio management-centric acquisitions strategy.

The DoD should consider modifying its governance structure to recognize "portfolio manager" as an official career field. This is consistent with the Section 809 Panel recommendations, which assigned these responsibilities and authorities to portfolio acquisitions executives (PAE; Section 809 Panel, 2019a). The PAE construct is analogous to the current PEO, except with expanded responsibilities and authorities. Concurrently, the Services should support acquisitions professionals obtaining PfMP certifications and include PfMP certification in the requirements for key acquisition positions. Figure 5 shows a notional structure proposed for PPM in defense acquisitions as recommended by the Section 809 Panel.

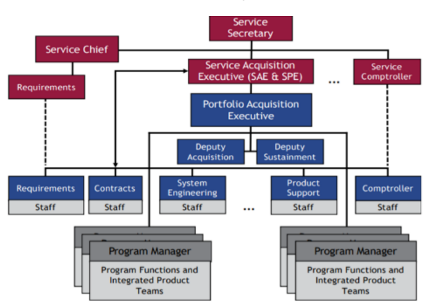

Figure 5. Notional Portfolio Manager Structure.
(Section 809 Panel, 2019a, p. 62).

The transition to portfolio management is an opportunity to increase collaboration amongst the Services, achieve commonality, and reduce redundancies. This is also consistent with the Section 809 Panel recommendations, which include establishing Enterprise Capability Portfolios. This involves working in a joint manner on related areas such as battlespace awareness tools, logistics, or command and control. This enables the DoD to better organize for innovation, streamline delivery of essential items and reduce redundancy amongst the Services (Section 809 Panel, 2019a). Figure 6 is an example of how this can look under a portfolio management-centric structure. PEOs, or future PAEs, at the service level are integrated and collaborating with Enterprise Capability Portfolios at the joint level.

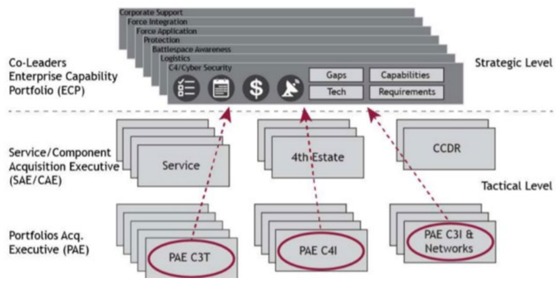

Figure 6. Notional Joint (Enterprise) Portfolio Management Structure.
(Section 809 Panel, 2019a, p. 69).

Lastly, future research should address funding transfer authorities within defense acquisitions and the establishment of portfolio elements for budgeting rather than program elements (PE’s). Portfolio managers should be given milestone decision authority of assigned programs and projects and be allowed to manage cost, schedule, and performance within a portfolio acquisition baseline as opposed to an acquisition program baseline (APB).

References

Ahern, D., & Driessnack, J. (2019, June 30). *Implementing a multitier portfolio management structure for defense acquisition.* Olde Stone Consulting. http://www.oldestoneconsulting.com/blog/2019/6/30/implementing-a-multitier-portfolio-management-structure-for-defense-acquisition

Anton, P., McKernan, M., Munson, K., Kallimani, J., Levedahl, A., Blickstein, I., Drezner, J., & Newberry, S. (2019). *Assessing Department of Defense use of data analytics and enabling data management to improve acquisition outcomes* (Report No. RR-3136-OSD). RAND Corporation. https://www.rand.org/pubs/research_reports/RR3136.html

Biedenbach, T., & Müller, R. (2012). Absorptive, innovative, and adaptive capabilities and their impact on project and project portfolio performance. *International Journal of Project Management, 30*(5), 621–635. https://doi.org/10.1016/j. ijproman.2012.01.016

Chairman of the Joint Chiefs of Staff. (2018, August 31). *Charter of the Joint Requirements Oversight Council (JROC) and implementation of the Joint Capabilities Integration and Development System (JCIDS)* (CJCSI 5123.01H). Joint Staff. https://www.jcs.mil/Portals/36/Documents/Library/Instructions/CJCSI%205123.01H.pdf?ver=2018-10-26-163922-137

Defense Acquisition University. (n.d.). *Certification standards & core plus development guide: Program management level III.* Retrieved October 6, 2021, from https://icatalog.dau.edu/onlinecatalog/CareerLvl.aspx?lvl=3&cfld=9

Defense Acquisition University. (2020, June). *DOD program management career field functional competencies.* https://icatalog.dau.edu/onlinecatalog/Doc/CFcompetencys/PMCompetencies.pdf

Defense Acquisition University. (2021, August 17). *PMT 4020 Executive program manager’s course.* https://icatalog.dau.edu/onlinecatalog/courses.aspx?crs_id=12460

Distel, D., Hannon, E., Krause, M., & Krieg, A. (2020, December 7). *Finding the sweet spot in product portfolio management.* McKinsey & Company. https://www.mckinsey.com/business-functions/operations/our-insights/finding-the-sweet-spot-in-product-portfolio-management

Ewing, L., Dell, R., MacCalman, M., & Whitney, L. (2013, January). *Capability portfolio analysis tool (CPAT) verification and validation report* (Report No. NPS-OR-13-001). Naval Postgraduate School. https://calhoun.nps.edu/handle/10945/27340

Fast, W. (2010). Improving defense acquisition decision making. *Defense AR Journal, 17*(2), 220–241. http://libproxy.nps.edu/login?url=https://www-proquest-com.libproxy.nps.edu/scholarly-journals/improving-defense-acquisition-decision-making/docview/220023524/se-2?accountid=12702

GAO. (2015, August). *Report to congressional committees: Weapon system acquisitions: Opportunities exist to improve the Department of Defense's portfolio management* (GAO-15-466). https://www.gao.gov/assets/gao-15-466.pdf

GAO. (2020, June 3). *Defense acquisitions annual assessment: Drive to deliver capabilities faster increases importance of program knowledge and consistent data for oversight* (GAO-20-439). https://www.gao.gov/products/gao-20-439

Gutiérrez, E., & Magnusson, M. (2014). Dealing with legitimacy: A key challenge for Project portfolio management decision-makers. *International Journal of Project Management, 32*(1), 30–39. https://doi.org/10.1016/j.ijproman.2013.01.002

Heising, W. (2012). The integration of ideation and project portfolio management: A key factor for sustainable success. *International Journal of Project Management, 30*(5), 582–595. https://doi.org/10.1016/j.ijproman.2012.01.014

Janiga, M., & Modigliani, P. (2014, November–December). Think portfolios, not programs. *Defense AT&L Magazine, 43*(6), 12–16. https://dair.nps.edu/bitstream/123456789/3013/1/SEC809-RSC-14-0038.pdf

Johnson, M. (2019). Section 809 Panel: Hacking away at the regulatory underbrush and empowering the acquisition workforce. *Contract Management, 59*(5), 12–13. https://www-proquest-com.libproxy.nps.edu/docview/2278736758?accountid= 12702

Karnes, J. L. (2020, December). *Aligning DoD program management competencies with the Project Management Institute standards* [Master's thesis, Naval Postgraduate School]. Defense Acquisition Innovation Repository. https://dair.nps.edu/bitstream/123456789/4298/1/NPS-PM-21-009.pdf

Kendall, F. (2017). *Getting defense acquisitions right.* Defense Acquisition University Press. https://dod.defense.gov/Portals/1/Documents/pubs /Getting-Acquisition-Right-Jan2017.pdf

Kock, A., Schulz, B., Kopmann, J., & Gemünden, H. G. (2020). Project portfolio management information systems' positive influence on performance: The importance of process maturity. *International Journal of Project Management, 38*(4), 229–241. https://doi.org/10.1016/j.ijproman.2020.05.001

Langford, G., Franck, R., Huynh, T., & Lewis, I. (2008, April). *Gap analysis: Rethinking the conceptual foundations.* Naval Postgraduate School. http://hdl.handle.net/10945/33274

Li, Y. M., Chen, H. M., Liou, J. H., & Lin, L. F. (2014). Creating social intelligence for product portfolio design. *Decision Support Systems, 66*, 123–134. https://doi.org/10.1016/j.dss.2014.06.013

MacStravic, J. A. (2016, September 6). *Program management functional career field competencies* [Memorandum]. Department of Defense. https://www.dau.edu/training/career-development/program-management/Lists/Blog/Attachments/29/Prog%20Mgmt%20Funct%20Competencies_160906%20(003).pdf

Modigliani, P. (2015, April 1). *Portfolio acquisition: How DoD can leverage the commercial product line model.* Naval Postgraduate School. https://calhoun.nps.edu/handle/10945/53650

National Defense Authorization Act for Fiscal Year 2020, Pub. L. No. 116-92, Sec. 861 (2019). https://www.congress.gov/116/bills/s1790/BILLS-116s1790enr.pdf

National Defense Authorization Act for Fiscal Year 2021, Pub. L. No. 116-283, Sec. 836 (2021). https://www.congress.gov/116/bills/hr6395/BILLS-116hr6395enr.pdf

Nippa, M., Pidun, U., & Rubner, H. (2011). Corporate portfolio management: Appraising four decades of academic research. *Academy of Management Perspectives, 25*(4), 50–66. https://doi.org/10.5465/amp.2010.0164

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2019, September 13). *Defense acquisition workforce education, training, experience, and career development program* (DoDI 5000.66). Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500066.PDF?ver=2019-09-13-063647-267

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2021, April 28). *2020 Acquisition & Sustainment annual report.* https://www.acq.osd.mil/resources/acq/docs/AS2020-Annual-Report-FINAL.pdf

Office of U.S. Congressman Joe Wilson. (2020, July 7). *DoD portfolio management accountability act included in National Defense Authorization Act* [Press release]. https://joewilson.house.gov/media-center/press-releases/dod-portfolio-management-accountability-act-included-in-ndaa

Petit, Y. (2012). Project portfolios in dynamic environments: Organizing for uncertainty. *International Journal of Project Management, 30*(5), 539–553. https://doi.org/10.1016 /j.ijproman.2011.11.007

Pringle, S., & VanOrden, M. A. (2009, March). *Applying modern portfolio theory and the capital asset pricing model to the DoD's information technology investments.* Naval Postgraduate School. https://calhoun.nps.edu/bitstream/handle/10945/4795/09Mar_Pringle.pdf?sequence=1&isAllowed=y

Project Management Institute. (2013). *Portfolio Management Professional (PfMP) examination content outline.*

Project Management Institute. (2017a). *Portfolio Management Professional (PfMP) handbook.*

Project Management Institute. (2017b). *The standard for portfolio management* (4th ed.).

Section 809 Panel. (2017, May). *Advisory panel on streamlining and codifying acquisition regulations: Section 809 Panel interim report.* Defense Technical Information Center. https://discover.dtic.mil/wp-content/uploads/809-Panel-2019/Interim-Report/Sec809Panel_Interim-Report_May2017.pdf

Section 809 Panel. (2018a, January). *Advisory panel on streamlining and codifying acquisition regulations: Volume 1 of 3.* Defense Technical Information Center. https://discover.dtic.mil/wp-content/uploads/809-Panel-2019/Volume1/Sec809Panel_Vol1-Report_Jan2018.pdf

Section 809 Panel. (2018b, June). *Advisory panel on streamlining and codifying acquisition regulations: Volume 2 of 3.* Defense Technical Information Center. https://discover.dtic.mil/wp-content/uploads/809-Panel-2019/Volume2/Sec809Panel_Vol2-Report_Jun2018.pdf

Section 809 Panel. (2019a, January). *Advisory panel on streamlining and codifying acquisition regulations: Volume 3 of 3 part 1.* Defense Technical Information Center. https://discover.dtic.mil/wp-content/uploads/809-Panel-2019/Volume3/Sec809Panel_Vol3-Report_Jan2019_part-1_0509.pdf

Section 809 Panel. (2019b, January). *Advisory panel on streamlining and codifying acquisition regulations: Volume 3 of 3 part 2.* Defense Technical Information Center. https://discover.dtic.mil/wp-content/uploads/809-Panel-2019/Volume3/Sec809Panel_Vol3-Report_Jan2019_part-2_0307.pdf

Section 809 Panel. (2019c, February). *Advisory panel on streamlining and codifying acquisition regulations: A roadmap to the Section 809 Panel reports.* Federal Depository Library Program. https://permanent.fdlp.gov/websites/discover.dtic.mil/discover.dtic.mil/discover.dtic.mil/wp-content/uploads/809-Panel-2019/Roadmap/Sec809Panel_Roadmap_DEC2019.pdf

Shultz, B. (2020, March). A portfolio management–based acquisition model? *Contract Management, 60*(3), 42–47. https://www-proquest-com.libproxy.nps.edu/ docview/2458099153?accountid=12702

Thompson, R., & Johnson, M. (2019, July 10). 809 Panel calls for managing "capabilities," not weapons. *Breaking Defense.* https://breakingdefense.com/ 2019/07/809-panel-calls-for-managing-capabilities-not-weapons/

Tolonen, A., Shahmarichatghieh, M., Harkonen, J., & Haapasalo, H. (2015). Product portfolio management: Targets and key performance indicators for product portfolio renewal over life cycle. International Journal of Production Economics, 170, 468–477. https://doi.org/10.1016/j.ijpe.2015.05.034

Tsiopanas, N. (2018, April 4). Smarter acquisition of defense business systems prioritizes results over reviews. *Federal Times.* https://www.federaltimes.com/opinions/ 2018/04/04/smarter-acquisition-of-defense-business-systems-prioritizes-results-over-reviews/
Weller, J. (2018, October 17). *The complete guide to gap analysis.* Smartsheet. https://www.smartsheet.com/gap-analysis-method-examples
Wright, K., Dacanay, C., & Guzman, M. (2020, December). *Implementing category management across United States Special Operations Command (SOCOM)* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/bitstream/handle/10945/66747/20Dec_Wright_Dacanay_Guzman.pdf?sequence=1&isAllowed=y
Young, M., & Conboy, K. (2013). Contemporary project portfolio management: Reflections on the development of an Australian competency standard for project portfolio management. *International Journal of Project Management, 31*(8), 1089–1100. https://doi.org/10.1016/j.ijproman.2013.03.005

Appendix A. PMI Portfolio Domain Tasks

Domain 1: Strategic Alignment. The purpose of the Strategic Alignment domain is to evaluate an individual's ability to align all components that make up a portfolio, including programs and projects, to the organization's overall strategic objectives and priorities (PMI, 2013). This highlights portfolio management's focus on strategic management. The Strategic Alignment and Portfolio Performance domains are the most heavily weighted portions of the exam at 25% each. The Strategic Alignment domain contains eight tasks, as listed in Table 11.

Table 11. Domain 1: Strategic Alignment Tasks.
(PMI, 2013, p. 4).

Tasks	Strategic Alignment (25%)
Task 1	Evaluate organizational strategic goals and objectives using document reviews, interviewing, and other information gathering techniques in order to understand the strategic priorities.
Task 2	Identify prioritization criteria (e.g., legislative, dependencies, ROI, stakeholder expectations, strategic fit) using information gathering and analysis techniques in order to create a basis for decision making.
Task 3	Rank strategic priorities working with key stakeholders and using qualitative and quantitative analyses in order to provide a guiding framework to operationalize the organizational strategic goals and objectives.
Task 4	Identify existing and potential portfolio components by reviewing documentation such as business plans/proposals in order to create portfolio scenarios.
Task 5	Create portfolio scenarios (what-if analysis) by reviewing components against prioritization criteria and using analysis techniques (e.g., options analysis, risk analysis, SWOT analysis, financial analysis) in order to evaluate and select viable options.
Task 6	Recommend portfolio scenario(s) and related components, based on prioritization analysis/criteria, in order to provide governance with a rationale for decision making.
Task 7	Determine the impact to portfolio and portfolio components due to changes in strategic goals and objectives, in order to sustain strategic alignment.
Task 8	Create high level portfolio roadmap working with key stakeholders using prioritization, interdependency analysis, and organizational constraints in order to confirm and communicate the portfolio components sequencing, dependencies, and strategic alignment.

Domain 2: Governance. The purpose of the Governance domain is to evaluate an individual's ability to oversee the portfolio; to create the overall management plan, including performance standards, best practices, processes and procedures, and overall management structure; and to manage decision-making elements to ensure proper authorization of portfolio execution (PMI, 2013). The Governance domain, weighted at 20%, is the third most important set of competencies behind Strategic Alignment and Portfolio Performance. It includes the five tasks as listed in Table 12.

Table 12. Domain 2: Governance Tasks.
(PMI, 2013, p. 5).

Tasks	Governance (20%)
Task 1	Define and establish a governance model including the structure (including but not limited to steering committees, governance boards), policies, and decision-making roles, responsibilities, rights and authorities in order to support effective decision-making and achieve strategic goals.
Task 2	Determine portfolio management standards, protocols, rules, and best practices, using organizational assets (such as information systems, subject-matter experts) and industry standards in order to establish consistent portfolio management practices.
Task 3	Define and/or modify portfolio processes and procedures including but not limited to benefits realization planning, information management, performance, communication, risk management, stakeholder engagement, resource management, and change management in order to manage the portfolio efficiently and effectively.
Task 4	Create the portfolio management plan including, but not limited to, roles and responsibilities, governance model, escalation procedures, risk tolerances, and governance thresholds, change control and management, key performance indicators, prioritization model, and communication procedures using standards, models, and other organizational assets in order to ensure effective and efficient portfolio management.
Task 5	Make recommendations and obtain approval regarding portfolio decisions (e.g, components, plans, budget, roadmap) through communication with key decision makers as defined by the governance model, in order to authorize the execution of the portfolio.

Domain 3: Portfolio Performance. The purpose of the Portfolio Performance domain is to evaluate an individual's ability to oversee the execution of the portfolio within the established governance parameters set under the previous domain, to assess and balance the components of the portfolio based on performance and changes in strategic alignment, and to monitor the overall health of the portfolio (PMI, 2013). The Portfolio Performance domain, along with Strategic Alignment, is weighted at 25%. It includes the 10 tasks listed in Table 13.

Table 13. Domain 3: Portfolio Performance Tasks.
(PMI, 2013, p. 6).

Tasks	Portfolio Performance (25%)
Task 1	Initiate the portfolio using the portfolio roadmap and supporting artifacts in order to authorize the portfolio structure and activate the components.
Task 2	Collect and consolidate key performance metric data, as defined by portfolio governance and using various techniques, in order to measure the health of the portfolio.
Task 3	Monitor the portfolio performance on an ongoing basis, using reports, conversations, dashboards, and auditing techniques in order to ensure portfolio effectiveness and efficiency and maintain strategic alignment.
Task 4	Manage and escalate issues by communicating recommended actions to appropriate decision makers for timely approval and implementation of proposed solution(s).
Task 5	Manage portfolio changes using change management techniques, in order to improve portfolio performance and maintain strategic alignment.
Task 6	Balance portfolio and prioritize portfolio components, using established criteria and methods in order to optimize resource utilization and achieve strategic portfolio objectives.
Task 7	Analyze and optimize the consolidated allocation/reallocation of capacity (e.g., people, tools, materials, technology, facilities, financial) using supply/demand management and scenario analysis techniques to ensure portfolio efficiency and effectiveness.
Task 8	Update and refine existing portfolio road maps, using change analysis in order to facilitate re-allocation of organizational resources to the portfolio.
Task 9	Measure the aggregated portfolio performance results against the defined business or strategic goals and objectives in order to demonstrate progress toward the achievement of business or strategic goals.
Task 10	Maintain records by capturing portfolio artifacts, such as approvals, prioritizations, and other decisions, in order to ensure compliance with organizational policies, regulatory requirements, and portfolio management standards.

Domain 4: Portfolio Risk Management. The purpose of the Portfolio Risk Management domain is to evaluate an individual's ability to evaluate portfolio risk and align it with the risk appetite of the organization (PMI, 2013). It is weighted at 15% and includes the six tasks listed in Table 14.

Table 14. Domain 4: Portfolio Risk Management Tasks.
(PMI, 2013, p. 7).

Tasks	Portfolio Risk Management (15%)
Task 1	Determine acceptable level of risk for the portfolio, based on organizational and stakeholder risk tolerances, in order to provide input to governance.
Task 2	Develop the portfolio risk management plan, using governance risk guidelines, processes, and procedures and other organizational assets in order to capitalize on opportunities, and respond to risks.
Task 3	Perform dependency analysis to identify and monitor risks related to the interdependencies and intradependencies within or across portfolios in order to support decision-making.
Task 4	Develop, monitor, and maintain portfolio-level risk register, including risks to strategic goals and objectives, to business value, and escalated from portfolio components, using risk management processes in order to support decision making.
Task 5	Promote common understanding and stakeholder ownership of portfolio risks, through communications with stakeholders, in order to facilitate risk response.
Task 6	Provide recommendation and obtain approval for a portfolio management reserve, based on aggregate portfolio risk exposure, in order to optimize portfolio strategic goals and objectives.

Domain 5: Communications Management. The purpose of the Communications Management domain is to evaluate an individual's ability to conduct activities including stakeholder management, conflict management, and stakeholder engagement (PMI, 2013). It is weighted at 15% and includes the six tasks listed in Table 15.

Table 15. Domain 5: Communications Management Tasks.
(PMI, 2013, p. 8).

Tasks	Communications Management (15%)
Task 1	Analyze internal and external stakeholders using techniques such as meetings, interviews, surveys/questionnaires, in order to identify stakeholder expectations, interests, and influence on the success of the portfolio.
Task 2	Create the aggregate communication strategy and plan, including methods, recipients, vehicles, timelines and frequencies in order to enable effective communication to stakeholders.
Task 3	Engage stakeholders, through oral and written communication, to ensure awareness, manage expectations, foster support, and build relationships and collaboration for the success of the portfolio roadmap.
Task 4	Maintain the communication strategy and plan by evaluating current communications capabilities, identifying gaps, and documenting communications plan to meet stakeholder requirements.
Task 5	Prepare and/or facilitate stakeholder understanding of portfolio management-related processes, procedures, and protocols using organizational assets (e.g., information systems, training delivery methods) in order to promote common understanding and application of the portfolio management process.
Task 6	Verify accuracy, consistency, and completeness of portfolio communication, utilizing governance guidelines, to maintain credibility and satisfaction with all stakeholders.

A CMS-Based Competency Assessment of the DoD Contracting Workforce

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Abstract

In April 2020, the DoD senior procurement executives established a new contracting competency model and a single level of certification program for the DoD contracting workforce. The new competency model is based on the National Contract Management Association (NCMA) Contract Management Standard (CMS). This new DoD contracting competency model complies with the requirement in Section 861 of the Fiscal Year 2020 National Defense Authorization Act (NDAA) to base a professional certification on standards developed by a third-party accredited program. The purpose of this research is to conduct a competency assessment on a sample of the DoD contracting workforce using the NCMA CMS. This research will answer the following question: Based on the competency assessment results, in which contract management competencies is the workforce less proficient and less knowledgeable? Based on the competency assessment results, recommendations for competency development are provided to the assessed organization.

Introduction

Both the Government Accountability Office (GAO) and the Department of Defense Inspector General (DoD IG) continue to list DoD contract management as a high risk and a top DoD management challenge (DoD OIG, 2021; GAO, 2021). Both agencies identify the need for increased technical competency in the contracting workforce.

Recent legislative initiatives reflect Congress's concerns about the adequacy of the DoD's acquisition workforce training and competency. In the 2020 National Defense Authorization Act (NDAA; 2019), Congress directed the secretary of defense to implement a professional certification program for all members of the acquisition workforce that is based on standards developed by a third-party accredited program based on nationally or internationally recognized standards (NDAA, 2019). In September 2020, the under secretary of defense for acquisition and sustainment (USD A&S) implemented the Back-to-Basics (BtB) talent management program to be fully deployed by October 1, 2021 (OUSD[A&S], 2020). This would be a major change to the acquisition certification program established by the Defense Acquisition Workforce Improvement Act (DAWIA) and enacted by Congress in 1990. In February 2021, the office of the under secretary of defense (OUSD) principal director for defense pricing and contracting (DPC) published a memorandum restructuring the DoD Contracting Professional Certification Program and Contracting Competency Model. The new contracting competency model would be based on the American National Standards Institute (ANSI)/National Contract Management Association (NCMA)–accredited Contract Management Standard (CMS; OUSD[A&S], 2021). This new contracting workforce competency model complies with the 2020 NDAA (2019) requirement to base a professional certification on standards developed by a third-party accredited program (OUSD[A&S], 2021).

Purpose of Research

Given the backdrop of the congressional legislation and the establishment of the new contracting workforce competency model, the purpose of this research is to conduct a competency assessment on a sample of the DoD contracting workforce using the newly adopted NCMA CMS. This research will answer the following question: Based on the competency assessment results, in which contract management competencies is the workforce less proficient and less knowledgeable? Based on the competency assessment results, recommendations for competency development are provided to the assessed organization.

Methodology

The methodology for this research consists of two components. The first component is the deployment of a CMS-based competency assessment instrument to a DoD contracting organization. (The development of the NCMA CMS competency instrument is discussed in Rendon and Schwartz [2021]). The second component is the analysis of the assessment results to identify contract management competencies that need additional training emphasis.

DoD Contract Management Workforce Competency Model

The new DoD contracting workforce competency model, based on the NCMA CMS, is significantly different from the legacy DoD contracting competency model in both structure and scope and thus provides an innovative approach for talent and competency management (Rendon, 2019; Rendon & Winn, 2017). The top-level structure of the NCMA CMS is reflected in Figure 1 (NCMA, 2019b).

The CMS's concise and detailed contract life cycle and greater emphasis and granularity in each of the life-cycle phases and job tasks may help develop and fortify the DoD's contracting processes and practices, as well as the training of its contracting workforce on these competencies. Providing greater emphasis on each of the contract life-cycle phases and also structuring the competencies using a hierarchical approach that aligns each competency with processes, tasks, and subtasks will support the development of a professional contracting career path that associates contracting technical competencies and key work experiences (Rendon, 2019). The CMS also has an overarching narrative of guiding principles aligned with professional competencies that apply across all phases of the contracting life cycle. Additionally, the CMS uses contract management terms that are relevant and applicable across the DoD, federal agencies, and industry.

In terms of scope, the CMS differs from the legacy DoD contracting competency model in that the CMS also includes the industry (seller) competencies, processes, and job tasks. Expanding the DoD's contracting workforce knowledge to include industry's side of contracting (e.g., industry operations and processes) as reflected in the CMS will help in developing technical and professional skills that can transfer across government and industry, as well as improve communication and collaboration between government and industry. Including the industry side of contracting would also result in strengthening systems thinking within the DoD contracting workforce (Carlson, 2017). Contracting officers applying systems thinking to contract management will know that "problems can have hidden, indirect causes" and it is the "relationships among the parts that matter the most” (Carlson, 2017). Using systems thinking, contracting officers will be able to “see the gaps where complications or opportunities can arise” within the acquisition process and understand how their contracting decisions may impact contractors and subcontractors (Carlson, 2017).

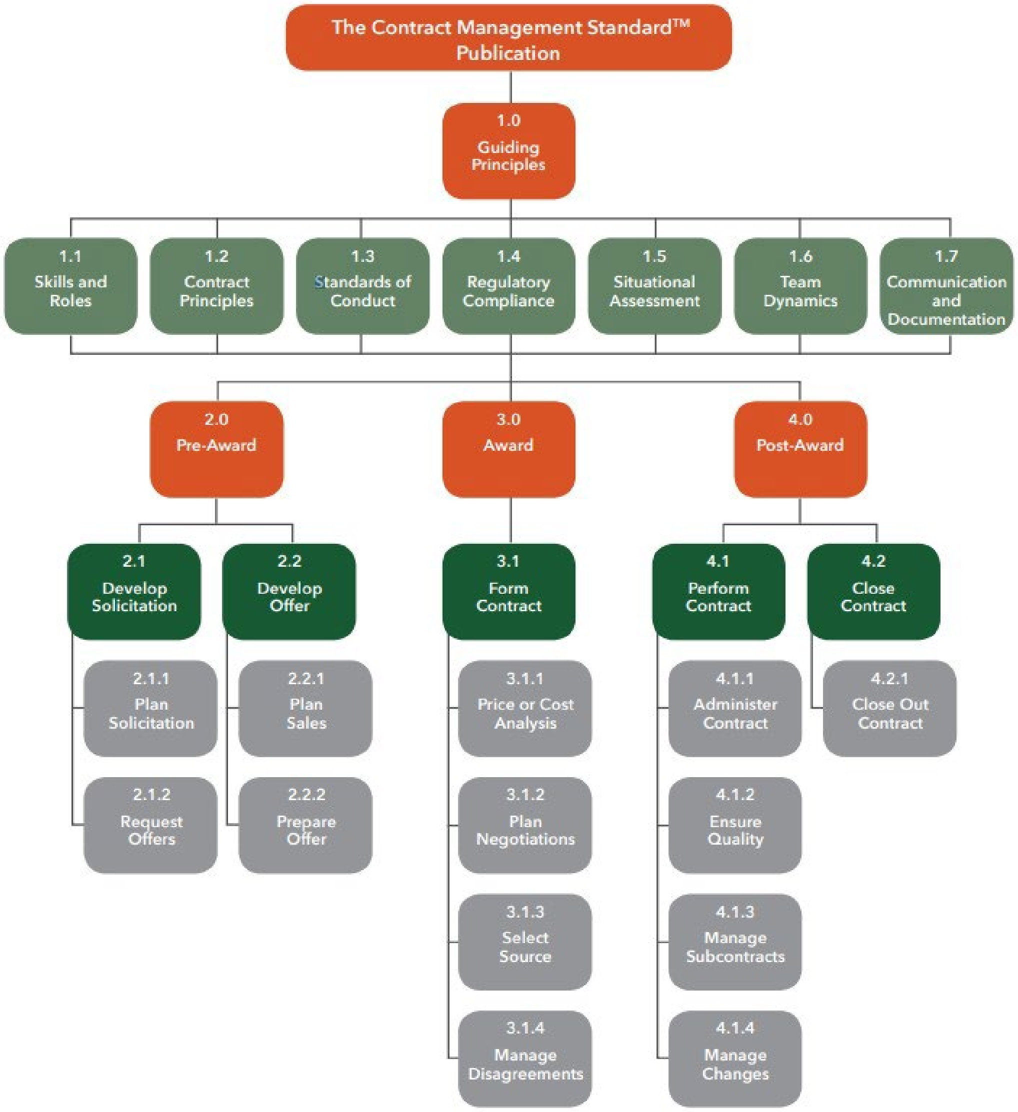

Figure 1. NCMA Contract Management Standard. Source: NCMA (2019b).

Additionally, adopting the CMS competency framework may provide the DoD contracting workforce with a stronger foundational understanding of not only the complete contract life cycle, but also the different perspectives in contract relationships (e.g., buyer, seller, subcontractor, supplier, end users). This understanding of different perspectives may enable DoD contracting officers to introduce innovation and process change into the DoD contracting processes.

Finally, providing training on the seller-side competencies to the DoD contracting workforce may also strengthen “communication, collaboration, problem-solving, and adaptability” skills (Carlson, 2017). A recent RAND study found that within the defense acquisition workforce, knowledge gaps in business acumen, industry operations, and industry motivation exist (Werber et al., 2019). The RAND report also found that the lack of standardized definitions and competency model formats obscures the need for knowledge related to business acumen, industry operations, and industry motivation (Werber et al., 2019) .

Structure of Competency Assessment Instrument

The structure of the contracting competency assessment instrument consists of contracting competency statements for each of the contract management phases (pre-award, award, post-award), as well as from both buyer and seller contracting perspectives. More specifically, the contracting competency statements reflect the contracting competencies and the specific job tasks for each contract management phase and for each perspective as reflected in the CMS. The competency statements will be rated by the contracting workforce members using a Likert scale reflecting different levels of proficiency for performing the buyer job tasks and a different Likert scale reflecting the different levels of knowledge of the seller job tasks. The proficiency rating levels for performing buyer job tasks are identified and defined as follows:

1. Aware: Applies the competency in the simplest situations and requires close and extensive guidance.
2. Basic: Applies the competency in somewhat difficult situations and requires frequent guidance.
3. Intermediate: Applies the competency in difficult situations and requires little or no guidance.
4. Advanced: Applies the competency in considerably difficult situations and generally requires no guidance.
5. Expert: Applies the competency in exceptionally difficult situations, serves as a key resource, and advises others.
6. N/A: Not applicable/not needed in my job.

The knowledge rating levels for understanding seller job tasks are identified and defined as follows:

1. None: I am not aware of this Contractor competency.
2. Aware: I am aware but have no knowledge of this Contractor competency.
3. Basic: I have some basic-level knowledge of this Contractor competency.
4. Intermediate: I have intermediate-level knowledge of this Contractor competency.
5. Advanced: I have advanced-level knowledge of this Contractor competency.

Deployment of Competency Assessment Instrument

The competency assessment instrument link was deployed to the Marine Corps expeditionary contracting workforce that makes up the three Marine Corps Expeditionary Contracting Platoons (ECPs) and the three co-located Regional Contracting Offices (RCOs). Marine Corps ECP contracting officers and specialists attach to a deploying unit to provide contracting support to the deploying unit commander. Marine Corps RCOs provide contracting support when tasked to Marine Corps contingency contracting operations.

The competency assessment instrument was deployed using the Naval Postgraduate School (NPS) open-source survey tool LimeSurvey. The web-based LimeSurvey allows participants to respond anonymously to the self-assessment items. The Marine Corps expeditionary contracting workforce (ECPs and RCOs) population consists of 100 contracting professionals.

Findings

Of the 100 Marine Corps expeditionary contracting workforce military contracting professionals, between 33 and 41 contracting professionals completed the assessment, equating to approximately 33–41% of the expeditionary contracting workforce. Forty-one contracting professionals responded to the survey and initiated and progressed through the assessment. Thirty-three contracting professionals completed the entire assessment. The demographic data of the responding population are reflected in Table 1. As can be seen in Table 1, almost half of the respondents either had no DAWIA certification or were certified at Level 1, with the remaining respondents certified at DAWIA Level 2 or Level 3. Additionally, the majority of the respondents (83%) had between 0 and 8 years of contracting experience.

Table 1. Expeditionary Contracting Workforce Competency Assessment Demographics

DAWIA Contracting Certification Level	Number		Years of Contracting Experience	Number
None	8		3 or Less	15
Level 1	11		4 to 8	19
Level 2	16		9 to 13	5
Level 3	6		14 to 18	2
			19 or more	0

Buyer Proficiency Levels

Figure 2 reflects the assessment results of the Buyer Proficiency component of the competency assessment. The figure reflects the buyer competencies (e.g., Plan Solicitation, Request Offer) that include buyer associated job tasks, as reflected in the NCMA CMS. Also reflected in Figure 2 are the average proficiency ratings for each competency, based on the buyer proficiency rating scales discussed earlier. As can be seen in Figure 2, the average buyer proficiency ratings ranged within Basic (2.0) and Intermediate (3.0) proficiency levels. Specifically, the lowest average proficiency rating was 2.09 (Basic) for Manage Disagreement, and the highest average proficiency rating was 3.47 (Intermediate) for Request Offer.

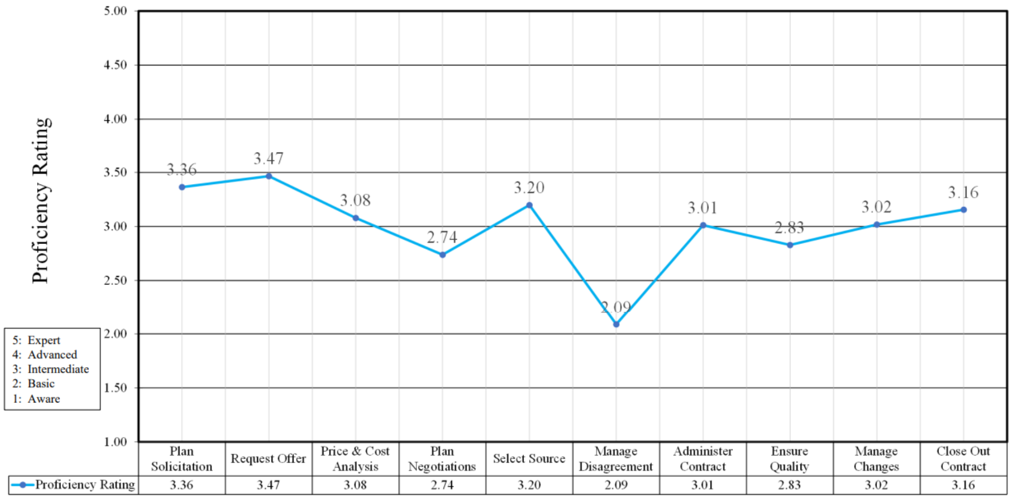

Figure 2. Expeditionary Contracting Workforce Competency Assessment: Buyer Proficiency

Seller Knowledge Levels

Figure 3 reflects the assessment results of the Seller Knowledge component of the competency assessment. The figure reflects the seller competencies (e.g., Plan Sales, Prepare Offer) that include seller associated job tasks, as reflected in the NCMA CMS. Also reflected in Figure 3 are the average knowledge ratings for each competency, based on the seller knowledge rating scales discussed earlier. As can be seen in Figure 3, the average seller knowledge ratings ranged predominantly within the Aware (2.0) knowledge level. Specifically, the lowest average knowledge rating was 2.35 (Aware) for Manage Disagreement, and the highest average knowledge rating was 3.04 (Basic) for Plan Negotiations.

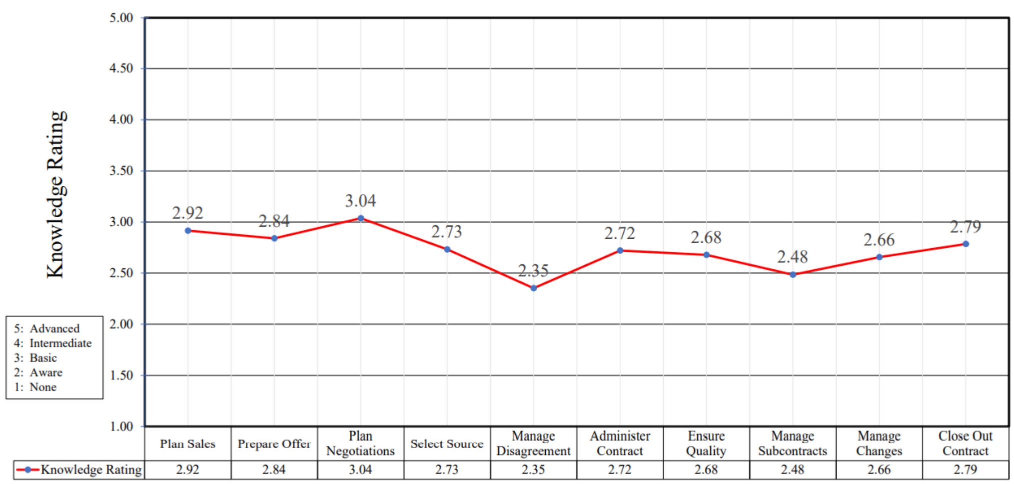

Figure 3. Expeditionary Contracting Workforce Competency Assessment: Seller Knowledge

Discussion of Findings

The overall findings from the Marine Corps expeditionary contracting workforce (ECPs and RCOs) competency assessment indicate that the organization's competency levels for the buyer proficiency tasks are higher than the organization's knowledge levels of seller tasks. Specifically, based on the competency assessment, the majority of the buyer proficiency competency ratings are at an Intermediate level, with seven out of 10 competencies rated within this range. The remaining three competencies received ratings of Basic. Additionally, when these competency ratings are analyzed by contract life-cycle phases, buyer proficiency ratings in the pre-award phase are the highest, and buyer proficiency ratings in the award phase are the lowest of the three life-cycle phases. The assessment revealed that the survey respondents demonstrated an average proficiency rating of Intermediate (3.30) in pre-award buyer competencies (Plan Solicitation, Request Offer), an average proficiency rating of Basic (2.67) in award buyer competencies (Price & Cost Analysis, Plan Negotiations, Select Source, Manage Disagreement), and an average proficiency rating of Intermediate (3.00) in post-award buyer competencies (Administer Contract, Ensure Quality, Manage Changes, Close Out Contract). The lowest-rated competency was Manage Disagreements, found in in the Award phase, which was closely followed by the competency of Plan Negotiations, also in the Award phase.

Based on the competency assessment, seller knowledge competency ratings are predominantly at the Aware level, with nine out of 10 competencies rated at this level. The remaining competency is rated just above the Basic level. When these competency ratings are analyzed by contract life-cycle phases, the pre-award, award, and post-award phases all rate at an Aware level. The assessment revealed that the survey respondents demonstrated an average knowledge rating of Aware (2.88) in pre-award seller competencies (Plan Sales, Prepare Offer), an average knowledge rating of Aware (2.70) in award seller competencies (Plan Negotiations, Select Source, Manage Disagreements), and an average knowledge rating of Aware (2.66) in post-award seller competencies (Administer Contract, Ensure Quality, Manage Subcontracts, Manage Changes, Close Out Contract). The lowest-rated competency was Manage Disagreements, found in the Award phase, which was closely followed by the competency of Manage Subcontracts, in the Post-Award phase.

The Intermediate and Basic average proficiency ratings for the Buyer tasks may be related to the background of the surveyed workforce. Almost half of the respondents had either no DAWIA certification or were certified at Level 1, with the remaining respondents certified at DAWIA Level 2 or Level 3. Additionally, the majority of the respondents (83%) had between 0 and 8 years of contracting experience. This level of training and experience may indicate a lower competency level in performing the buyer tasks reflected in the CMS.

The higher average proficiency ratings for the buyer tasks (Intermediate and Basic) compared to the lower average knowledge ratings of the seller tasks (Aware) may reflect the scope and focus of the contracts training received by the DoD acquisition workforce. The contracts training provided by the Defense Acquisition University (DAU) and based on the previous DoD contracting competency framework reflects only the buyer processes and related tasks, as reflected in the Federal Acquisition Regulation (FAR). The DAU contracts training courses do not cover the seller (industry) processes and related tasks. (See Rendon and Winn [2017] for a comparison of the previous DoD contracting competency model and the NCMA Contract Management Standard).

Finally, the consistency in the lower average proficiency and knowledge ratings for both the buyer and seller Manage Disagreements competency is indeed an interesting finding. This CMS competency specifically deals with the seller tasks of submitting protests and appeals and the buyer tasks of responding to protests and appeals. The low average proficiency and knowledge ratings from the assessed contracting workforce in this competency area may reflect a deficiency in the knowledge, skills, and abilities related to these contract management tasks.

Based on these competency assessment findings, this researcher provides recommendations to the assessed organization for competency development. These recommendations can be used by the organization for developing a training roadmap for targeting buyer task proficiency and seller knowledge areas needed for improvement within the contracting workforce.

Recommendations for Competency Development

Based on the findings of the Marine Corps expeditionary contracting workforce (ECPs and RCOs) competency assessment, the following recommendations for competency development are provided for the organization.

The first recommendation for the assessed organizations is to incorporate training to increase knowledge of the CMS seller competencies and related job tasks (NCMA, 2019b). The assessment results reflect that the average knowledge ratings of the seller competencies and related job tasks are lower than the average proficiency ratings of the buyer tasks. Specifically, the knowledge levels of the seller tasks are predominantly rated at the Aware level. This means that, in terms of knowledge of the seller competencies and job tasks, this contracting workforce is aware but has no knowledge of this contractor competency or related job tasks. Thus, the recommendation is contracting workforce training for this organization to incorporate knowledge of seller competencies and job tasks from the CMS for all the contract life-cycle competencies (NCMA, 2019a). Development of this training module could start by incorporating information from Contract Management Body of Knowledge (CMBOK) sections 4.0, 5.0, and 6.0 (NCMA, 2019a).

The second recommendation for the assessed organization is to emphasize its training on the CMS buyer competencies and related job tasks (NCMA, 2019b). The assessment results reflect that the average proficiency ratings of the buyer tasks are predominantly at the Intermediate level, indicating that the workforce can apply the competencies in difficult situations and requires little or no guidance. The job tasks that were rated at the Basic level indicate that the workforce can apply the competency in somewhat difficult situations and requires frequent guidance. Thus, the recommendation is for this training to emphasize buyer competencies and job tasks from the CMS for all of the contract life-cycle competencies (NCMA, 2019a).

The third recommendation for the assessed organizations is to develop and/or improve the contracting workforce training on the competency of Manage Disagreements. The assessment results reflect that the Manage Disagreements competency and related job tasks within the Award phase had the lowest scores for both buyer task proficiency and seller task knowledge. Development of this training module could start by incorporating information from section 5.4 of the CMBOK, Manage Disagreements (NCMA, 2019a). Additional information from the CMBOK could also be incorporated to improve skills such as critical thinking, problem solving, and decision-making related to managing contract disagreements, as well as resolving protests and appeals. Specifically, the CMBOK covers information on these skill sets within the Leadership, Management, and Guiding Principles Competencies (NCMA, 2019a).

Areas for Further Research

The primary area for further research is to conduct a follow-on competency assessment of the Marine Corps expeditionary contracting workforce (ECPs and RCOs) after the contracting workforce has received the recommended training based on the initial assessment. This follow-on assessment would measure any increased learning, in terms of buyer proficiency and seller knowledge of both the buyer and seller competencies as reflected in the CMS.

A second area for further research is to conduct workforce competency assessments on additional contracting organizations throughout the DoD. This would enable benchmarking workforce competency assessment data from DoD activities with diverse contracting mission sets. For example, the organization assessed for this research, the Marine Corps expeditionary contracting workforce (ECPs and RCOs), has a primary mission focused on expeditionary contracting. Conducting workforce competency assessments on organizations whose missions include other contracting responsibilities, such as major systems acquisition, construction, or base support contracting, would likely show assessment results with different levels of proficiency of buyer tasks and knowledge of seller tasks and produce different targeted recommendations.

Conclusion

The GAO and the DoD IG both continue to identify contract management as a high risk and a top management challenge for the DoD (DoD IG, 2021; GAO, 2021). The 2020 NDAA (2019) resulted in congressional direction to the secretary of defense to implement a professional certification program for all members of the acquisition workforce based on standards developed by a third-party accredited program that is based on nationally or internationally recognized standards (NDAA, 2019). In April 2020, the DoD senior procurement executives established a new contracting competency model and a single level of certification program. The new competency model is based on the NCMA CMS, which is accredited by the ANSI. The purpose of this research was to conduct a competency assessment on a sample of the DoD contracting workforce using the NCMA CMS. Based on the competency assessment results, recommendations for competency development were provided to the assessed organization. This specific research reflects the competency assessment of the Marine Corps expeditionary contracting workforce (ECPs and RCOs). Based on the assessment results, the organizations can develop a training roadmap for targeting competencies and knowledge areas needed for improvement within the contracting workforce. This research should be expanded by conducting competency assessments on other DoD contracting organizations as a way of benchmarking the DoD contracting workforce competencies against the newly adopted NCMA CMS.

References

Carlson, S. (2017). A new liberal art: How systems thinking prepares students for a complex world. *The Chronicle of Higher Education*, *64*(5). https://www.chronicle.com/article/a-new-liberal-art/

Department of Defense Office of Inspector General. (2021, October 15). *Fiscal Year 2022: Top DoD management challenges.* DoD.

GAO. (2021, March). *High-risk series: Dedicated leadership needed to address limited progress in most high-risk areas* (GAO-21-119SP). https://www.gao.gov/products/gao-21-119sp

National Contract Management Association. (2019a). *Contract management body of knowledge* (6th ed.).

National Contract Management Association. (2019b). *Contract management standard* (2nd ed.). https://www.ncmahq.org/Web/Standards---Practices/Contract-Management-Standard-Publication.aspx

National Defense Authorization Act for Fiscal Year 2020, Pub. L. No. 116–92, 133 Stat. 1198 (2019). https://www.govinfo.gov/content/pkg/PLAW-116publ92/html/PLAW-116publ92.htm

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2020, September 2). *“Back-to-basics” for the defense acquisition workforce* [Memorandum]. https://4edacm.dau.edu/assets/Back_to_Basics_Memo_2_Sep_2020.pdf

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2021, February 17). *Restructuring of the certification program for the contracting functional area* [Memorandum]. https://dair.nps.edu/handle/123456789/4487

Rendon, R. G. (2019). Enhancing professional and technical excellence: Analysis of contract management competency models (SYM-AM-19-036). *Proceedings of the Sixteenth Annual Acquisition Research Symposium*, 86–112. https://calhoun.nps.edu/handle/10945/63019

Rendon, R. G., & Schwartz, B. (2021). *An innovative approach to assessing DOD contracting workforce competency* (NPS-CM-21-036). Acquisition Research Program. https://dair.nps.edu/handle/123456789/4487

Rendon, R. G., & Winn, T. (2017). Competency in contract management: A comparison of DoD and CMBOK competency models. *Contract Management*, *57*(12), 66–81.

Werber, L., Ausink, J., Daugherty, L., Phillips, B., Knutson, F., & Haberman, R. (2019). *An assessment of gaps in business acumen and knowledge of industry within the defense acquisition workforce: A report prepared for the U.S. Department of Defense in compliance with Section 843(c) of the Fiscal Year 2018 National Defense Authorization Act* (RR-2825-OSD). RAND.

Predictability and Forecasting of Acquisition Careers in the Army

Eduardo López—primary expertise is in the application of complex network techniques to the study of real-world systems. This has been applied in a wide range of contexts that include patterns of human communication in social networks, search and matching processes on networks specialized to employment, biological nutrient transport in networks of fungi, and data traffic in data networks. From the methodological direction, López has worked on the basic properties of network transport, robustness, and percolation and temporal evolution, including single-layer as well as multiplex networks. López has been employed at the Physics Department at Universidad del Zulia as Faculty in Training (1996–2000), at the Physics Department at Boston University as a Research Assistant (2001–2005), at the Center for Nonlinear Studies at Los Alamos National Laboratory as a Postdoctoral Research Fellow (2005–2008), at the University of Oxford (2008–2012) as a Postdoctoral Fellow of Complexity Science and as a James Martin and Senior Researcher (2012–2016), and at the Department of Computational and Data Sciences as an Assistant Professor (2016–present). His degrees include a BA in physics (summa cum laude) from the Universidad del Zulia, Venezuela; an MA in physics from Boston University; and a PhD in physics from Boston University. [elopez22@gmu.edu]

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Abstract

A great deal is known about the movement of personnel population within large organizations (manpower). On the other hand, far less is known about how individual careers unfold through the structure of such organizations, with no established methods to forecast the positions individuals will take in so-called internal labor markets. In this paper, based on methods from network science, probability, and data analysis, we provide a new, empirically calibrated modeling framework for forecasting careers in large organizations. We show that, without the use of information that goes beyond the memoryless framework provided by Markov models, it is not possible to understand and forecast career moves in an organization. When memory effects are included, models improve significantly and begin to provide both useful predictions as well as information about the limits of predictability in career forecasting. Our method is applied to the Army acquisition workforce.

Introduction and Background

An effective way to summarize how organizations assign personnel to their tasks is offered by Bidwell (2017), who stated, "Perhaps the most basic challenge in talent management is ensuring that a company has the right people in the right places when it needs them." This succinct description contains a great deal of information. The places that Bidwell mentions represent positions in the organization responsible for certain tasks. Furthermore, the people that perform these tasks must possess the appropriate skills, training, experience, and social capital to be able to successfully complete these responsibilities. Seen from the lens of a mathematical description, both job positions and individuals are each represented by collections of attributes designed to capture the respective tasks, skills, experiences, and other important characteristics that can describe this system.

Mathematical descriptions of systems of this type have been studied in the past from the standpoint of the organization (De Feyter & Guerry, 2011; Wang, 2005) or the individuals embedded in it (see, for example, Stewman & Konda, 1983; Stewman & Yeh, 1991). This division reflects the multiscale perspective of the problem. The first literature, focused on *manpower* at the organizational scale, conceived the organization as made up of a set of fixed position types (similar to classifications or ranks) and personnel moves (also called stock moves) among these types. On the other hand, the individual perspective is connected to the literature in *career* studies (Gunz et al., 2020), sometimes also referred to as internal labor markets (Stewman, 1986), and is highly influenced by the idea that each employee inside the organization sporadically moves between vacancies that become available, effectively establishing two dynamic populations of vacancies and workers that interact with each other. The descriptions at either scale share many characteristics. First, they are predominantly stochastic in nature, almost always reliant on Markov models (or generalizations such as semi-Markov models; see, for example, Ginsberg, 1971). Second, they conceptualize the organization as static, which means that any temporal behavior is limited to the micro-dynamics of individual vacancies or individuals. Third, mostly due to lack of detailed micro-level information, they abstract much of the multidimensional information about the system such as the internal administrative structure of organizations (its subunits), the details of each job position, the social networks, the work teams, or other local behavior. The overall performance of these modeling approaches has been mixed: while the organizational level manpower literature has been able to offer rather reliable forecasts of personnel stocks in the system, the individual level literature has been less successful in predicting how people will move through the organization as they progress in their careers.

Much has changed over the past two and a half decades during which modeling questions took a back seat to other theoretical considerations that have occupied the research community studying careers in and out of organizations (for a discussion, see, for example, Bidwell, 2017). First, computational power and the availability of extensive data have transformed the way in which we view human-centric problems, where it is now feasible to consider modeling approaches that used to be found only in the physical sciences and engineering. Second, a new conceptual framework for highly complex and heterogeneous systems emerged in the form of the discipline of Complex Networks (see, for example, Barabási, 2014, for a popular presentation, and Newman, 2018, for a formal presentation), which provides a precise mathematical description of large interacting and heterogeneous systems such as human organizations. Both of these factors have played an important role in the development of a new theoretical view of job mobility, the concept of *Labor Flow Networks* (LFN), introduced for the purposes of modeling job changes with a simultaneous high-resolution and large system visibility (Guerrero & Axtell, 2013; Axtell et al., 2019; López et al., 2020).

An important consideration emerging from the LFN literature and other lines that have sprouted from it (see, for example, Mealy et al., 2018) refers to what is tracked in such career sequences. The traditional choice in career studies has been rank or some equivalent of it (see Rosenbaum, 1979; Stewman, 1986). The recent LFN literature focuses on firms (Guerrero & Axtell, 2013) due to their critical role in the economy and the fact that most approaches to the problem of job search have unfortunately ignored the firm scale. As will be shown, when enough information is available, there are multiple choices one has to track careers.

In this paper, by combining the LFN notion and stochastic processes with memory (Rosvall et al., 2014), we present a framework for tracking and modeling the movement of personnel through a large organization and apply the method to the Army acquisition workforce (AAW). The method seeks a clearer understanding of the formation of career sequences in an organization and how probable each sequence is. This information can be used to forecast future careers of interest to individual employees as well as the organization as a whole. We find that the introduction of memory dramatically increases the performance of a forecasting model, eliminating most of the unrealistic career sequences predicted by the current state of the art, while simultaneously generating better probability estimates of the number of employees actually choosing a sequence. Longer career sequences are generally less well predicted, although performance is still quite good. Our method also identifies career sequences that are unlikely to occur from the standpoint of what is known in the theory careers, and thus provides an opportunity to add new understanding to this field. Our results benefit greatly from the development of complex network techniques in recent decades.

We study two different definitions of career stops within the organization, operational units and occupational series (as defined by the U.S. Office of Personnel Management [OPM]). The study of the first type of stop (operational units) is an important addition that we bring to the literature, extending the notion of career sequences to the operating units/departments. This result follows a similar line of thinking as in the LFN literature. The relevance of this notion is that, while understanding a career in terms of the occupations says a great deal about skills, it says very little about social capital. On the other hand, career sequences tracked at operational units can carry social information in the form of personal contacts that are generated by directly working with others.

The first step in our framework involves an empirical analysis of personnel movements in the organization. This analysis yields a set of transition probabilities that can be used in either a memoryless form, the common approach in most personnel modeling, or by drawing on information about prior personnel movements in order to inform future ones. The second step in the framework involves a stochastic process that simulates how personnel would move inside the organization. To understand the impact of memory, our stochastic processes are chosen to be either first- or second-order Markov chains; first order chains are memoryless, whereas second order chains remember the most recent transitions before picking among subsequent choices. Although in some simple cases, these models could be solved mathematically, for almost any realistic data set, numerical approaches are needed to measure the statistics of outcomes. The third step in the framework corresponds to its evaluation, along with the tracking of any behaviour that deviates considerably from the predictions of the stochastic process. This evaluation is performed through the use of tools from information theory (Cover & Thomas, 2006) and statistics.

Our work creates a renewed opportunity to understand and forecast careers in organizations. In particular, by modifying the scale at which careers are studied, moving away from stocks of individuals progressing through ranks to looking at them in a more granular way, it makes it possible to bring into the picture other literatures such as that of quantitative career clustering, initiated by the work of Abbott and Hrycak (1990) and further perfected in subsequent decades (Aisenbrey & Fasang, 2010). Another line of this literature is the one initiated by Rosenbaum (1979), which provided the first empirical evidence from administrative records of history playing a role in the speed and attainment of career progression through a mechanism of tournaments (in a sense, highlighting the weakness inherent in memoryless models).

Materials and Methods

Data

The data we study is for the AAW and has two parts, one associated with individuals and the other with the structure of the AAW. The data sets cover the period between 2012 and 2020. All employee records are anonymized by associating to each individual a hashed key. Each employee record contains the position occupied on every month when the employee is part of the AAW. This information includes the operational unit of the individual as well as his/her occupational series (from the OPM classification). Over the period of the data, the AAW has ranged in size between under 35,000 to close to 42,000 individuals. There are around 1,000 operational units in the AAW, and employees span close to 100 occupational codes.

Methods

Our approach to career sequences in organizations deals with ordered chains. This literature emerged with White (1970), who realized their role in careers, paying special emphasis to the notion of vacancy chains. A vacancy chain emerges when a person leaves the post they are occupying to take a new job inside or outside an organization, leading to another person eventually occupying the vacancy but creating a new one, and so on. The successive vacancies created are called vacancy chains. Subsequently, a broader notion of social sequences has emerged that spans well beyond careers (see Cornwell, 2015) and has gained traction in the mathematical sociology literature.

The quantities we use in this paper are formal, and their detailed definitions are given in the Appendix. Here we merely introduce the notation and explain the spirit of these quantities. The application of these quantities in evaluating our models is done in the Results section.

As mentioned in the Introduction, career modeling is based on stochastic processes. Our approach is to use the data from observed job transitions to create information about future transitions, specifically, probabilities for such transitions. The spirit behind this idea is supported by the work of Collet and Hedström (2013) and López et al. (2020), which shows that once a job transition is observed between two firms in an open economy, the chance that any new random occurs between those two firms is about 1,000 times larger than between two firms without any previous transitions. This notion led Guerrero and Axtell (2013) to define the LFN.

Therefore, to capture the probabilities of transitions an individual may have of performing a particular job change in the AAW, we define two versions of transition probabilities, one for the model that ignores memory, and another for the model with memory of the most recent job change. These two quantities are, respectively, $p_{l,g}$ and $p_{(l,g),(g,h)}$, where l, g, and h all represent stopping points along a career sequence. Note that such transition probabilities are the result of an aggregation of the actions by many people going through job changes in the AAW over a period of time. Hence, this captures a notion of popular moves.

Note that, as in the LFN literature, we think of an organization as structured into such stops, connected if there have been job transitions between those stops. The stops can represent, for example, the occupational series a person has while in a job, and the career sequence is a sequence of occupations. Another stop could be the operational unit to which the employee is attached while having a post, and in this case the career sequence is a sequence of operational units. The stops can be other concepts as well. Critically, those stops are equivalent to nodes in a network, while the connections between the nodes represent observed job changes.

The models we apply make use of the transition probabilities stated above when an employee decides to change jobs, either recalling or ignoring the previous job change it performed.

Another quantity we rely on is $\square_l$, which are the chances that somebody at stop/node *l* separates (decides to leave or is told to do so) from their current position in any given interval of time. Individuals will not have to decide on where to go unless they separate from their current position. In our model, each time interval is of 1 month.

Models then generate *in silico* careers (simulated in the computer). One can generate as many as desired and, in fact, this is needed since job changes all have an element of randomness. With careers starting at a node *l*, we track all the career sequences *observed* from that starting node; some are performed by multiple people, some by just one. This allows us to create probabilities $F(S|s_1=l)$ of observing a specific career sequence *S* that started at stop $s_1 = l$. In a similar way, the careers we simulate have probabilities captured in $\square(S|s_1=l)$. Both $F(S|s_1=l)$ and $\square(S|s_1=l)$ are examples of so-called probability distributions. The quality of a model is assessed by the similarity that $F(S|s_1=l)$ and $\square(S|s_1=l)$ may have.

Because these probabilities have multiple parameters, we check for their similarity in multiple ways. We check if they produce exactly the same sequences. This is done by a quantity called the Jaccard index. We also check if the probabilities assigned to the careers that are both simulated and observed are similar, independent of whether all observed careers are generated in our models. This is done in two ways. One is based on a concept from information theory called the Jensen–Shannon Divergence (*JSD*; Lin, 1991), which measures the number of bits (in terms of information in a computer) that separate the two probability distributions (observed and simulated). The other is based on a comparison of career sequence by career sequence, that is, $\square(S|s_1=l)/F(S|s_1=l)$ for every *S* in starting from every *l*. The closer these ratios are to 1, the better the model. To assess this proximity to 1, we introduce a final set of variables, the most important of which is called Var($\square_l$), capturing the cumulative deviations from one of the logarithms of the ratio of probabilities. Basically, the bigger this number is, the worse the model is doing.

As an important technical point, the use of random simulations means that we do not typically generate the same $\square(S|s_1=l)$ in every simulation. This means that comparisons between $\square(S|s_1=l)$ and $F(S|s_1=l)$ are actually done between the latter and a whole set of samples of the former (for which we use a labelling index *r*). In particular, we calculate *JSD* between pairs of distinct simulations of $\square(S|s_1=l)$, with each result being labelled $t_{r,r'}$. We also calculate *JSD* between $\square(S|s_1=l)$ and $F(S|s_1=l)$, with each result being labelled m_r.

With or without memory, this network construction based on previous job transitions does a good job of modeling the career sequences of the system, although memory makes the results considerably better in some key ways. On the other hand, the probability ratios allow us to spot career sequences that are inherently difficult to model, which we briefly discuss.

Results

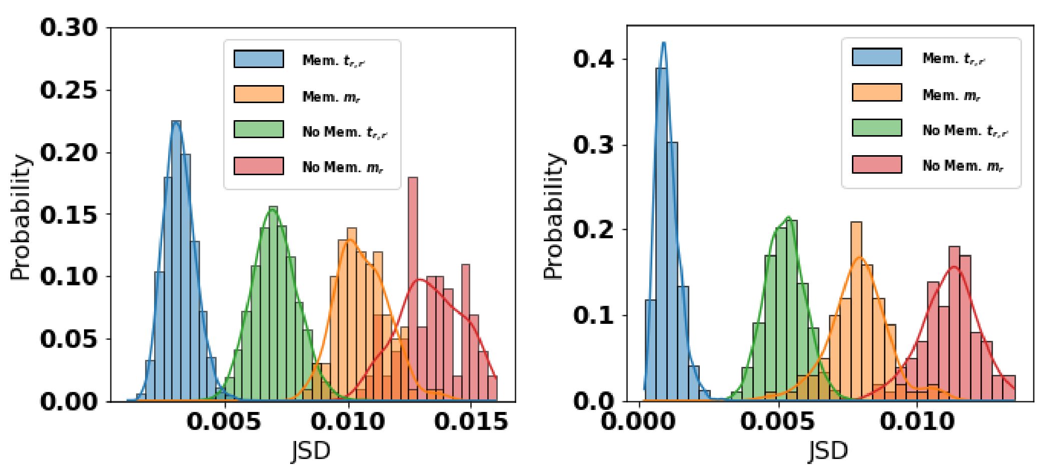
We divide the presentation of our results into two career sequences defined on occupation nodes or on operational units. As the results show, there is great consistency between the two.

Occupational Model Results

We first focus on the application of the model to occupational series. In this case, each stop corresponds to the occupational series an employee has upon being first observed in the data. The working unit of this employee is not considered in this analysis.

In Figure 1, we present results for the *JSD* distributions ($m_r(l)$ and $t_{r,r'}(l)$) for two different starting occupations *l.* The two occupations are 0346 (Logistics Management Series) and 0802 (Engineering Technical Series). The values of *JSD* generated from the models are considerably small, indicating their general quality. Moreover, comparing the memoryless and the one-step memory models, in both examples we see how the latter model performs better than the former. This is not a feature of these two occupations as comprehensive exploration of all occupational series leads to the same result.

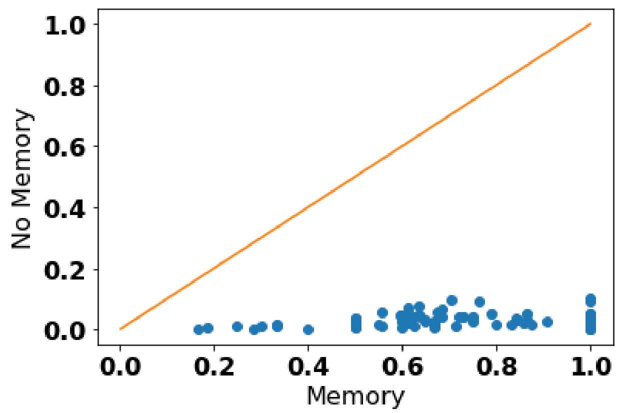
An interesting effect to explain is the fact that the values $m_r(l)$ are typically larger than the values $t_{r,r'}(l)$. This is due to the fact that while the samples $□_r(S|s_1=l)$ from any of the models are self-consistent (one value of *r* is similar to another one *r'*), the consistency between each $□_r(S|s_1=l)$ and $F(S|s_1=l)$ is generally less. In other words, the models are good but not perfect. In our analysis, we do find some occupations where the simulations match the data well, but this is not guaranteed.



Note. Each panel is associated with an initial occupation (in this case 0346 on the left and 0802 on the right). In each panel, four distributions are displayed, differentiated by color (blue corresponds to $t_{r,r'}(l)$ for the model with memory, green corresponds to $t_{r,r'}(l)$ with no memory, orange corresponds to $m_r(l)$ with memory, and red corresponds to $m_r(l)$ with no memory). In all cases, the distribution of $m_r(l)$ peaks at smaller values (of *JSD*) for the model with memory.

Figure 6. Probability Distributions of $m_r(l)$ and $t_{r,r'}(l)$ for Two Different *l*, and Models

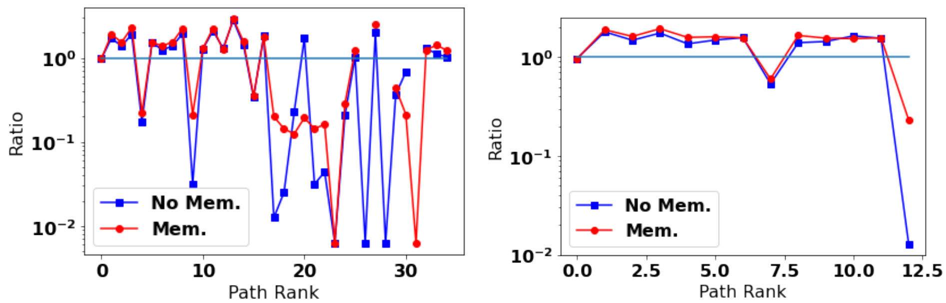
As explained in the Methods section, *JSD* captures an aggregate measurement of the discrepancy between $F(S|s_1=l)$ and the models. However, other differences between model and $F(S|s_1=l)$ can remain unseen in this analysis. The most critical of those features is the possibility that a model generates career sequences that do not always reflect well the collection of observed careers. These possible differences can be assessed by the Jaccard index (see Figure 2). The results of this analysis clearly show the considerable improvement brought on by the introduction of memory: while the values of the index for the memoryless cases remain bounded from above by a value near 0.1, the one-step memory leads to indices with values ranging from about 0.2 to 1.0. If there were a strong correlation between the Jaccard indices of the models for the same starting occupations, the points would lie near the reference line along the diagonal, but this is not the case. The main reason why the Jaccard index improves so dramatically is because the number of careers generated in the one-step memory model is considerably smaller than in the memoryless model. Furthermore, the generated careers generally capture the observed careers, making it possible for the index to reach values that tend to 1.



Note. Each point corresponds to a starting occupation and has as its horizontal coordinate the value of the Jaccard index for the one-step memory model, and as its vertical coordinate the value of the Jaccard index for the memoryless model. The modeled careers correspond to the union of all careers created in the $n_w n_{\square}$ total number of walks across all $n_{\square}$ realizations. While the values of Jaccard indices for the one-step memory span the range between approximately 0.2 to 1.0, the Jaccard indices of the memoryless model remain quite low, usually no larger than 0.1. The orange line runs along the diagonal as a visual reference. If the two models provided similar values of Jaccard indices, one would expect to see the cloud of points near that line.

Figure 7. Scatter Plot of the Jaccard Indices Between the Memoryless and One-Step Memory Models, Calculated Between the Careers Generated From Simulations and From Observation

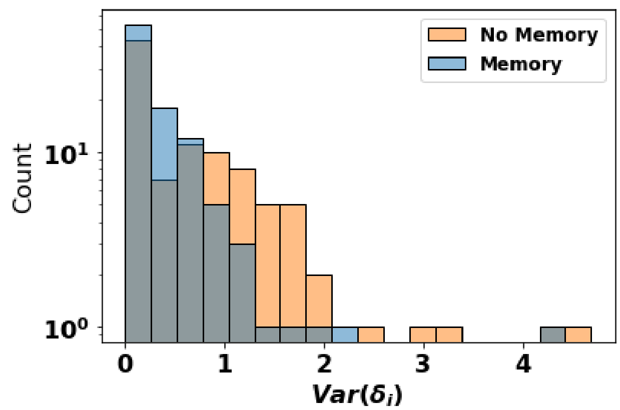
Both *JSD* and Jaccard indices produce a summary statistic about the details of the relationship between $F(S|s_1=l)$ and the model outputs captured in the realizations $\square_r(S|s_1=l)$. As defined in the Methods section, a more direct analysis of each career sequence S that belongs to these distributions can be achieved through $d(S_i)$. For a given l, we plot $(i, d(S_i))$ for the two models. This is shown in Figure 3. The blue and red curves present, respectively, the memoryless and one-step memory models. Generally, for any career S_i, $d(S_i)$ is closer to 1 for the one-step memory model, which is desired.



Note. The blue curve represents the memoryless model, whilst the red curve represents the one-step memory model. Both plots also show a horizontal line of height 10^0 (i.e., 1), which is the target achieved for an "ideal" model that reproduces careers perfectly. The red curve is generally closer to the horizontal line = 1 for both starting occupations.

Figure 8. Profiles of Models in Terms of Their Relation to Observed Careers, Captured in (i,$d(S_i)$), for Starting Occupations 0346 and 0802

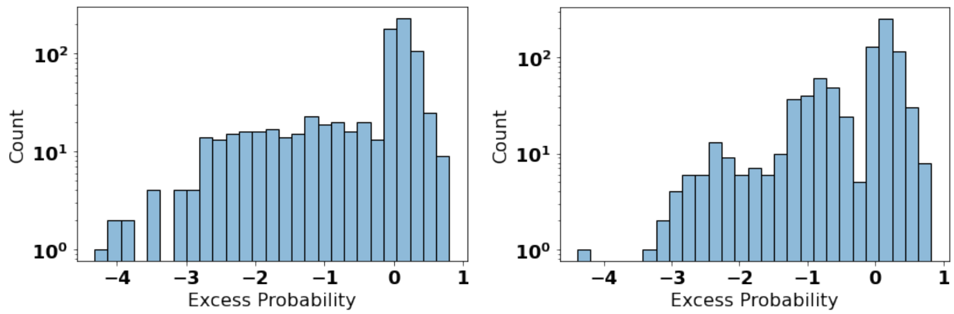
The results offered by the analysis of $d(S_i)$ are limited in that they require I by I analysis. However, it is desirable to quantify all I in a systematic way, which was the reason for the introduction of δ_I and its variance Var(δ_I). This last quantity can be studied for the entire system through its histogram (see Figure 4).



Note. The histogram clearly shows the larger values corresponding to the memoryless model.

Figure 9. Histogram of Var(δ_I) for Both the Memoryless and One-Step Memory Models for Occupations

A final analysis comes from a careful study of Figure 3, which illustrates examples of careers that, while simulated by the random models, appear with frequencies far different than observed. This is reflected in the values of $d(S_i)$, which, due to the clarity of its interpretation, we analyse as |log $d(S_i)$|. When one of these values exceeds some arbitrarily chosen threshold, career sequence S_i is taken to be significantly outside the model. To first develop a notion of the possible values that log $d(S_i)$ can take, we present Figure 5 for the two models and across all careers in the system. It is clear that the majority of the career sequences have values of log $d(S_i)$ in the vicinity of 0 and < 1. On the other hand, both models have a relatively long tail of values below 0, which means particular career sequences observed in the data are not simulated as often in the models. The memoryless model shows even more careers that significantly deviate from their observed frequencies than the model with memory. In addition, the one-step memory model shows multi-modality (although we do not present this analysis, we have traced this result to career sequence length, i.e., longer careers are harder to model accurately).



Note. The model with memory concentrates more of its probability mass between −1 and 1 than the memoryless model.

Figure 5. Histogram of Values of log $d(S_i)$ for the Memoryless and One-Step Memory Models for Occupational Career Sequences

On the basis of the results in Figure 5, we see that considerable interesting behaviour occurs when log $d(S_i) \leq -1$. Are there common features to careers that cross this threshold? One feature, mentioned above, involves the length of paths. Longer career sequences are harder to forecast and lead to values of □$(S|s_1=l)$ that deviate from $F(S|s_1=l)$ more. Beyond this length effect, other details of career sequences may be responsible for leading to poor forecasts from models.

A comprehensive exploration of career sequences in order to identify all possible reasons behind poor predictions of those sequences is not likely to be very informative, as any single sequence can have its own reasons for being hard to predict. A more productive approach may be to identify temporal features shared by many poorly forecasted careers so that especial approaches can be applied to improve those forecasts. The concept of a temporal pattern in a network is known as a temporal motif (Holme & Saramäki), and our method for understanding poorly forecasted careers is basically a search for such temporal motifs.

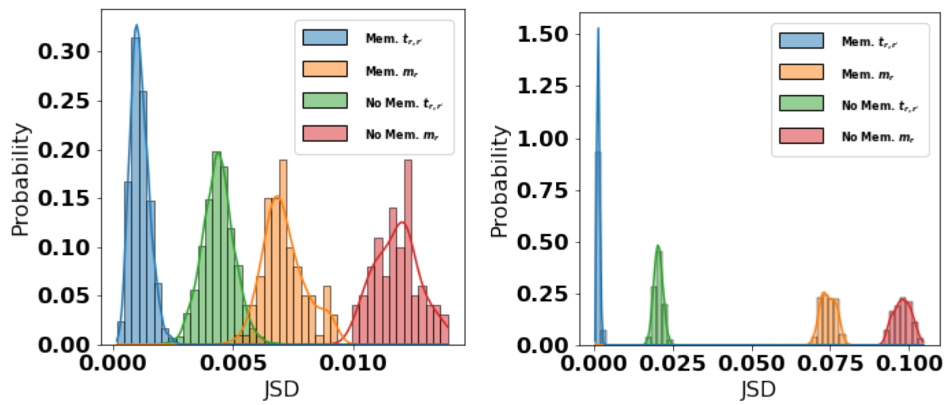
Our analysis has yielded an interesting and unexpected result. One of the key temporal motifs contributing to poor prediction is one characterized by employees going back to positions they previously held. This is a surprising result. In the observed paths, 24.5% contain this motif. Without memory, the model was able to produce 79.6% of those motif paths while memory improved this to 88.2%.

In summary, the results for the analysis of careers sequences defined on occupations shows that the models we have constructed are certainly useful and, furthermore, that the one-step memory model performs better.

Units Model Results

The approach deployed for the study of occupations can also be applied to the study of careers occurring along operational units of the organization. Methodologically speaking, there is no difference in the calculation of the quantities presented above, but interpretation of the results has to take into account the nature of the nodes. Qualitatively speaking, we find the same behavior in career sequences tracked on the basis of operational units as we observe for sequences over occupational series.

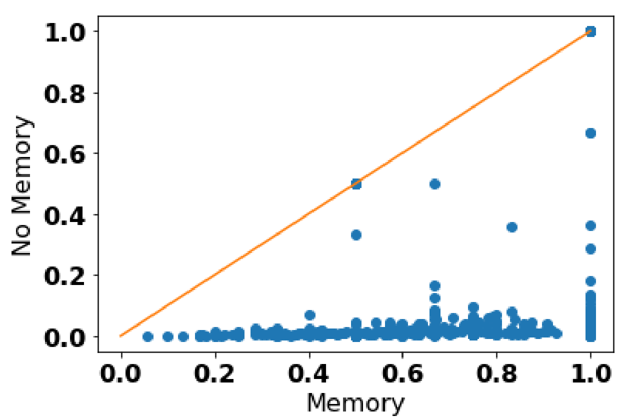
As an illustration of the similarity between modeling by occupational series or operational units, we present Figure 6, which shows the *JSD* measurements of careers starting from two such units. The observed features of these plots do not differ from those in Figure 1, that is, better performance for the one-step memory, as well as the observation that both models still have room for improvement.



Note. Each panel is associated with an operational unit (kept undisclosed). In each panel, four distributions are displayed, differentiated by color (blue corresponds to $t_{r,r'}(l)$ for the model with memory, green corresponds to $t_{r,r'}(l)$ with no memory, orange corresponds to $m_r(l)$ with memory, and red corresponds to $m_r(l)$ with no memory). In all cases, the distribution of $m_r(l)$ peaks at smaller values (of *JSD*) for the model with memory.

Figure 10. Probability Distributions of $m_r(l)$ and $t_{r,r'}(l)$ for Two Different *l*, and Models

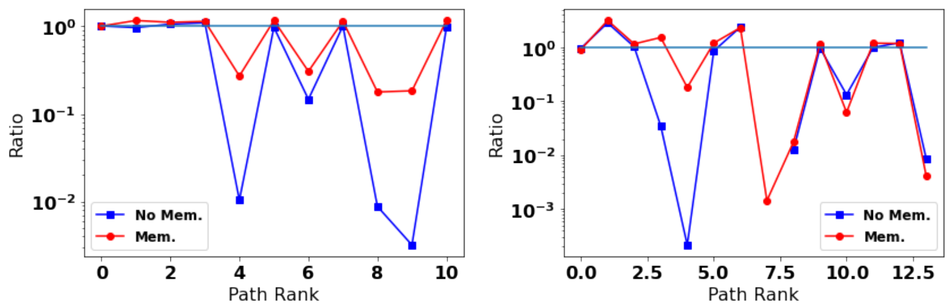
Next, we discuss the Jaccard over operational units. In contrast to the case of occupational series, there are a very distinct few units for which the memoryless model leads to good Jaccard indices (Figure 7). However, this is the exception rather than the rule. Overwhelmingly, the one-step memory model performs much better.



Note. Each point corresponds to a starting operational unit and has as its horizontal coordinate the value of the Jaccard index for the one-step memory model, and as its vertical coordinate the value of the Jaccard index for the memoryless model. The modeled careers correspond to the union of all careers created in the n_w n_l total number of walks across all n_l realizations. While the values of Jaccard indices for the one-step memory span the range between approximately 0.2 to 1.0, the Jaccard indices of the memoryless model remain quite low, usually no larger than 0.1. The orange line runs along the diagonal as a visual reference. If the two models provided similar values of Jaccard indices, one would expect to see the cloud of points near that line.

Figure 7. Scatter Plot of the Jaccard Indices Between the Memoryless and One-Step Memory Models, Calculated Between the Careers Generated from Simulations and from Observation

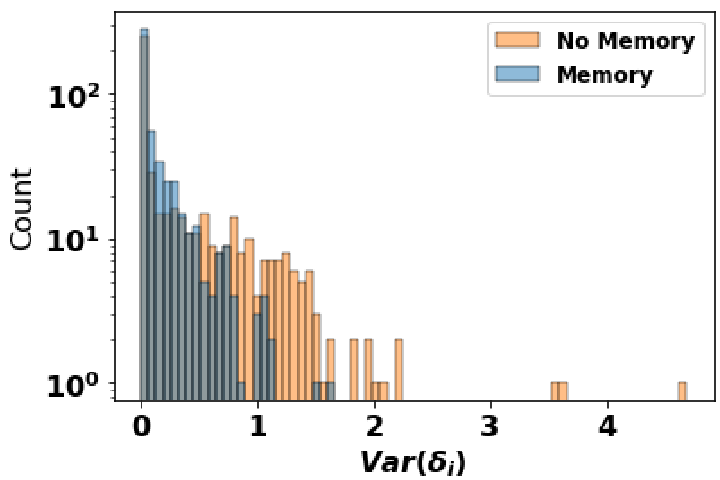
Results connected to $d(S_i)$, Var(δ_i), and log $d(S_i)$ also have the same qualitative features for units as they do for occupations. For $d(S_i)$, we present Figure 8, which is constructed with the same units as in Figure 6. As for occupations, the match of the one-step memory model and observation is quite reasonable.



Note. The blue curve represents the memoryless model, whilst the red curve represents the one-step memory model. Both plots also show a horizontal line of height 10^0 (i.e., 1), which is the target achieved for an "ideal" model that reproduces careers perfectly. The red curve is generally closer to the horizontal line = 1 for both starting occupations.

Figure 8. Profiles of Models in Terms of Their Relation to Observed Careers, Captured in (i,$d(S_i)$), for Two Starting Undisclosed Operational Units

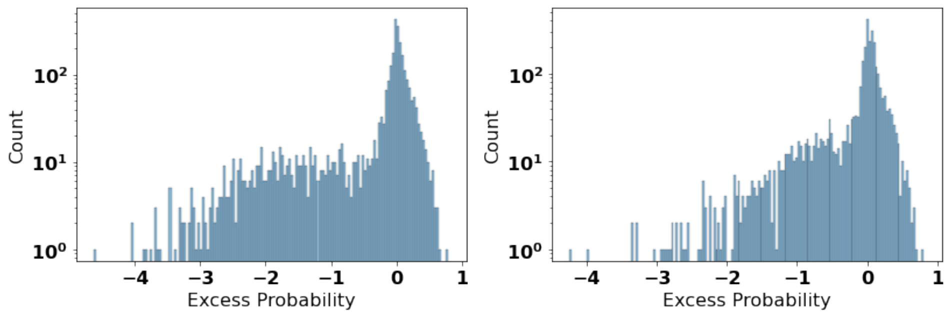
The values of Var(δ_i) are shown in Figure 9.



Note. The histogram clearly shows the larger values corresponding to the memoryless model.

Figure 9. Histogram of Var(δ_i) for Both the Memoryless and One-Step Memory Models for Operational Units

Finally, we present results for the collection of all log $d(S_i)$ in Figure 10.



Note. The model with memory concentrates more of its probability mass between −1 and 1 than the memoryless model.

Figure 10. Histogram of Values of log $d(S_i)$ for the Memoryless and One-Step Memory Models for Operational Units Career Sequences

As in the occupational series model, the motif of employees leaving one state for another and then returning to it is present in the units implementation. Here, 10.8% of the observed paths exhibit this motif. The model without memory is able to produce 88.2% of paths containing the motif. However, with memory, the model captures 98.1% of such paths.

Discussion and Conclusions

The modeling approach we have taken in this work has been highly driven by statistical analysis. The network structure implicit in the transition probabilities specified above (either for memoryless or one-step memory models) creates a network substrate that allows us to generate forecasts of the workforce job changes at a microscopic level, that is, for any career sequence.

The introduction of a notion of career sequences occurring on a network of operational units is new in the study of careers, and we expect that as we focus more on its details, numerous relevant features of the system will start to emerge, such as the value of work or friendship ties in people's careers.

An important limitation of our current methodology is that it is calibrated against observed job transitions rather than *possible* job transitions. This is an important issue because the finite nature of the system does not make it possible to observe enough job transitions that a probability for *any* arbitrarily chosen pair of transitions to occur can be extracted from the data. In order to overcome this, study of the characteristics of each job (say, occupational series, location, career field) offers a new direction to pursue in order to create a more flexible model that may be able to predict what could happen even if it has never been observed.

From the standpoint of the contribution that this work may bring to the acquisition workforce, we note that the Department of Defense requires the ability to understand high volumes of behavioral and environmental data, in an institutionally informed framework, to produce reliable forecasts of workforce behaviors across an extended planning horizon. This goal is consistent with the fact that one of the three priorities in the 2019 National Defense Strategy is to reform the department's business practices for performance and affordability (Mattis, 2018). Further, *The Army People Strategy* calls for the implementation of 21st century talent management, enabled by leading-edge research and leveraging technology and "data-driven organizational research to continuously improve Army people programs and policies" (Secretary of the Army, 2019).

Improving understanding about the way the government workforce moves within and across different organizations in detail, how to plan for it, and how to optimally manage it are clearly relevant strategic resource usage and institutional effectiveness concerns. Mission completion across the board is impacted directly by government organizations' ability to ensure capable people are in the right place, at the right time to perform critical tasks. In addition, findings from our ongoing research offer the promise of expanding the body of knowledge and theory of processes, systems, and policies both inside and outside the government.

In conclusion, our method allows us to create reliable forecasts of career sequences, especially as the memory of the model is increased. We expect this method to become useful in the near future as a forecasting tool for career moves inside the AAW. Longer term, we expect to develop a more extensive characterization of the forecasting power and limitations of this model.

Appendix: Formal Definitions

In order to provide some concrete definitions and notation, let us consider one hypothetical career sequence $S = (s_1, s_2, \ldots s_n)$. Each transition between two stops s_i and s_{i+1} provides information that the second of these stops can be reached by individuals in the first. Each stop s_i for all i of any career sequence takes its value from a set of allowed stops L, where the elements of L correspond to the kind of stop we are interested in modeling. For example, if we want to model movement of individuals through the units/departments of the organization, the elements of L will be the distinct organizational units; if we care about individuals moving through occupations, the elements of L will be occupational series codes and so forth.

To model careers, we define a stochastic process following the logic in López et al. (2020). An individual currently located in stop l has a decision to make: either remain in l with probability $1 - \square_l$, or depart with probability $\square_l$, where $l \in L$. Each element of an individual career s_i corresponds to a stop such as l. Another possible action that an individual can take is to exit the organization. In our approach, this is predetermined at the outset of an individual's career by assigning it a total time in the organization. Once the time assigned to the individual has elapsed, or the stipulated duration of the model is reached, the individual disappears.

Transitions between stops occur with some probability. In order to calibrate our model, we use information from observed careers. Using Q to denote the total number of sequences observed in our data, we can create a set of transition probabilities for our model by counting the number of individuals performing a given transition. As explained in the Introduction, we employ two different rules. First, in the case where prior transitions by an individual are considered irrelevant, we use the transition probability

$p_{l,g} = n_{l,g} / \square_g \, n_{l,g}$ [memoryless case],

where $l, g \in L$. In other words, the likelihood that an individual currently in l will transition to g as its next stop is given by the proportion of individuals in the past that, upon leaving l, decide to move to g.

The second type of transition probability we employ keeps track of the last transition made by an individual (if the individual indeed has a career sequence spanning at least one transition up to that point). In this case, we define the transition probability as

$p_{(l,g),(g,h)} = n_{(l,g),(g,h)} / \square_{(g,h)} \, n_{(l,g),(g,h)}$ [one-step memory case], where $l,g,h \in L$ and (l,g) and (g,h) are transitions. The denominator sums over all possible destinations $h \in L$ that an individual that has arrived at stop g from stop l has been seen to reach. This case allows for the possibility that $g = h$, that is, that g is a terminal node for an individual that has reached g from l.

Two other rules apply to the model with memory. An individual for which l is their first stop, if they decides to change jobs, they does so under the rules of the memoryless model on this first change. This is because at that point, such individual does not have any prior history in the system to draw from. The second rule, already hinted at in the previous paragraph, is that memory can lead an individual to remain in a location due to their history. This is the case in which $p_{(l,g),(g,h)} = 1$ when $g = h$, because it means that in the data all those that arrived at g from l never moved away from g.

In both cases above, the process is Markovian in nature, as they abandon the memory of more remote events in the past. Extending memory is, in principle, straightforward, although computationally costly. However, as we shall see, single memory is sufficient to provide a strong predictive value to the model.

Both the memory and one-step memory processes described above can be encoded in a complex network, that is, an object in which every stop $l, g, h, \ldots$ can be thought of as a node of the network, and every transition between two stops (nodes) can be considered a link between the nodes. Thus, both $p_{l,g}$ and $p_{(l,g),(g,h)}$ lead to sets of nodes and links that represent the entire organization and its job transitions in the form of a network. When the nodes correspond to occupational series, the network is one of occupations and transitions between those occupations; when the nodes correspond to operational units, the network represents those operational units and the job transitions that occur across them. Given this interpretation of the model, in what follows, we interchangeably use nodes or stops to refer to either an occupation or unit of the organization.

In order to evaluate our models, we must compare their behavior to that of observed career sequences. Since the entry point of a career may play a role in its subsequent progression, we define a probability distribution $F(S|s_1=l)$ for all *observed* career sequences that share the same initial stop l. Thus, $F(S|s_1=l)$ is the probability that an individual that begins a career at l indeed performs the career sequence S. Our models also generate career sequences with some probability. We denote the probability distribution of *simulated* career sequences by □$(S|s_1=l)$. Note that, in contrast to $F(S|s_1=l)$, □$(S|s_1=l)$ is not fixed in our model. This is because every time we construct a set of paths through a random process using a stochastic (Monte Carlo) computer simulation, the specific set of sequences and their relative proportions can be different. By the Law of Large Numbers, the larger the simulation in terms of the number of samples created, the less difference one expects between two separate Monte Carlo simulations, but it is very unlikely that for even a moderately large system one will obtain the same □$(S|s_1=l)$ twice. The detailed way in which examples (also called realizations) of □$(S|s_1=l)$ are constructed is explained in the Results section.

A model that is both perfect and can be simulated an infinite number of times would lead to $F(S|s_1=l)$ = □$(S|s_1=l)$ for any starting l, where both probability distributions would be defined over the same set of sequences. However, no model is perfect nor can it be simulated an infinite number of times. In order to measure the discrepancy between F and □, we employ three complementary methods. The first of these tracks how different the sets of sequences from each of the models are in comparison to the actually observed sequences. For this we introduce the notation $G_l = \{S|s_1 = l, S$

observed} to represent the set of all observed career sequences that being at l (i.e., where the first stop s_1 is l). Similarly, we use $H_l = \{S|s_1 = l,\ S \text{ simulated}\}$ to represent the set of simulated sequences. Then, we define the so-called Jaccard index

$$J = |\, G_l \cap H_l \,| \;/\; |\, G_l \cup H_l \,|,$$

where $G_l \cap H_l$ corresponds to the set intersection of G_l and H_l, and $G_l \cup H_l$ represents their union. Furthermore, the symbol | | measures the number of elements of a set. Thus, J measures the ratio of the number of common elements between G_l and H_l versus the total number of distinct elements contained in G_l and H_l. If $G_l = H_l$, J = 1, and if the two sets have no common elements, J = 0. Therefore, with the Jaccard index, we seek to determine if a model produces similar career paths, regardless of the rate (i.e., probability) at which they may be produced.

The second measure we employ in evaluating our models is the *JSD* (Lin, 1991), based on ideas from information theory. Whereas the Jaccard index captures the unweighted similarity between collections of sequences, the *JSD* measures "distance" between distributions. The units of *JSD* are basically those of information (i.e., bits). To interpret *JSD* results, it is useful to recall that a bit measures the information needed to describe something; more bits means more information needed. Now, since *JSD* is a distance between distributions, one expects that two identical distributions would have a *JSD* with a value of 0; distributions that are not equal will have a *JSD* > 0. The concrete definition of *JSD* requires the use of the concept of information entropy, that is, Shannon entropy *H,* which measures the number of bits needed to describe a probability distribution. Symbolically, it is given by Cover and Thomas (2006)

$$H(P) = - \square_r\, P(r) \log_2 P(r),$$

where $P(r)$ is a probability distribution of some random variable r. A large value of $H(P)$ means that the distribution $P(r)$ requires a large amount of information to be described.

For the definition of H, we can now introduce the *JSD* we use. In particular, the *JSD* between $F(S|s_1=l)$ and an example of $\square(S|s_1=l)$ is defined as

$$JSD(F,\square) = H[(F+\square\square\square\square] - [H(F)+H(\square)]/2.$$

As explained above, *JSD* acts as a distance in bits between probability distributions. In this specific case, the distance is measured between each distribution and the average distribution (F+□□□□. Ultimately, the intuition of how the value of *JSD* changes is clear: the more the difference between F and □□□the larger *JSD* becomes. Its lower bound is 0, but there is no upper bound in principle, although for any finite system, an upper bound could be found.

Note that because *JSD* is based on entropy, which, in turn, is calculated from probability distributions, the relative differences in likelihoods of career sequences are captured in this measure. However, because entropy is a sum, it does not keep track of which career sequences are the ones responsible for the most important contributions to H or *JSD.* For this reason, we need another measure.

In order to simultaneously address differences in probabilities between observed and simulated career sequences one sequence at a time, we introduce a graphical method that allows us to study discrepancies between $F(S|s_1=l)$ and examples of $\square(S|s_1=l)$. However, before we can deploy this approach, we require a prior step.

The career sequences generated by our models are not always the same as those observed. This occurs due to model stochasticity. Furthermore, the less accurate the model is, the more likely it is that observed and simulated careers differ. For the method we will present next, which focuses on the comparison of observed and simulated probabilities of career sequences, it is useful to correct $\Box(S|s_1=l)$ so that it is conditioned on only those careers that are also observed. Therefore, we define

$$\Box(S|s_1=l, S \text{ observed}) = \Box(S|s_1=l) \,/\, \Box_{S'\text{ observed}}\, \Box(S'|s_1=l).$$

This expression creates a conditional probability of the simulated careers that are also observed careers.

We are now ready for the next analytical approach, which we first apply as a graphical method and then define from it a quantity that tracks difference so that we can systematically evaluate each modeling method over the entire set of sequences departing from any l. To be concrete, we define an ordered set of values $d(S_1), d(S_2), \ldots, d(S_{bl})$ where each S_i for i between 1 and b_l is taken to be an *observed* career sequence, and b_l is the number of them that have been observed starting at l. Then, any $d(S_i)$ is defined by

$$d(S_i) = \Box(S_i|s_1=l) \,/\, F(S_i|s_1=l) \; [F(S_1|s_1=l) \geq F(S_2|s_1=l)\,) \ldots \geq F(S_{bl}|s_1=l)],$$

where the square brackets stipulate that the career sequences are indexed with i so that the sequence with the largest probability to be observed in the data is S_1, the sequence with the second largest probability to be observed is S_2, and so forth. Note that, if $\Box(S_i|s_1=l) = F(S_i|s_1=l)$, for career S_i then $\Box(S_i|s_1=l) / F(S_i|s_1=l) = 1$. Thus, we will be trying to evaluate the quality of each model by measuring how close to 1 the values $d(S_i)$ are.

The collection of $d(S_i)$ have another use: they are helpful in determining career sequences that substantially deviate from their observed probabilities. Thus, as part of our analysis, we track sequences that exceed some arbitrarily chosen threshold of deviation (specifically, we do this through $\log[d(S_i)]$, as explained later).

A given ordered set $d(S_1)$, $d(S_2)$, …, $d(S_{bl})$ can be plotted as a set of points $(i, d(S_i))$. This produces for each starting location l a *profile plot* that indicates how well each of the career sequences out of l have been captured by a model. This is a visual method to evaluate the models, one l at a time. However, to explore the entire set of all possible l, we cannot rely on visual inspection always, especially if careers are being studied using stops that are quite numerous in an organization (e.g., each job post). To address this, we introduce

$$\Box_l\Box\Box\Box\Box_i \log[d(S_i)] \,/\, b_l\,,$$

$$\mathrm{Var}(\Box_l) = \Box_i\, (\log[d(S_i)] - \Box_l)^2 \,/\, b_l\,,$$

which compute a measure of deviation between $F(S|s_1=l)$ and examples of $\Box(S|s_1=l)$ combining the effect of all S_i. The use of the logarithm has a nice property from the standpoint of interpretation: when $\Box(S_i|s_1=l) = F(S_i|s_1=l)$, $\log[\Box(S_i|s_1=l) / F(S_i|s_1=l)] = \log(1) = 0$. The second of the two quantities, $\mathrm{Var}(\Box_l)$, captures a deviation from 0, and can only be positive, whereas $\Box_l$ may have cancelations included (due to positive and negative values of $d(S_i)$). Therefore, we see $\mathrm{Var}(\Box_l)$ as a more robust quantification of deviation.

As indicated in the Methods section, each $\Box(S|s_1=l)$ is generated through computer simulation in which in silico employees remain at a stop s_i with a probability $1 - \Box_{si}$, move to another stop based on a probability $\Box_{si}$ multiplied by a transition rate p that may depend on s_i only in the memoryless case or in the latest transition (s_{i-1}, s_i) in the one-step memory, and will exit the network after a number of predetermined steps

□□□the latter being drawn from a distribution for the entire workforce. These rules will not always produce the exact same career sequences emerging from an initial stop *l*. Therefore, in order to generate a realization of □($S|s_1=l$) that is representative of transitions observed, we create a number n_w of career walks. Usually, we employ 5,000 such career walks for a single □($S|s_1=l$).

This, however, is not entirely sufficient to perform our analysis. If we consider the process of determining *JSD*, a single example of □($S|s_1=l$) produces a single value of *JSD.* To provide us with enough statistics to understand the possible values of *JSD*, we generate *n*□ such simulations. We label the different realizations of □($S|s_1=l$) emerging from this approach through the index *r*, that is, □$_r$($S|s_1=l$), where r =1, …, *n*□. We then compute *JSD* in two different ways. To determine the similarity between model outputs and $F(S|s_1=l)$, we create *n*□ samples of *JSD* and label them $m_r(l)$, each given by

$m_r(l)$ = *JSD*[$F(S|s_1=l)$,□□$_r$($S|s_1=l$)].

This generates a histogram of *n*□ values, each providing a *JSD* value between observed and simulated career sequences. The histograms are shown below in the subsections concerned with whether stops are defined as occupational codes or operational units.

Our second use of the *n*□□realizations is to create a notion baseline value of *JSD* between simulations. This is done through the variable

$t_{r,r'}(l)$ = *JSD*[□$_r$($S|s_1=l$)],□□$_{r'}$($S|s_1=l$)] [r, r' = 1,…, *n*□, $r \neq r'$].

These pairwise combinations of the outputs of simulations *r* and *r′* lead to a total of *n*□ (*n*□ - 1)/2 values $t_{r,r'}$. We study these values using probability distributions as well (see Figure 1 and Figure 6). Usually, we employ *n*□ = 100, with *n*□ (*n*□ − 1)/2 = 100 × 99/2 = 4,950. This generates per *l* a total of 100 samples of $m_r(l)$ and 4,950 samples of $t_{r,r'}(l)$.

Why do we need to create samples for $m_r(l)$ and $t_{r,r'}(l)$? The overall reason is that they create ways of comparing the performance of the models against each other, and also as a way to determine if any of these models is actually achieving the ultimate objective of predicting the system. To explain the logic, consider the ideal case that a model essentially captures the behavior of the system. In this case, □($S|s_1=l$) would approach $F(S|s_1=l)$ as n_w becomes very large. This would lead to *JSD*[$F(S|s_1=l)$,□□($S|s_1=l$)] tending to 0. The key difficulty with this statement is that n_w cannot really be made to approach infinity, which is likely to be necessary to fully confirm a possible equality between $F(S|s_1=l)$ and□□($S|s_1=l$). Instead, a realistic optimal level of agreement between $F(S|s_1=l)$ and□□($S|s_1=l$), given that we can only do a finite number of walks n_w to create a □($S|s_1=l$), would be signalled by the fact that $F(S|s_1=l)$ would be indistinguishable from any one of the *n*□ realizations □$_r$($S|s_1=l$). In this case, the probability distributions of $m_r(l)$ and $t_{r,r'}(l)$ should be indistinguishable (i.e., should overlap). This implies that the samples of $t_{r,r'}(l)$ act as a baseline check, to see how far the model is from the “ideal” modeling of the system. Figure 1 and Figure 6 show these results for two sample units and occupational series. For most *l* in the system, the results show that the models are not a perfect match with the system, but the very small values of *JSD* indicate that they are also not that far off.

The use of the $m_r(l)$ samples, as briefly indicated above, allows performance comparison between the models. This is done simply by determining which model leads to a distribution of $m_r(l)$ with *smaller* values. As we see in Figure 1 and Figure 6, the model with memory indeed performs better.

References

Abbott, A., & Hrycak, A. (1990). Measuring resemblance in sequence data: An optimal matching analysis of musicians' careers. *American Journal of Sociology*, *96*(1), 144–85.

Aisenbrey, S., & Fasang, A. E. (2010). New life for old ideas: The "second wave" of sequence analysis bringing the "course" back into the life course. *Sociological Methods & Research*, *38*(3), 420–462.

Axtell, R. L., Guerrero, O. A., & López, E. (2019). Frictional unemployment on labor flow networks. *Journal of Economic Behavior & Organization*, *160*, 184–201.

Barabási, A-L. (2014). *Linked: How everything is connected to everything else and what it means for business, science, and everyday life*. Basic Books.

Bidwell, M. (2017). Managing talent flows through internal and external labor markets. In *The Oxford Handbook of Talent Management* (pp. 281–298). Oxford University Press.

Collet, F., & Hedström, P. (2013). Old friends and new acquaintances: Tie formation mechanisms in an interorganizational network generated by employee mobility. *Social Networks*, *35*(3), 288–299.

Cornwell, B. (2015). *Social sequence analysis: Methods and applications*. Cambridge University Press.

De Feyter, T., & Guerry, M.-A. (2011). Markov models in manpower planning: A review. In *Handbook of Optimization Theory* (pp. 67–88). Nova Science Publishers Inc.

Ginsberg, R. B. (1971). Semi-Markov processes and mobility. *Journal of Mathematical Sociology*, *1*, 233–262.

Guerrero, O. A., & Axtell, R. L. (2013). Employment growth through labor flow networks. *PlosONE*, *8*(5), e60808. https://doi.org/10.1371/journal.pone.0060808

Guerrero, O. A., & López, E. (2015). Firm-to-firm labor flows and the aggregate matching function: A network-based test using employer-employee matched records. *Economic Letters*, *136*, 9–12.

Gunz, H., Lazarova, M., & Mayrhofer, W. (2020). *The Routledge companion to career studies*. Routledge.

Lin, J. (1991). Divergence measures based on Shannon entropy. *IEEE Transactions on Information Theory*, *37*(1), 145–151.

López, E., Guerrero, O. A., & Axtell, R. L. (2020). A network theory of inter-firm labor flows. *EPJ Data Science*, *9*, 33.

Mattis, J. (2018). *Summary of the 2018 National Defense Strategy of the United States of America*. Joint Chiefs of Staff.

Mealy, P., del Rio-Chanona, R. M., & Farmer, J. D. (2018). *What you do at work matters: New lens on labour*. SSRN. http://dx.doi.org/10.2139/ssrn.3143064

Newman, M. (2018). *Networks* (2nd ed.). Oxford University Press.

Rosvall, M., Esquivel, A. V., Lancichinetti, A., West, J. D., & Lambiotte, R. (2014). Memory in network flows and its effects on spreading dynamics and community detection. *Nature Communications*, *5*, 4630.

Secretary of the Army. (2019). *The Army people strategy*. Office of the Assistant Secretary of the Army, Manpower, and Reserve Affairs.

Stewman, S. (1986). Demographic models of internal labor markets. *Administrative Science Quarterly*, *31*(2), 212–247.

Stewman, S., & Konda, S. L. (1983). Careers and organizational labor markets: Demographic models of organizational behavior. *American Journal of Sociology*, *88*(4), 637– 685.

Stewman, S., & Yeh, K. S. (1991). Structural pathways and switching mechanisms for individual careers. *Research in Social Stratification and Mobility*, *10*, 133–168.

Wang, J. (2005, February). *A review of operations research applications in workforce planning and potential modelling of military training*. DSTO Systems Sciences Laboratory.

White, H. C. (1970). *Chains of opportunity: System models of mobility in organizations*. Harvard University Press.

PANEL 6. SUPPLY CHAIN CONCERNS

Wednesday, May 11, 2022	
11:05 a.m. – 12:20 p.m.	**Chair: Matthew R. Beebe,** Director, Acquisition (J-7), Defense Logistics Agency ***Supply Chain Resilience in an Era of Long-Term, Peacetime Competition: The Semiconductor Case and a New Framework for Supply Chain Assessment*** Emily de La Bruyere, Horizon Advisory Nathan Picarsic, Horizon Advisory ***Organizational Change Considerations for Implementation of Performance-Based Logistics Contracts*** Jake Smithwick, University of North Carolina at Charlotte Daniel Stroder, University of North Carolina at Charlotte ***Acquisition Security Framework: Integration of Supply Chain Risk Management Across the DevSecOps Lifecycle*** Carol Woody, Carnegie Mellon University Charles M. Wallen, Carnegie Mellon University Christopher Alberts, Carnegie Mellon University Michael Bandor, Carnegie Mellon University

Matthew R. Beebe—currently serves as Director of Acquisition (J-7), Defense Logistics Agency, Fort Belvoir, Va., including responsibilities as Component Acquisition Executive and Senior Procurement Executive. In this capacity, he is responsible for the development, application, and oversight of DLA acquisition policy, plans, programs, functional systems and operations for the annual Agency acquisition program exceeding $35 billion.

Mr. Beebe has been a member of the Senior Executive Service since 2010 when he joined DLA as the Executive Director of the Joint Contingency Acquisition Support Office (JCASO). JCASO was established to orchestrate, synchronize and integrate program management of contingency acquisition across combatant commands and U.S. government agencies during pre-conflict operations, contingency operations and combat operations.

Mr. Beebe attended Clarkson College, Potsdam, N.Y., from which he received a Bachelor of Science Degree in Civil Engineering in 1983 and was commissioned as an Ensign in the Navy Civil Engineer Corps later that year. He completed his postgraduate education at the University of Illinois in 1989, where he received a Master's Degree in Civil Engineering.

Mr. Beebe retired from the Navy in 2007 with the rank of Captain after 25 years of service. His service included tours in the Naval Construction Force with multiple deployments to the Middle East and East Asia, a combined 17 years of federal acquisition experience and three Washington, D.C. tours. Following his military service, Matthew joined PMA Consultants, LLC, a program, project and construction management firm, to establish their new Washington, D.C. office and lead their business development efforts in the federal sector.

Mr. Beebe is a registered Professional Engineer, a certified Project Management Professional, a member of the Defense Acquisition Professional Community, and a graduate of the Carnegie Mellon University Program for Executives. He is a recipient of the Exceptional Civilian Service Award and his military decorations include Seabee Combat Warfare Officer, Legion of Merit (two awards), Meritorious Service Medal (two awards), Navy and Marine Corps Commendation Medal (three awards), and Navy and Marine Corps Achievement Medal (two awards).

Supply Chain Resilience in an Era of Long-Term, Peacetime Competition: The Semiconductor Case and a New Framework for Supply Chain Assessment

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Nathan Picarsic—is a co-founder of Horizon Advisory, a geopolitical consultancy. His work focuses on the development of competitive strategies that help businesses, investors, and governmental actors navigate economic, technological, and political change. His research on topics ranging from geopolitical competition to human rights abuses has been profiled in The New York Times, the Wall Street Journal, and the Washington Post, among other leading international outlets. His expertise has been cited by outlets ranging from Barron's to Vice and he has testified before the US-China Economic Security and Review Commission on US-China relations and the strategic role of capital markets. He serves as a mentor and advisor to technology startups at Carnegie Mellon University's Project Olympus. He holds a Bachelor of Arts from Harvard College and has completed executive education programs through Harvard Business School and the Defense Acquisition University. [nate.picarsic@post.harvard.edu]

Abstract

The U.S. defense acquisition system is positioning for strategic competition with China. That effort must be informed by and responsive to the nuances of China's global supply chain positioning—a competitive dynamic unique relative to past eras of great power competition. Updating for this reality demands a thorough understanding of how Beijing leverages its military–civil fusion (MCF) strategy to weaponize its manufacturing prowess, relative industrial self-reliance, and the asymmetric supply chain dependencies that result. The immediate security risks of Beijing's approach—and the challenge it poses to the U.S. ability credibly to compete—have been evident since China cut off rare earths exports to Japan in the midst of a territorial dispute in 2010. Yet U.S. acquisition processes have not updated. The Pentagon, military services, and defense acquisition program officials must rethink frameworks for assessing supply chain integrities, the risks that dependencies all along acquisition program value chains can create, and responsive acquisition processes. Until it does so, the U.S. approach to defense acquisition will feed into Beijing's continued, subversive global positioning.

The U.S. defense industrial base is grappling with two parallel and mutually reinforcing trends: a growing role in military supply lines for dual-use commercial technologies, and a growing reliance on complex, global supply chains. Both create *efficiencies* in terms of cost, access to, and pace of adopting innovation. But both also create major vulnerabilities that threaten the *effectiveness* of the U.S. security apparatus; the resilience of individual weapons programs in the face of supply shocks; and, in turn, the credibility of U.S. deterrence and power projection capacity *vis-à-vis* strategic competitors.

Specifically, the past generation of increasingly globalized supply lines shaping defense-relevant technology exposes the U.S. defense industrial base dependence on, and access from, an insecure, international ecosystem—and, with it, the risk of adversarial influence. Pandemic-induced supply chain challenges have brought these risks to the fore over the past several years. But even that recent and available manifestation of the challenge glosses over the reality: Chinese dominance of upstream materials, component assembly and testing, and manufacturing and production grant the Chinese Communist Party—the American military's pacing threat—leverage over critical defense-relevant supply chains.

These risks are particularly acute considering China's deliberate approach to competing in peacetime competition with the United States: Beijing's strategy of military–civil fusion (军民融合) (MCF). With MCF, Beijing leverages commercial positioning for military ends, and vice versa. This approach includes turning supply chains into battlefields for geopolitical competition. Beijing seeks to weaponize its manufacturing dominance, relative industrial self-reliance, purchasing power of its domestic market, and resultant asymmetric supply chain dependencies in order to secure coercive leverage over the international system. This has been evident for over a decade: In 2010, China cut off rare earth exports—critical for both commercial and security applications—to Japan in the midst of a territorial dispute.

U.S. acquisition processes must update for this reality and the security threats it poses. As acquisition reform and rewiring of a Cold War–era shaped bureaucracy take place, the Pentagon, military services, and defense acquisition program officials must rethink frameworks for assessing supply chain integrity, the risks that dependencies all along acquisition program value chains can create, and responsive acquisition processes. More broadly, the U.S. government and capital markets need to rethink investment in the domestic industrial base to ensure that these new frameworks can be operationalized and capitalized; that the necessary industrial capacity exists so that developments in U.S. military–relevant capabilities can create a more lethal fighting force, not a more vulnerable one.

Using the semiconductor industry as a case study, this paper seeks to develop and present such an updated framework for supply chain assessments—tailored to today's era of peacetime, strategic competition with China. The framework differentiates itself along three core dimensions:

- First, it looks not only at provision of goods and technology, but also at provision of capital. For example, a Chinese pool of capital's investments in a semiconductor manufacturer should be considered a risk factor—alongside, say, reliance of that manufacturer on electronic-grade polysilicon sourced from China or dependence on China-based or -owned packaging steps in the semiconductor value chain.
- Second, the framework looks holistically all along the supply chain, from the upstream to the downstream: Beijing's approach to weaponizing supply chains treats them as integrated wholes, and in many cases prioritizes upstream footholds over the more surface-level, downstream ones. Accordingly, U.S. acquisition processes should include screening against these n-th tier supply chain risks within the definition of program requirements and assessment of alternatives.
- Third, in its analysis, this paper seeks also to present best practices for using open-source information to implement supply chain assessments, focusing on information that is available for, and often goes overlooked in, the Chinese industrial ecosystem. Examples of such open-source information include strategic partnership agreements, government subsidies, and the network of MCF industry projects that animate China's positioning in military-relevant semiconductor supply chains.

The first section of this paper reviews the semiconductor supply chain as an example of under-appreciated risks in military-relevant value chains, compounded by China's effort to secure influence in key international industries as well as a growing U.S. interest in commercial solutions to military problems. The second section explains the inadequacies in existing methods for vetting and programs for protecting against these risks. And the conclusion presents an outline for a new, updated framework to inform the defense acquisition apparatus's approach to supply chain integrity. This framework's application could vary in tactics at different stages of the acquisition cycle. But the microelectronics realm demonstrates the imperative that protection against adversarial supply chain influence be incorporated into strategic planning for the use of acquisition as a means of influence in long-term, peacetime competition with China.

The Semiconductor Supply Chain

Semiconductors—which are cited here as shorthand for the realm of microelectronics covering memory chips and microprocessors—are necessary inputs into the entire basket of modern electronic products, ranging from computers to smartphones to medical equipment. They are broadly recognized as critical for the defense industry: Semiconductors are a prerequisite for everything from unmanned aerial vehicles to fighter planes to electronic warfare components (Defense Microelectronics Activity. n.d.). And in some cases, sophisticated military systems rely on the same semiconductors that fuel civilian, consumer goods (Inboden & Klein, 2022).

Accordingly, semiconductors used for defense purposes also rely on the same—global, interconnected—value chain as do those used for civilian purposes. The semiconductor production process is comprised of three main steps: design, fabrication, and assembly. Every step requires its own set of technological equipment, and chemical and material inputs. No single country has every element of the semiconductor production stack within its borders. Rather, production of these critical goods depends on a multi-step value chain integrating the United States, Taiwan, South Korea, Japan, Europe, and China. This global value chain promises an efficient division of labor. But in creating efficiencies, it sacrifices effectiveness. And, this paper argues, beyond simply raising concerns about the supply chain's resilience, today's global semiconductor value chain layout also hardwires a dangerous reliance on China that permeates many downstream acquisition supply lines.

At a surface level, the United States is a leader in the international semiconductor industry, boasting major, downstream, high-tech brand names like Intel, Micron, and Qualcomm. Intel is the world's largest semiconductor company by revenue. U.S. companies maintain a near-monopoly over global Electronic Design Automation (EDA) software tools, on which leading-edge chip design depends (Kleinhans & Baisakova, 2020). The United States houses some of the world's major equipment vendors, including Applied Materials, KLA, and Lam Research (Kleinhans & Baisakova, 2020). In 2019, the United States claimed a more than 50% global market share of integrated circuits, based on total sales. The U.S. leadership in core elements of semiconductor technology is sufficient that export restrictions on sales to China in recent years have imposed real costs on Chinese industry (He, 2021).

But this surface level and downstream leadership belies a set of major dependencies. First, U.S. semiconductor national champions depend on Chinese production, testing, and packaging as well as the Chinese market of downstream electronics product assembly. This grants Beijing the ability to disrupt their operations—as well as to influence their boardrooms. Second, the upstream of the international semiconductor value chain disproportionately relies on Chinese inputs. This means that the industry is built on a foundation controlled by Beijing.

Dependent Champions

China dominates international production of electronic components and the subsystems and commercial products built on top of them. As a result, most U.S., and international, semiconductor vendors have some degree of dependence on manufacturing facilities in China. They also sell their products back into the Chinese market. The result is a pincer of dependence whereby a centralized Chinese economic system enjoys leverage over the global market by virtue of both supply and demand.

Intel offers a ripe example. Intel directly supplies the Department of Defense (Cherney, 2021). It also cooperates with key defense contractors, like Lockheed Martin, on military technologies (Lockheed Martin, 2022). Intel's website lists 17 campuses in China, the company has at least two production sites in China, and it operates a series of innovation and R&D centers across the country (Intel, n.d.; Intel China, n.d.). Intel also relies on a host of Chinese suppliers. And on the sales side, in 2020, China accounted for 20.26 billion USD of Intel's 77.9 billion in revenue, or 26% (Pan, 2022). These ties in terms both of production and sales grant Beijing influence over Intel's operations, and therefore over the U.S. industry, including defense industry, built on top of them. Disruption in China, intentional or not, can stop Intel production: In September 2021, forced power shutdowns imposed by the CCP compelled key Intel suppliers in China to shut down their facilities (Shilov, 2021). And Intel's revenue stream requires that it remain in favor with the CCP. In January 2022, Intel removed reference to Xinjiang from its annual letter after facing backlash from China (Pan, 2022). Nor is this a vulnerability unique to Intel. Micron, the major U.S. DRAM company, had to halt production at its Xi'an, China, manufacturing facility in December 2021 as COVID-19 shut down the city (King, 2021).

Other international semiconductor companies from allied and partner countries with whom the United States cooperates risk even greater exposure to Chinese industrial influence. Take, for example, TSMC, the world's most valuable semiconductor company by market capitalization, recently lauded for beginning construction of a new facility in Arizona (Reuters, 2021). China serves as a critical manufacturing hub and revenue generator for TSMC; the company has supply relationships with customers that participate in China's MCF strategy; and TSMC invests into and alongside semiconductor-relevant Chinese government-guidance funds.

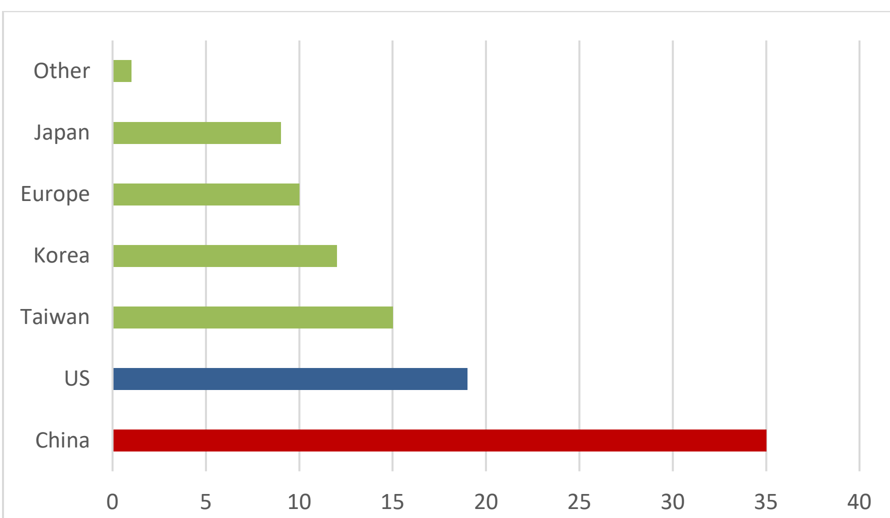

Figure 1. Global Semiconductor Sales by Location of Electronic Device Assembled (Semiconductor Industry Association, 2021)

A Chinese Communist Party Foundation

In addition, while the United States may boast high-profile leaders at the downstream of the semiconductor value chain, China increasingly dominates the upstream. These steps—including packaging and testing as well as production of electronic-grade silicon—are not the flashy or high-margin segments of the semiconductor value chain. They are considered "dumb"; labor and energy but not as capital or technology intensive. Yet their relative sophistication has little bearing on the influence that can be derived from dominating them. This is the foundation on which the international semiconductor industry is built. And this is where China has succeeded in making well-defended inroads.

After silicon wafers are manufactured in a fab, they proceed to the "back-end" packaging and testing step. This process is highly labor intensive. It does not require cutting-edge technology. And China has been investing significantly in this step of the value chain. Between 2009 and 2019, China's share of the global assembly and testing market grew from less than 5% to higher than 19%. In 2020, that figure stood at 38% (Kleinhans & Baisakova, 2020). Beijing's influence in semiconductor assembly and testing extends beyond explicitly Chinese companies as well. China has also invested in other, major, international assembly and testing (OSAT) players, securing concealed beachheads. For example, the largest shareholder of Powertech Technology Inc., a Taiwanese OSAT operation that in 2019 ranked fifth in the world by revenue, is the State-owned China Life Insurance Co., Ltd.

Even farther upstream, the material most frequently used in semiconductors is silicon. In 2021, China accounted for some 70% of global silicon production. This is a function of deliberate government industrial policy, not natural endowment. Silicon is the second most abundant element in the Earth's crust, surpassed only by oxygen. But extracting and processing it is energy-intensive. Recognizing silicon's strategic value in industries ranging from semiconductors to solar power technology, the CCP has, over the past two decades, provided significant State support (e.g., subsidies) to domestic silicon producers, allowing them to undercut their international competitors and dominate the market. Silicon might be among the least sophisticated inputs into the semiconductor value chain. But it is also the input on which all others depend: Advanced EDA software tools have little value without a product to design.

Military–Civil Fusion and an Underappreciated Defense Acquisition Risk Environment

Chinese leverage over the international semiconductor value chain creates very real risks for the defense industrial base. China sees today's international competition as one for control of supply chains. And over the past decades, Beijing has deliberately invested to capture key nodes in strategic international supply chains, including that for semiconductors, in order to secure coercive leverage in strategic competitions. At the same time, Beijing has sought to build relatively autonomous domestic industrial capabilities in order to ensure that its coercive leverage be asymmetric; that it be able to threaten adversary's industrial bases without facing equivalent consequences. Beijing's industrial policy explicitly states this ambition: "The competition in the global industrial and supply chain is becoming increasingly fierce," declared the director of the National Development and Reform Commission's Price and Cost Investigation Center in 2021. "We must improve the resilience of China's industrial and supply chain through coordination of 'supplementing the chain' and 'strengthening the chain'; filling in gaps but also consolidating 'industries with competitive advantages'" (Economic Daily, 2021) Beijing's actions also bear it out. In 2010, China cut off rare earth exports to Japan in the midst of a territorial dispute—proving that it was prepared to weaponize supply chains in geopolitical contests (Bradsher, 2010).

U.S. acquisition processes have not updated for this reality. Existing protocols for assessing supply chain integrity fail appropriately to address upstream vulnerabilities or dependencies that influence firm decision-making through means other than majority ownership—precisely the areas where China's manufacturing prowess and enormous market risk granting it the greatest influence. Even the most thorough application of existing tools for foreign ownership, control, or influence (FOCI) review of industrial base players would miss, entirely, the scope of dependencies that contemporary Chinese economic statecraft pursues and leverages. And mitigation against risks of that nature is not formally incorporated into the development of requirements at a program level. As the U.S. defense acquisition apparatus is increasingly turning to off-the-shelf commercial products and dual-use technologies and seeking more rapid acquisition approaches, these risks are certain to increase both in their number and in their impact to the complex industrial base ecosystem. Efficiencies in terms of cost and access to technology may come at the cost of relatively unscreened value chains, amplifying the defense industrial base's exposure to China's MCF strategy, and therefore injecting vulnerabilities into the fighting force.

Take the Department of Defense's Trusted Foundry Program: Formulated in the early 2000s, the program screens companies across the electronics supply chain (e.g., IC design houses, specialty foundries, packaging houses) to build a roster of trusted suppliers. But this screening doesn't go far enough: There is no evidence to suggest that the program accounts for trusted suppliers' silicon sourcing, for example. Moreover, the greater threat is that this "trusted" program is limited in its scope. Even its best intentions do not protect against supply chain risks in off-the-shelf technologies that are not produced specifically for the defense community under the purview of the Trusted Foundry Program.

The microelectronics example presents a daunting task. But it is one of universal importance across the defense acquisition system. It is also a familiar one to a range of national security stakeholders from policy-makers and legislators to warfighters. Instituting a systemic concern for supply-chain risks, like those reflected in the global semiconductor ecosystem, into acquisition considerations would go a long way toward orienting the broader defense acquisition environment for the effectiveness mission of strategic competition with China. And that, in turn, would go a long way toward making the acquisition system a viable means for signaling, deterrence, and strategic shaping of the adversary.

Two points of intervention may exist based on existing acquisition processes: The System Threat Assessment phases of the JCIDS process and within security monitoring requirements of program management. At present, the intelligence inputs that guide the System Threat Assessment could be extended beyond threatening offensive and defense foreign adversary operational capabilities to include the strategic-to-tactical manifestations of related supply chain risks. Capstone Threat Assessments and related foreign country- and system-specific inputs developed by the Defense Intelligence Agency for acquisition customers could also address the relative adversarial influence over material inputs and supply lines that a given program's requirements and operational objectives demand. And as reference to FOCI reviews above suggests, acquisition oversight and program management bring additional opportunity to monitor and mitigate adversarial supply chain leverage throughout a program's life cycle.

But FOCI reviews and related industrial base security monitoring and training conducted by the Defense Counterintelligence and Security Agency should be broadened in scope to address a wider means of influence and legacy vectors of industrial espionage:

How can supply chain vulnerabilities and supply chains shape decision-making at a firm level? How can companies be incentivized and educated to incorporate those risks—and the latent costs they may carry—into their profit formulae?

Certainly, there are positives to be taken and expanded from past supply chain security initiatives like the Trusted Foundry example and the progress over time in understanding and protecting against insider threats within the industrial base. But today's strategic competition—and today's pacing technological threat—demand a renewed emphasis on supply chains and their impact through the acquisition process. More is needed across the board. Supply chain security is a game of effectiveness and not efficiency.

Conclusion: A Risk-Informed Defense Acquisition Process

A new framework for risk-informed defense acquisition processes should adopt a new methodology for identifying and assessing threats in the acquisition system that owe to supply chain and upstream vulnerabilities. As dual-use, commercial technologies expand throughout the U.S. defense industrial base, existing acquisition processes and inputs need to be updated and to take into account the new risks that may accompany new supply lines. Considerable effort has been dedicated to recognizing and acting on the "promote" line of effort in a defense technology competition with a strategic competitor like China. Those "promote" efforts and investments need to be paired with proactive investment in "protect" lines of effort to guarantee that the acquisition system's ability to deliver a technological edge is not built on someone else's foundation (Doshi et al., 2021).

Defense

China's MCF strategy, and the complex nature of today's global supply chains, are such that risk assessments must account for:

- Entire value chains, not just first and second tier suppliers: An updated risk assessment model requires prioritizing supply chain integrity at the upstream, "dumb" stages of production as well as at the downstream, more sophisticated points.
- Companies' sales as well as their suppliers: Adversarial influence can be secured through control over revenue as well as control over its suppliers. If the dry cleaner has all your clothes, the dry cleaner owns you.
- Sources of capital—in addition to location, sources of supply, and outright ownership: China can, and does, secure access to and influence over companies by investing in them, including through State actors masquerading as private players.

Offense

These defensive screening measures need to be paired with proactive ones to ensure that they *can* be operationalized; that the United States has alternatives to dependence on China; and that those alternatives provide resultant capabilities with credible signaling, deterrence, and adversarial shaping value. The U.S. government needs to invest in, and encourage the private sector to invest in, trusted domestic production—all along the value chain. The CHIPS Act suggests a positive intention on this front. However, it is insufficient. It fails to address upstream dependencies. It also fails to address ties at the company level (e.g., sale dependence, capital exposure) to China. And it risks failing sufficiently to marshal private sector investment, and therefore the resources necessary to resolve vulnerabilities in the U.S. defense industrial base. At a strategic level, effective proactive moves will demand:

- Investment all across the value chain, not simply at demand-side, consumer-facing stages: There is little value in building a semiconductor foundry in the United States if that foundry will remain reliant on inputs from China.
- Cooperation with the private sector to ensure that Washington's investments are a guide for Wall Street's: In today's technological and commercial environment, the government alone cannot resolve industrial weaknesses. The private sector is a necessary partner. Washington should focus on incentivizing the private sector to invest in the long-term, strategic interest of the United States.
- Regulations on the private sector to ensure actions in the national interest: China's market and distortive industrial policies incentivize companies to defect; to share technologies, move production, and accept CCP influence. The U.S. government needs to impose an updated set of regulations on the private sector to disincentive actions that undermine the long-term, strategic interest of the United States.

More tactically as it concerns the defense acquisition system, it would be both prudent and tractable to update the threat intelligence inputs incorporated into program planning and management to account for the reality of today's complex supply chain threat environment.

References

Bradsher, K. (2010, September 22). Amid tension, China blocks vital exports to Japan. *The New York Times*. https://www.nytimes.com/2010/09/23/business/global/23rare.html

Cherney, M. (2021, August 23). Intel wins Defense department contract for advanced chips. *Barron's*. https://www.barrons.com/articles/intel-stock-chips-defense-51629757043

Defense Microelectronics Activity. (n.d.). *DMEA Trusted IC Program*. https://www.dmea.osd.mil/TrustedIC.aspx

Doshi, R., de La Bruyere, E., Picarsic, N., & Ferguson, J. (2021, April). *China as a cyber great power: Beijing's two voices in telecommunications*. The Brookings Institution. https://www.brookings.edu/wp-content/uploads/2021/04/FP_20210405_china_cyber_power.pdf

Economic Daily. (2021, October 18). 提升产业链供应链韧性要强化科技创新 [To improve the resilience of the industrial chain and supply chain, it is necessary to strengthen scientific and technological innovation].

He, T. (2021, July 27). When the chips are down: Biden's semiconductor war. *The Interpreter*. https://www.lowyinstitute.org/the-interpreter/when-chips-are-down-biden-s-semiconductor-war

Inboden, W., & Klein, A. (2022, March 20). Judge the CHIPs Act as defense policy, not industrial policy. *The Hill*. https://thehill.com/opinion/national-security/598783-judge-the-chips-act-as-defense-policy-not-industrial-policy/

Intel. (n.d.). *Worldwide campus locations*. https://www.intel.sg/content/www/xa/en/support/contact-intel.html?tab=campus-locations#support-world-locations

Intel China. (n.d.). 认识英特尔—**根植中国 服务中国** [Know Intel: Rooted in China to serve China].

King, I. (2021, December 29). *Micron says output at Chinese facility hit by city's shutdown*. Bloomberg. https://www.bloomberg.com/news/articles/2021-12-29/micron-says-china-facility-output-hit-by-xi-an-city-shutdown

Kleinhans, J.-P., & Baisakova, N. (2020, October). *The global semiconductor value chain*. Stiftung Neue Verantwortung. https://www.stiftung-nv.de/sites/default/files/the_global_semiconductor_value_chain.pdf

Lockheed Martin. (2022, April 4). *Lockheed Martin, Intel sign agreement to advance 5G-ready communications for U.S., allied defense systems*. https://news.lockheedmartin.com/2022-04-04-Lockheed-Martin,-Intel-Sign-Agreement-to-Advance-5G-Ready-Communications-for-U-S-,-Allied-Defense-Systems

Pan, C. (2022, January 11). Intel removes reference to Xinjiang in annual letter to suppliers after Chinese backlash. *South China Morning Post*.

Reuters. (2021, June 1). *TSMC says has begun construction at its Arizona chip factory site*. https://www.reuters.com/technology/tsmc-says-construction-has-started-arizona-chip-factory-2021-06-01/

Semiconductor Industry Association. (2021, July 13). *Taking stock of China's semiconductor industry*. https://www.semiconductors.org/taking-stock-of-chinas-semiconductor-industry/

Shilov, A. (2021, September 27). *Apple, Intel, and Nvidia suppliers halt production in China due to mandated power shutdown*. Tom's Hardware. https://www.tomshardware.com/news/power-outages-in-china-could-affect-apple-intel-nvidia

Sohu News. (2019, September 24). 英特尔中国区总裁杨旭：我们要和中国一道共赢未来 [Yang Xu, president of Intel China: We want to win the future together with China]. https://web.archive.org/web/20220124200936/https://www.sohu.com/a/343026382_123753

Organizational Change Considerations for Implementation of Performance-Based Logistics Contracts

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Abstract

Performance-Based Logistics (PBL) administrators have long struggled with developing contracts that result in a win-win relationship for both the contractor and the customer in terms of costs under dynamic conditions, contract length, and sustained performance. These inefficiencies lead to a perpetual cycle of reexamining outdated data, due to current data unavailability, or lack of publications. Thus, outdated practices or cost barriers can often plague outcome-based contracts (OBC). This research entailed seeking out other industries that utilize OBC in asset maintenance. In particular, several state Department of Transportation agencies adopted and successfully implemented Performance-Based Maintenance Contracts (PBMC). In both the qualitative and quantitative spheres, three areas of concern were identified: internal resistance towards performance-based procurement, ineffective relationships between the contractor and customer, and misalignment between contractor performance and scope complexity. After examining 75 contract performance scorecards and conducting interviews with Department of Defense personnel, this research determined that the organizational change required to tackle these specific challenges suggest a paradigm shift in how PBL contracts are implemented and administered.

Introduction

PBL is a type of product delivery method that focuses on obtaining prescribed outcomes as opposed to the traditional/transactional method. Customers are not exactly purchasing an asset, whether this is an electronic component, engine system, or an aircraft fleet. Instead, PBL customers have a business need to fill and there exists a product that will aid in fulfilling the customers' needs. Consider a simplified example of purchasing an aircraft for the U.S. military. The military is primarily interested in the aircraft's operational performance when and where they need it (i.e., reliability). The military's interest is in providing the warfighter with the resources to accomplish the mission. Utilizing a PBL contract would ease the military's burden on maintenance and repair (M&R) of that aircraft because that responsibility would transfer to the contractor who provides that service. The contractor's purpose, in this case, is to understand the client's needs and provide a product that will deliver those outcomes.

While the two parties involved on the contract (i.e., service and buyer) have a mutual interest in a successful outcome, their own motivating factors can differ (a reasonable profit vs. acceptable performance). From the contractor's perspective, the ideal PBL is a firm fixed price (FFP) with the longest contract length (> 5 years). The reason being is that a key attribute of PBLs is innovation; thus, contractors who innovate, stand to make a higher return on investment (ROI) due to increased product reliability from a guarantee of a contract. Conversely, from the client's perspective, the ideal PBL is cost-plus-incentive fee (CPIF) with short contract lengths (< 5 years). The clients are counting on the unlikelihood that a product needs replacing or repairing; however, they are willing to provide monetary incentives (and disincentives) that may persuade contractors to make critical, persistent maintenance decisions.

If PBLs are an attempt to offer a support strategy that delivers positive outcomes, it is necessary to explore why there is resistance to full implementation of the method. The Department of Defense (DoD) performs business case analysis (BCA) on two procurement options: transactional and outcome-based. The analysis aims to determine which strategy will offer the greatest value at the lowest cost. There exist several reasons why many program managers are hesitant to go with the unfamiliar PBL option. The PBL BCA lacks a consistent method that sparks innovation, concrete cost avoidance atmospherics, and risk tradeoff studies (Randall et al., 2012). Simply put, there are not enough examples of PBL implementation that result in a sound BCA.

Adopting a performance-based strategy is not only limited to military assets, but occurs in a variety of other industries (e.g., healthcare, energy, transportation, etc.). This research effort is intended to defense professionals understanding and effort in this area. The research teams evaluated other industries to gather a well-rounded understanding of the PBL framework of both success and failure.

One of the most prominent studies is the Deloitte *Proof Point* research that unveiled challenges to the PBL structure. Table 1 lists the critical pain points that exists in PBL strategies. Additional comments in this study suggested a lack of commitment from top management and personnel reverting back to transactional practices due to PBL unfamiliarity (Deloitte, 2011).

Table 4. Proof Point—Challenges to Overcome (Deloitte, 2011)

Challenge Area	Description
Service equities	PBLs present the Services with a transformational change challenge that is both complex and most often involves the transfer of workload (accompanied by a sense of loss of control) to the commercial sector.
Full costing organic DoD sustainment	The full price of commercially provided PBL sustainment is clearly known by the Services—it is the amount paid to the provider. In contrast, fully costing organic DoD sustainment is difficult if not impossible given existing funds flows and accounting capabilities.
Absence of robust BCAs, agreed upon facts and transparency of data	Bottom line: in many situations, decision makers do not have the quantity and quality of information and data essential to execute their roles with confidence.
Speed-to-savings	Unlike transactional sustainment where savings can be harvested through the simple act of a budget cut, PBL savings are a lead time away from the initial planning process.

Gansler & Lucyshyn (2006) discovered six key areas that add to the complexity of successful PBL implementation: the cultural barrier, human capital, depot requirements, the type of money for funding, technical data rights, and loss of competitive pressure. These strategic roadblocks have continued since their original discovery; however, identifying lessons learned may help identify underlying issues that seem to plague performance-based support.

Throughout performance-based contracting's history, there have been studies that have highlighted and collected lessons learned when implementing performance-based contracting (PBC). Randall et al. (2011) suggested that support from senior management, education with both internal and external stakeholders, and collaboration are paramount to ensure PBL effectiveness. The skeletal structure of PBL contracts should avoid ambiguity, require data sharing between parties, have client metrics clearly defined, and also hold the contractor accountability for explaining how they aim to achieve product innovation (Sols et al., 2007). Transitioning to the transportation industry's recommendation, stakeholders must acknowledge the baseline of performance before performance metrics are established, which will enable a more accurate incentive calculations when measuring actual performance in the future (Ozbek & de la Garza, 2011). Gelderman et al. (2019) interviewed industry experts in performance-based maintenance contracts (PBMC) and a unanimous series of recommendations were contract longevity, employee morale, and monitoring performance standards, along with their associated costs.

PBL has been the DoD's preferred weapons system support (WSS) strategy for nearly 20 years, and yet, this product support method has not evolved significantly since its inception. Reports on key areas in need of improvement have been a guiding rubric for PBL programs. Access to detailed PBL contract performance data was not available to the researcher. The research team pivoted and derived the root causes to PBL shortcomings and examined how other industries (e.g., Department of Transportation) addressed various issues in an effort to identify potential best practices for the Department of Defense. The team discovered that the internal resistance towards performance-based procurement, ineffective relationships between the contractor and customer, and misalignment between contractor performance and scope complexity are all the key contributors that disallow PBL to evolve into a consistent optimal outcome.

Background

The premise of PBL is to encourage collaboration through innovation that results in a "win-win" relationship between the customer and contractor. This paper focuses primarily on the customer's perspective. One of the challenges with broader adoption with PBL is limited training and educational opportunities. When insufficient training is provided, employees who are unsure how to enact the change within their job functions will typically revert back to their traditional practices (Lines & Smithwick, 2018). In this case, program managers should anticipate longer than expected timelines when measuring PBL effectiveness.

Randall et al. (2012) recognized that PBL practitioners have both system knowledge and source knowledge, but have limited supply chain knowledge (i.e., partners, relationships, customers, and interactions). Adopting new practices related to PBL, especially after spending years of executing contracts in a certain method, can be a hinderance. One fundamental solution to PBL adoption resistance is to receive senior management's support. This commitment enables teams to utilize resources (e.g., training) needed to facilitate relationship-based initiatives (Aldossari et al., 2021).

The research team also found that reliability is the best metric. When juxtaposed with transactional contracts, PBC have shown to be 20%–40% more efficient in terms of addressing the mean time between unplanned removals (MTBUR; Guajardo et al., 2011). Sols et al. (2007) identified four categorizations of aircraft assets with respect to reliability in PBL assessments: operational, planned maintenance, aircraft on ground, and under maintenance. Performance-based strategies are not just confined to military assets. Industries, such as transportation, healthcare, and energy, also implement what is referred to as performance-based maintenance contracts (PBMC), or some close variant. Hyman

(2009) reported that 80% of the respondents believe that PBMC fosters creativity and innovation on the part of the contractor(s) because they are generally free to achieve the performance targets or standards in any manner they choose (Gelderman et al., 2019). States that are active practitioners of PBMC, such as Florida, can experience a 2%– 2.5% increase over traditional contracting, which leads to a substantial increase in the condition of the assets. In fact, Florida stated that they were not losing money with the PBMC (Gelderman et al., 2019).

Case Study

The research team was able to secure an interview with one branch's logistics division, whose mission is to deliver life cycle logistics support to ensure sustainable materiel readiness for various aviation equipment and missile systems worldwide. The topics covered during the interview with logistic division's subject matter provided excellent insights, as highlighted below.

PBL Advantages (customer perspective)

- Smaller inventory pipeline
- Efficiency
- Less flexible

Incentives

- FAR adherence
- Metrics can lead to undesired behaviors
- Not all incentives or disincentives are monetary
- Time can be an incentive
- Firm Fixed Price is ideal
- The customer measures risk with in-house data

PBL Contract

- Subcomponents on PBL may have different payment structure
- Key stakeholders (e.g., engineers) aid in defining scope of work

PBL Advantages (supplier perspective)

- Consistency of funding
- Vendors want to be known as the best
- Vendors are eager to participate in PBL
- Vendors get visibility

PBL Disadvantages

- Division's expectations are transactionally oriented
- Forecasting attempts to account for demand 2–3 years out
- Institutional resistance
- Sole source stifles competition

After concluding the meeting, the team found that the listed topics offered a plethora of starting points to unravel PBL challenges. Having access to data that would support some of these concerns would establish a sound foothold in the PBL research initiative. However, due to confidentiality protocols, the research team was not provided with pertinent data that would permit detailed analysis.

In May 2021, a follow-up interview was conducted with an experienced PBL practitioner who dealt mainly with a specific type of military aircraft. This project manager had 13 years of experience in military procurement and was familiar with recurring PBL studies. The following are the key comments discussed during the interview:

- Owner's internal poses challenges to successful PBL implementation
- Internal environment poses challenges to PBL scalability (i.e., when demand for flight hours decreases, PBL contracts do not allow the metrics to decrease). The PM's counter argument to this was that when assets are not flying, it still requires services and maintenance.
- System's Analysis Program (SAP) is primarily used for forecasting and replenishing parts.
- Services prefer internal depots when they own intellectual property.
- Business case analysis (BCA) is performed every 4–5 years for PBL contracts.

The research team conducted follow-up a different military agency to better with a long history of PBL implantation. The goal of this second phase of research was to gain a better understanding of PBLs through recorded metrics since its inception. The agency's corporate communications provided the responses from subject-matter experts who have knowledge to the corresponding questions:

1. On a system level, how does the agency identify key impact areas that drive performance while reducing life-cycle costs?

[Response] PBLs inherently drive performance while reducing life cycle costs. The main focus of our PBLs is performance and our main metric is availability. The contractor is paid for performance so if they meet their metrics and deliver the performance that's required under contract, they get paid fully. If they fail to achieve metrics, then there are contractual downward price adjustments. Our financial mandate that's required for all PBLs is break even or better. Using a BCA, we measure/forecast what our costs would be under traditional support. We are not authorized to spend more than what it would cost us to support the system using a traditional support strategy. Using our experienced contract negotiators, we often award at less than traditional support costs which contributes to reducing life cycle costs. In addition, we often benefit from improvements (process and reliability, etc.) that we often get under PBL which also contribute to reductions in life cycle costs.

2. What is the general workflow in determining performance metrics on a system in PBL?

[Response] Our primary metric is availability, and we measure this using an SRT (supply response time) metric. The SRT metric is calculated by our research department based on our retail sparing levels.

3. How has the agency responded to contractors who desire a long-term fixed price contract in order to meet desired performance-based outcomes? Any insights on how the contract length is negotiated between the government and the supplier?

[Response] PBLs are predicated on long term FFP contracts, so it is the government who sells the benefit to industry. If the contractor is already on board, then there's nothing to sell. With few exceptions, our PBLs are a minimum of 5 years and we have the ability to go as long as 10 years. The maximum we can do for a base term is 5 years. We typically will go with the longest base term possible and option years are also typically grouped as long as possible so for example, if we were doing a 10-year contract we would offer a 5 year base with a 5 year option. All options must be priced.

4. During the end of a PBL contract, what analysis does the agency execute in determining whether the current costs are on track to reduce life cycle costs, thus total cost of ownership?

[Response] All of our contracts require full cost reporting so we can determine profit margins and re-baseline costs for follow-on contracts to make sure that profits earned by the PBL provider are not in perpetuity. New BCAs are run for all follow-on contracts as well.

5. What post-PBL implementation results have you seen or experienced? Any positive outcomes or great lessons learned you'd like to share?

[Response] The following sample results illustrate positive outcomes of PBL contracts:

- Increase material availability
    - Display panels: 47%–99%
    - Satellite communications terminals: 78%–93%
- Decreased response times
    - Tires: 4 days world-wide
- Decreased repair turn-around-times
    - 25% reduction and 75% decrease in work-in-process
- Near elimination of awaiting parts problems
- Major reduction in backorders
    - Stores management system: 489 to 0
- Reduced logistics footprint
- Retail allowance reductions: tires decreased by two-thirds; $7 milion savings

The research team also contacted non-military users of PBL (or similar) contracts to develop an initial assessment of best practices and lessons learned. There are several other industries that use performance-based contracting practices in order to achieve outcomes over implementing the transactional approach. Of some of these industries, departments of transportation are prominent entities who exercise performance-based maintenance contracts (PBMC). What distinguishes PMBC from PBL is primarily the asset of concern (highway maintenance versus military fighter plane).

The team interviewed a PBMC representative from a state's DOT sector who administers performance-based contracts across several districts. Relevant background details of the state include:

- Performance-based contracting is associated with Asset Management (AM) contracts.
- This DOT organization implements AM contracts in three types of assets: roadways, bridges, and facilities.
- There are several in-house challenges in adopting performance-based contracting—as opposed to the traditional method of dictating courses of actions.
- One issue with PBCs is that it won't be perfect, yet stakeholders are paying for perfection.
- There seems to be difficulties in determining the "color of money" that results in poor expenditure oversight.

- The contractor knows the true costs of performing a service [the military interviewee also mentioned this].
- This DOT organization has a good working relationship with contractors.
- In-house is short staffed—which may lead to loss of institutional knowledge.
- This DOT organization attempts to put themselves in the contractors' shoes. They limit repetitive deductions.
- This DOT organization PBC staff has a high turnover rate, no handover of PBC practices, and what training that does exist, happens on Microsoft Teams or in-person groups.
- Sharing risks is an ongoing challenge. Right now, the contractor's risks are capped until a certain amount, then the State takes over.
- The Performance Evaluation Report (PER) is a means to periodically assess an asset maintenance (AM) contractor's performance in predetermined contract areas.
- This DOT organization personnel's recommendations: establish trust, change RFP for different programs, and communication.

The state provided detailed performance grades that covered contractor performance metrics, random sampling results, and the level of involvement between the department's personnel and the contractor.

The representative provided the team with 13 comprehensive grade reports that expanded each weighted section that resulted in the final period's performance score. Moreover, the section that covered the department's level of involvement between the department's personnel and the contractor and how that dictated the contractor's section score was insight as to the contractor's ability to perform well on a contract. This section included comments as to why a contractor was given a particular score for that period.

The DOT's performance-based contracts grade report was revised and updated in 2018. The report listed out the performance grade for 75 different contracts, each covering one or more items within their scopes: roads, bridges, rest areas, structures, weigh stations, and other. Within each contract, weighted subscores were divided into five sections (see Figure 1): Section I Performance Indicators, Section II Rest Area, Section III Structures, Section IV Roadway, and Section V Contractor Performance. The final score for each grading period comprised the weighted average from the section that corresponded with the scope of work for each contract (i.e., if the scope did not include rest areas, then no score for Section II was annotated).

Rating Date	Final Score	Section I	Section II Rest Area	Section III Structures	Section IV Roadway	Section V Contractor Performance
Jun-15	**95.4**	100		93	97.9	90
Feb-15	**95.9**	100		93	100	90
Sep-14	**96**	100		93	98.6	95
Mar-14	**96**	97		93	100	95
Sep-13	**97**	100		97.4	98.6	95
Mar-13	**98**	97		99.3	100	95
Sep-12	**90**	94		100	73.4	90
Mar-12	**96**	90		100	97.2	97.5
Sep-11	**88**	94		93	80	85
Mar-11	**88**	94		97.7	100	55
Sep-10	**90**	94		91.8	93.8	80
Mar-10	**92**	94		100	90	82.5
Sep-09	**93**	97		93	100	80
Mar-09	**93**	97		93	100	83
Sep-08	**93**	97		93	100	83

Figure 1. Sample Performance Evaluation Report

In Section V, Performance Intangibles are subjective due to an assigned department personnel who associates a contractor's performance with a numerical value. However, the DOT organization's management team would inquire about a poor performance if the rest of the PER consistently demonstrated otherwise.

Section V: Performance Intangibles

Contractor's 2017 Grading Period (Poor Performance)

Scope: Roads, Bridges, and Structures (Group 3)

A. <u>Interaction/Cooperation/Coordination with adjacent contracts, other government agencies, the public, and other customers.</u>

The Contractor has regressed in their interaction with the public. Several customers have been ignored due to their repeat status. On several occasions, I was asked by the adjacent Construction Project and Local Government Offices to get answers or commitments from [Contractor] because they were unresponsive. **Score 7/10**

B. <u>Cooperation with department personnel.</u>

At times, the Contractor has not returned emails or phone calls on pressing matters. Cooperation with the District Permits office has been poor. **Score 6/10**

C. <u>Quality control and compliance with contract.</u>

The Contractor has regressed with their Quality Control. The Guardrail Inspection report was submitted with 7 missing sections. As well as errors with the Crash Cushion Inspection reports. **Score 6/10**

D. <u>Department efforts required for contract administration and inspection.</u>

The Department was required to spend some effort and resources on the contract. **Score 7.5/10**

Section V: Performance Intangibles

Contractor's 2018 Grading Period (Good Performance)

Scope: Bridges and Structures (Group 2)

A. Interaction/Cooperation/Coordination with adjacent contracts, other government agencies, the public, and other customers.

[Contractor] addressed issues in a timely manner and work orders were thoroughly completed. Contractor interaction with the public and other customers was excellent. **Score 10/10**

B. Cooperation with department personnel.

The Contractor is always willing to go above and beyond the basic scope language to provide the Department with a quality product. They take great pride in the services they provide and continue to keep close coordination. [Contractor's] cooperation with the Department personnel is excellent. **Score 10/10**

C. Quality control and compliance with contract.

[Contractor] followed the contract documents and provided innovative ways for accomplishing work. The contractor was willing to listen to Department concerns and address the issue. [Contractor] is quick to respond to emergencies and looking for innovative ways to perform work while keeping traffic moving. **Score 10/10**

D. Department efforts required for contract administration and inspection.

[Contractor] makes the Contract Administration possible by supplying the District Manager with materials they need in a timely fashion. Time spent administering this contract is minimal and makes it a success. **Score 10/10**

Results

ANOVA

An ANOVA was performed to measure whether there was any statistically significant difference between a contract's performance grade and scope complexity (see Figure 3). Since the report included contracts at various points within their timeline, only contracts that provided the first five years of performance grades were included in the ANOVA. This allowed all measured contracts to have 10 performance grades (each performance review occurred bi-annually). The contracts were then separated into corresponding scope complexity: 1, indicating that the contractor had only one main asset to maintain, and 2, indicating that the contractor had two assets to maintain; this expanded all the way to 4. For each scope group, the average for each grading period was accounted for as providing a sound gauge of how several disparate contracts performed under similar scope complexity. For Group 1, there were 10 contracts observed; for Group 2, there were 11 contracts observed; for Group 3, there were 11 contracts observed; and for Group 4, there were 3 contracts observed. All averages from each group, covering the first five years, were the representative data used for the ANOVA test.

Cohen's D

A Cohen's D effect size was calculated to determine the magnitude of how each group's performance differed (see Figure 2). Cohen's D is a statistical measure that evaluates the means between two groups and indicates the degree of difference based on a pooled standard deviation. This measurement took the average of all individual performance grades in each group. For each group, the standard deviation decreased with increasing scope complexity, minus the similarities between the variance between Group 2 and Group 3. The groups were compared one way—meaning that switching the order (e.g., Group 1 compared with Group 2 vs. Group 2 compared with Group 1) would not change the effect, only the mathematical signs would change. It is important to note that in Cohen's D calculation, the pooled standard deviation was used, not an average of the two groups. The comparison between Group 1 and Group 2 illustrated the largest pooled standard deviation and had an effect size of |0.63|. The pooled standard deviation and smallest effect size occurred between Group 3 and Group 4 of 6.44 and |0.11|, respectively. After conducting both ANOVA and Cohen's D tests on four groups of this population, the role of both performance achievement and consistency indicated a unique balance associated with scope complexity.

	Mean	SD	N	
Quant 1	86.236	10.296	100	
Quant 2	91.660	6.623	110	
Quant 3	90.076	6.740	110	
Quant 4	90.803	5.154	30	
M_1-M_2	-5.424		M_2-M_3	1.584
Pooled SD	8.570		Pooled SD	6.682
Cohen's d	-0.633		Cohen's d	0.237
M_1-M_3	-3.840		M_2-M_4	0.857
Pooled SD	8.618		Pooled SD	6.342
Cohen's d	-0.446		Cohen's d	0.135
M_1-M_4	-4.567		M_3-M_4	-0.727
Pooled SD	9.381		Pooled SD	6.439
Cohen's d	-0.487		Cohen's d	-0.113

Figure 2. Results of Cohen's D Analysis

	0.5 Y	1 Y	1.5 Y	2 Y	2.5 Y	3 Y	3.5 Y	4 Y	4.5 Y	5 Y	AVERAGE
QUANTITY 1	80.9	74	73.6	75.2	66.3	42.5	62.9	59.8	70	67	86.6
	66.8	85.6	75.6	86.8	90.4	96	84.3	86.6	87	91	82.3
	87.8	72.2	89.4	92.2	92.2	94.7	96.3	93.9	95	98	85.4
	90.2	83.9	95.2	96.4	96.3	94.8	96.4	98	96	96	85.7
	74.7	68.9	76.1	77	75.4	79.6	79.5	68	78	80	86.3
	93.5	92.8	92.2	91.9	88.4	88.4	92.2	90.7	92	91	85.7
	93	95	96	94	92	90	92	92	92	91	86.9
	92.9	87.7	79.2	66.9	80.9	82.5	80.7	86.9	89	85	86.3
	93.4	70.6	84.4	82.9	86.4	92.8	88.6	90.6	94	94	88.5
	92.7	92.7	92.3	94.1	95.1	95.5	95.9	96.8	91.6	93	88.6
QUANTITY 2	97.8	98.4	98.1	98.6	98.4	98.9	97.8	98	99	96	90.2
	85.4	90.7	72.4	91.4	88.4	89.5	89.2	89.7	71	78	90.5
	97.2	94.7	93.9	92.2	96.1	91.9	98.4	98	96	96	90.6
	96.7	98.3	98	97.5	96.9	98	95.6	97	95	96	
	84.8	81.2	93.1	87.7	82.3	88	94.6	91	89	90	91.7
	91	93	87	80	95	93	96	68	92	92	92.5
	94	92	94	90	91	89	92	91	91	91	93.4
	94.9	94.4	96.5	96.5	97.6	97.6	96.8	93	93	95	92.6
	85	91	90	88	92	92	74	92	93	93	91.2
	95.2	90.6	96.1	96.2	93	96	92	92	95	93	91.7
	70.2	71	77.9	90.8	86.6	93.9	92.1	93.9	95	93	92.1
QUANTITY 3	95.4	95.9	96	96	97	98	90	96	88	88	90.9
	93.2	95	96.7	93	91	93	95	93	94	97	90.3
	87.7	75	77.4	83	82	80	79	80	71	75	91.8
	96	94.4	95.9	97.3	97.5	96.8	98.2	94.5	94	97	91.5
	97.7	93.3	96.3	90.6	93.5	91.4	88.6	90.6	86	85	89.9
	94.2	86.9	93.5	94.9	91.8	94.5	97.3	96.7	96	95	90.4
	84.3	81	84	88.6	94.9	88.3	87.3	89.8	90	90	89.9
	97.5	96.7	96.7	86.8	81.5	82.4	88.2	87.3	88	65	90.8
	92.4	95.8	95.4	90.2	80.5	85.4	82.6	90.5	94	82	88.5
	90.8	94.3	93.3	95.8	94.8	94.8	96.5	98	88	94	86.7
	70.5	85.5	84.2	89.9	84.9	90.1	86.4	82.8	84	86	
QUANTITY 4	96	87.9	82.8	90.3	84.6	81	89.8	81	88	90	91.9
	88.8	86.5	93.6	95	97.7	94.1	96.2	97.8	94	93	88.1
	91	90	94	93	95	86	97	97	92	81	90.1
											92.8
											92.4
											87.0
											94.3
											91.9
											91.3
											88.0

SUMMARY

Groups	Count	Sum	Average	Variance
Quantity 1	10	862.36	86.24	3.06
Quantity 2	10	916.60	91.66	1.07
Quantity 3	10	900.76	90.08	2.23
Quantity 4	10	908.03	90.80	5.72

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	172.00	3	57.33	18.99	1.49172E-07	2.87
Within Groups	108.70	36	3.02			
Total	280.70	39				

Figure 3. Results of ANOVA

Summary

Successful PBL contracts require a shared commitment from both the buyer and the services provider. The unique aspects of a PBL agreement (e.g., long-term nature of the contract, need for rapid repair/replacement of components, development and maintenance of unique assets) can pose a significant challenge to government agencies that are unfamiliar with its overall structure and related best practices. Adopting new contracting mechanisms requires the owner and service providers alike to adopt organizational change best practices. Leaders who are facilitating the adoption of these new practices should seek a strategic, measured approach that truly recognizes the substantial hurdles in place in making the change.

The research team evaluated performance of non-DoD PBL/PBL-like contract as to ascertain performance outcomes and lessons learned that might benefit DoD agencies who use PBL. One state transportation agency's asset management program developed a performance evaluation scorecard of all PBL contracts. The research team found statistically significant difference in terms of the service providers as well as the types of contracts performed. Interviews with the DOT identified that regular evaluation (and constructive feedback to the contractor) was beneficial in delivering a sustainable PBL program for the state.

Limitations

The inability to receive detailed PBL data, as it relates to specific military branches, significantly hindered efforts to use military-based examples that were up-to-date and served to derive any relationships between contractual attributes and PBL performance. The research team pivoted in pinpointing the root cause of PBL performance outcomes by examining state transportation agencies. Comparing DOT agencies PBMC contracts to PBL contracts does not encompass the same level of asset maintenance. Future research would benefit from evaluating DoD PBL contract performance data, which may provide better insights on intra-contractual performance. That is to say, instead of providing baseline data and then highlighting the end-of-life performance metrics, monitoring periodic feedback between the customer and the contractor throughout the life cycle would show the beginnings of a trend towards success or failure.

References

Aldossari, K. M., Lines, B. C., Smithwick, J. B., Hurtado, K. C., & Sullivan, K. T. (2021). Employee reactions to adoption of alternative project delivery methods within the AEC industry. *International Journal of Construction Education and Research*, 1–18. https://doi.org/10.1080/15578771.2021.1900463

Deloitte. (2011). *Proof point project a study to determine the impact of performance based logistics (PBL) on life cycle costs* [Review of *Proof Point Project A Study to Determine the Impact of Performance Based Logistics (PBL) on Life Cycle Costs*]. Office of the Deputy Assistant Secretary of Defense (Materiel Readiness).

Employment of Veterans in the Federal Executive Branch. (2020). https://www.fedshirevets.gov/veterans-council/veteran-employment-data/employment-of-veterans-in-the-federal-executive-branch-fy2018.pdf

Gansler, J. & Lucyshyn, W. (2006). Evaluation of performance based logistics. 54.

Gelderman, Semeijn, & Vries. (2019). Contracting for road maintenance in the Netherlands—the downside of performance-based contracting. *Infrastructures*, *4*(3), 41. https://doi.org/10.3390/infrastructures4030041

Guajardo, J. A., Cohen, M. A., Kim, S.-H., & Netessine, S. (2011). Impact of performance-based contracting on product reliability: An empirical analysis. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1807049

Hyman, W., 2009. *Performance-based contracting for maintenance,* NCHRP Synthesis Report. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_389.pdf

Lines, B. C., & Smithwick, J. B. (2018). Best practices for organizational change management within electrical contractors. *International Journal of Construction Education and Research*, *15*(2), 136–159. https://doi.org/10.1080/15578771.2018.1479723

Ozbek, M. E., & de la Garza, J. M. (2011). Comprehensive evaluation of Virginia Department of Transportation's experience with its first performance-based road-maintenance contract. *Journal of Transportation Engineering*, *137*(12), 845–854. https://doi.org/10.1061/(asce)te.1943-5436.0000294

Sols, A., Nowick, D., & Verma, D. (2007). Defining the fundamental framework of an effective performance-based logistics (PBL) contract. *Engineering Management Journal*, *19*(2), 40–50. https://doi.org/10.1080/10429247.2007.11431730

Wesley R. S., Brady, S. P., & Nowicki, D. R. (2012). Business case analysis and the confounds of innovation driven by performance-based postproduction support strategies. *Transportation Journal*, *51*(1), 33. https://doi.org/10.5325/transportationj.51.1.0033

Wesley, R. S., Nowicki, D. R., & Hawkins, T. G. (2011). Explaining the effectiveness of performance-based logistics: a quantitative examination. *The International Journal of Logistics Management*, *22*(3), 324–348. https://doi.org/10.1108/09574091111181354

Acquisition Security Framework: Integration of Supply Chain Risk Management Across the DevSecOps Lifecycle

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Abstract

Supply chain cyber risks stem from many organizational dependencies—in particular, processing, transmitting, and storing data; information technology; and communications technology. These risks are broad, significant, and growing as outsourcing options expand. Important mission capabilities can be undermined by an adversary's cyber-attack on third parties, even when the organization does not explicitly contract for technology. Virtually all products or services an organization acquires are supported by or integrate with information technology that includes third-party components/services. Practices critical to monitoring and managing these risks are scattered across the organization, resulting in inconsistencies, gaps, and slow response to disruptions. The Acquisition Security Framework (ASF) contains leading practices to support programs acquiring/building a secure, resilient software-reliant system to manage these risks. It defines the organizational roles that must effectively collaborate to avoid gaps and inconsistencies. It also establishes how an organization should ensure effective supply chain risk management that supports its mission and objectives. The framework contains proven, effective goals and leading practices, and it is consistent with supply chain risk management guidelines from the International Organization for Standardization (ISO), National Institute of Standards and Technology (NIST), and Department of Homeland Security (DHS).

Background

Concern for supply chain risk has been growing. The potential impact of cybersecurity attacks became evident with the Heartland payment system breach in 2008 (Gordover, 2015). Millions of dollars were lost because of a software error for a product from an organization that was fully compliant with all regulatory mandates. This incident, at the time, brought attention to the limitations of compliance alone in addressing cybersecurity issues. What really mattered was the existence of a weakness in the software.

The Target attack in December 2013 expanded the concern for supply chain risk. In this successful attack, the perpetrators connected to the operational environment using stolen credentials from a supplier to take advantage of the broad internal information-sharing capabilities available among third-party systems. These capabilities enabled the perpetrators to insert malware and siphon off credit card information from the point-of-sale system acquired from another supplier (Aorato Labs, 2014). New impacts from increasing the use of third-party software continue today. Most recently, a breach at SolarWinds leveraged a routine process for the automated distribution of software updates to send malicious code to 18,000 customers, potentially impacting government and industry through trusted network capabilities across the globe (Temple-Raston, 2021).

In a 2010 Software Engineering Institute (SEI) research project, we found that few organizations considered supply chain risk within the acquisition and development lifecycle beyond a narrowly defined vetting of the supplier's capabilities at the time of an acquisition. This failure to consider the responsibilities the acquirer had to assume based on the lifecycle use of the third-party product left the organization open to an extensive range of cyber risk that increased over time (Ellison et al., 2010). In later research, we investigated the lifecycle issues of supply chain risk and identified that the operational and mission impact of cyber risk increases as organizations become more dependent on suppliers and software.

The traditional focus on operational controls for security compliance does not address the (1) increasing supplier role in providing services, (2) design, and (3) introduction of code weaknesses into software-reliant systems. As reliance on third-party components and products increases, the supply chain becomes a growing source of cyber risk. In this research concerning lifecycle issues, we identified practices throughout the acquisition and development lifecycle that were critical to reducing the potential success of cyberattacks (Alberts & Woody, 2017). However, at the time, few programs were implementing effective cybersecurity practices and supplier oversight early in the acquisition lifecycle. Figure 1 shows the wide range of practices available for use, but these were not integrated into standard practice.

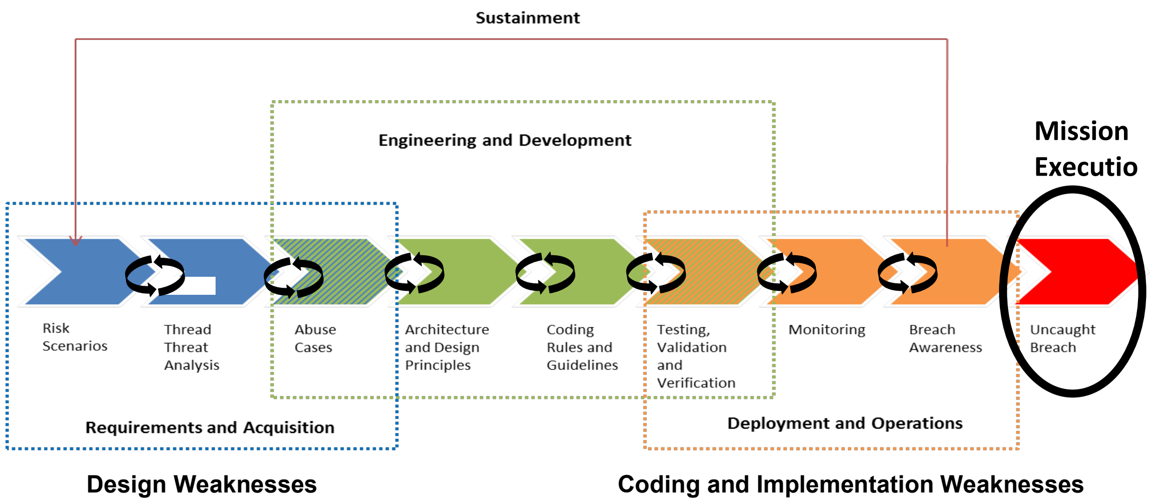

Figure 11. Cybersecurity Practices Available Across the Lifecycle to Address Security Weaknesses

Supplier-oriented risks were a key factor driving early CERT research into the development of more effective methods for managing cyber risks. We clearly recognized that the growing complexity of threats required that organizations use more systematic approaches to cyber risk management. Not only did organizations need better security methods, but their expanding outsourcing strategies led to major concerns that their suppliers also needed better security management tools. *Introducing the CERT Resiliency Engineering Framework: Improving the Security and Sustainability Processes* (Caralli et al., 2007), published in 2007, was the first release of these innovative concepts that helped reset security management approaches and formed the basis for work that continues to evolve today.

The *CERT Resilience Management Model (CERT-RMM)*, a process improvement model first published in 2011, assembles leading practices from industry and government for managing operational resilience, which requires integration across the key organizational areas of security management, business continuity management, and aspects of information technology (IT) and operations management (Caralli et al., 2011). In 2015, the CERT Division of the Software Engineering Institute developed the *External Dependencies Management (EDM) Assessment* to enable critical infrastructure organizations in the United States to manage external dependency and supply chain risks. This assessment is an extension of the *Cyber Resilience Review (CRR)* (Department of Homeland Security [DHS], 2014). Based on the CERT-RMM, the CRR establishes a baseline of cybersecurity capabilities that helps an organization understand (1) its operational resilience and (2) its ability to manage cyber risks to critical services during normal operations as well as during times of operational stress and crisis.

In 2016, researchers from both CERT acquisition and operational teams collaborated to create an integrated, systems-oriented perspective, called the *Acquisition Security Framework (ASF)*, that considers the full supply chain risk management lifecycle (Alberts et al., 2017). Managing supply chain cyber risk is especially challenging because it is broad and pervasive, and responsibility is spread widely across an organization. Acquisition and development must consider the operational context and plan for sufficient risk management, and operations must effectively integrate each added supplier into sustainment processes and practices.

The ASF organizes leading supply chain risk management practices to measure and improve an organization's ability to manage third-party cyber risks across a system's lifecycle. It provides a mechanism for increasing an organization's confidence about the level of its vendors' performance, improving its understanding of potential gaps, and making improvements based on a suggested roadmap.

Active development of the ASF was initiated in 2020 for use in applying integrated software security engineering practices into the systems lifecycle. This development effort includes defining a risk-based framework that enables a program to do the following:

- Manage program security risks collaboratively across the lifecycle and supply chain.
- Incorporate security practices that scale to selected acquisition pathways and development approaches.
- Implement an appropriate level of process management and improvement (i.e., maturity) for security practices.

Acquisition and engineering practices continue to evolve. Emerging threats and increased system complexity have given rise to new techniques that are designed to manage cyber risk from early requirements definition through operations. These new techniques have brought improved methods and outcomes, including the lifecycle orientation shared by DevSecOps and the ASF. Facilitating integrated cybersecurity in environments with complex supplier-dependent systems demands these new solutions.

Acquisition Security Framework

Supply chain issues impact every aspect of acquisition, development, and sustainment. The expanded use of third-party code, components, products, and services has further stretched the involvement of the supply chain into almost every aspect of the organization. Organizations' need to access a wide range of technical skills to create, integrate, and maintain the multi-faceted capabilities that have become operational necessities drives them further towards greater reliance on suppliers. Managing potential supply chain risk requires effective collaboration across the many participants interacting with each supplier over time.

The ASF is a collection of cybersecurity leading practices that each acquisition program should consider when building/acquiring a secure and resilient software-reliant system. These practices can be categorized into these practice areas:

- Program Management
- Engineering Lifecycle
- Supplier Dependency Management
- Certification
- Support
- Process Management and Improvement

The framework enables programs to evaluate and manage risks and gaps when acquiring, engineering, and operating secure and resilient software-reliant systems. The challenge is to manage the supply chain–related security risks collaboratively across the lifecycle and supply chain. This management requires processes that effectively connect those performing practices in the practice areas listed above to continuously integrate as all aspects of the acquisition, development, and operational needs change over time.

The growing challenges of supply chain risk coupled with the expanded use of automation in software development and implementation driven by moves to Agile at scale and DevSecOps require organizations to ensure the integration of effective and timely supply chain considerations through all acquisition, development, and operational practices.

ASF Structure

The framework contains layers of goals and supporting practices organized as shown in Figure 2. There are six primary practice areas: Program Management, Engineering Lifecycle, Supplier Dependency Management, Certification, Support, and Process Management and Improvement. Within each of these practice areas are two to three domains. Within each domain, there are six or more goals, each with a group of practices that support an organization in meeting each goal. The practices are phrased as questions that can be used in determining current and planned organizational capabilities.

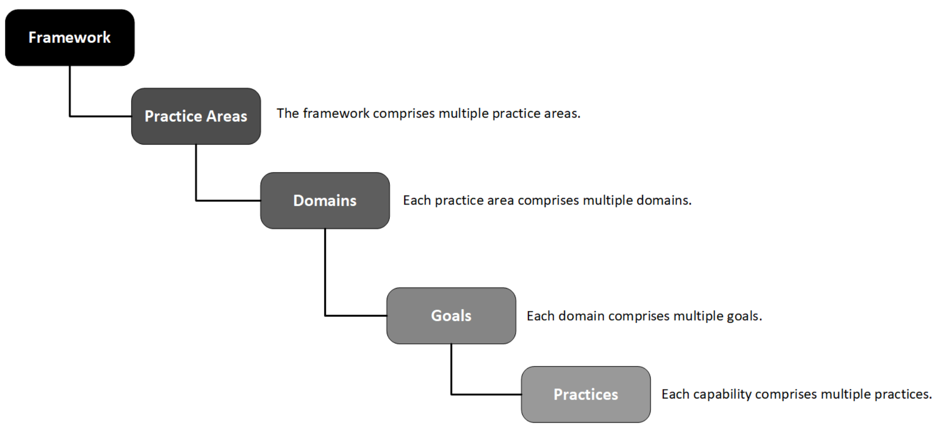

Figure 12. ASF Organizational Structure

Many of the practices are interrelated to support the communication that must occur among the practice areas on an ongoing basis. Limited collaboration and communication among systems teams on tasks that require supplier management creates potential risks. Program leaders may not be aware of risky choices made by acquisition and engineering teams or that the organization’s relationships with suppliers are not being managed effectively. For example, practices in Engineering Lifecycle domains connect to practices in the Program Management and Supplier Dependency Management domains to confirm that information sharing/reporting is occurring as needed for effective cybersecurity and supplier risk management.

Development of ASF Practice Areas and Domains

In current ASF development, we have completed practices for Engineering Lifecycle and Supplier Dependency Management, leveraging our previous work we described earlier in the Background section. In the remainder of this section, we share the information we assembled about the domains and goals in these two practice areas.

For the **Engineering Lifecycle** practice area, we identified the following domains:

- Domain 1: Engineering Infrastructure
- Domain 2: Engineering Management
- Domain 3: Engineering Activities

Domain 1 covers goals related to infrastructure development, operation, and sustainment. Domain 2 covers goals related to technical activity and product risk management. Domain 3 covers goals for engineering lifecycle activities, including requirements, architecture, third-party components, implementation, test and evaluation, transition artifacts, deployment, and secure product operation and sustainment.

For **Supplier Dependency Management**, we identified the following domains:[14]

- Domain 1: Relationship Formation
- Domain 2: Relationship Management
- Domain 3: Supplier Protection and Sustainment

Domain 1 covers goals related to planning, formal agreements, supplier evaluation, and supplier risk. Domain 2 covers goals related to supplier identification and prioritization, performance and management, continuous risk management, change and capacity management, supplier access to program and system assets, dependency management, and supplier transaction management. Domain 3 covers goals for supplier disruption, maintenance, and situational awareness.

Next Steps

We are actively developing the Program Management practice area and have identified the following three domains: (1) Program Definition, (2) Program Planning and Management, and (3) Requirements and Risk. Once our work on Program Management is complete, we plan to address the remaining three ASF practice areas: Certification, Support, and Process Management and Improvement.

To help bring value quickly, we have been building methods to deploy the ASF in organizations that support software-intensive systems environments. These deployment methods include exploring the use of the ASF as a baseline roadmap of practices for engineering and supplier management to improve current program considerations of cybersecurity and supply chain risk. We do this by comparing program and vendor deliverables, such as the statement of work, software assurance and cybersecurity checklists, and control plans to the ASF. By mapping these program items to ASF practices areas and goals, we can identify practice areas that are well addressed as well as gaps in practice areas that should be addressed.

Building the ASF is clearly a challenge, but the larger concern is making sure that the approach is usable by those who need it. The focus must shift from selecting guidelines that suppliers should follow to improved collaboration among the parts of the acquiring organization that interact with suppliers to establish clear and effective actions and measures for supply chain risk management. To that end, we have taken this multi-prong approach that concurrently focuses on ASF development and deployment strategies. While this approach requires more effort, we believe it will result in a more accessible and useful

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[14] Detail questions relevant to each goal in the Supply Dependency Management practice area are provided in an appendix at the end of this paper as an example of the depth of material currently available in the framework.

tool that will support the systems and cybersecurity risk management needs of acquiring organizations.

References

Alberts, C., & Woody, C. (2017). *Prototype software assurance framework (SAF): Introduction and overview.* Retrieved March 31, 2022, from the Software Engineering Institute: http://resources.sei.cmu.edu/library/asset-view.cfm?AssetID=496134

Alberts, C., Woody, C., Wallen, C., & Haller, J. (2017, May/June). Assessing DoD system acquisition supply chain risk management. *CrossTalk*. Retrieved March 31, 2022, from https://resources.sei.cmu.edu/asset_files/Article/2017_101_001_502299.pdf

Aorato Labs. (2014, August). *The untold story of the Target attack step by step.* Retrieved March 31, 2022, from Aorato Labs: http://aorato.webstick.co.il/labs/report/untold-story-target-attack-step-step/#

Caralli, R. A., Allen, J. H., & White, D. W. (2011). *CERT resilience management model: A maturity model for managing operational resilience.* Addison-Wesley. Retrieved March 31, 2022, from https://resources.sei.cmu.edu/library/asset-view.cfm?assetid=30375

Caralli, R. A., Stevens, J. F., Wallen, C. M., White, D. W., Wilson, W. R., & Young, L. R. (2007). *Introducing the CERT resiliency engineering framework: Improving the security and sustainability processes.* https://doi.org/10.1184/R1/6574805.v1

Department of Homeland Security. (2014). *Assessments: Cyber resilience review (CRR).* Retrieved March 31, 2022, from Department of Homeland Security, United States Computer Emergency Readiness Team: https://www.us-cert.gov/ccubedvp/self-service-crr

Ellison, R., Goodenough, J., Weinstock, C., & Woody, C. (2010). *Evaluating and mitigating software supply chain security risks.* https://doi.org/10.1184/R1/6573497.v1

Gordover, M. (2015, March 19). *Lessons learned from the 2008 Heartland breach.* Retrieved March 31, 2022, from Proofpoint: https://www.proofpoint.com/us/blog/insider-threat-management/throwback-thursday-lessons-learned-2008-heartland-breach

Temple-Raston, D. (2021, April 16). *A 'worst nightmare' cyberattack: The untold story of the SolarWinds hack.* Retrieved March 31, 2022, from NPR: https://www.npr.org/2021/04/16/985439655/a-worst-nightmare-cyberattack-the-untold-story-of-the-solarwinds-hack

Appendix: ASF Goals for the Supplier Dependency Management Practice Area

Domain 1: Relationship Formation has the following goals:

- **Goal 1—Establishing supplier relationships is planned.** The purpose of this goal is to assess whether entering into relationships with suppliers is planned.
- **Goal 2—Security/resilience requirements are included in formal agreements with suppliers.** The purpose of this goal is to assess whether supplier agreements include security/resilience requirements.
- **Goal 3—Suppliers are evaluated before entering into formal relationships with them.** The purpose of this goal is to assess whether suppliers are evaluated to determine if they can meet the security/resilience requirements for the program or system before entering into relationships.
- **Goal 4—Supplier risk is managed.** The purpose of this goal is to assess whether risk management is included in supplier risk considerations.

Domain 2: Relationship Management has the following goals:

- **Goal 1—Suppliers are identified and prioritized.** The purpose of this goal is to assess whether suppliers that the program or system depends on are identified and prioritized.

- **Goal 2—Supplier performance is governed and managed.** The purpose of this goal is to assess whether performance is considered when evaluating suppliers that support the security/resilience of the program or system.
- **Goal 3—Supplier risk management is continuous.** The purpose of this goal is to assess whether the risks of relying on suppliers to support the program or system are continuously managed.
- **Goal 4—Change and capacity management include suppliers.** The purpose of this goal is to assess whether change and capacity management are coordinated with suppliers that support the program or system.
- **Goal 5—Supplier access to program or system assets is managed.** The purpose of this goal is to assess whether the risks associated with supplier access to assets is managed. (These questions involve access granted to any supplier, not only those that support the program or system.)
- **Goal 6—Infrastructure and governmental dependencies are managed.** The purpose of this goal is to assess whether the risks of depending on infrastructure providers and/or government service providers are identified and managed.
- **Goal 7—Supplier transitions are managed.** The purpose of this goal is to assess whether managing the transition of supplier relationships is based on business considerations (e.g., insolvency, nonperformance, new technology).

Domain 3: Supplier Protection and Sustainment has the following goals:

- **Goal 1—Suppliers are included in disruption planning.** The purpose of this goal is to assess whether suppliers are included in incident management and service continuity for the program or system.
- **Goal 2—Planning and controls are maintained.** The purpose of this goal is to assess whether program or system controls and plans related to suppliers are regularly tested and updated.
- **Goal 3—Suppliers are included in situational awareness reviews and analysis.** The purpose of this goal is to assess whether situational awareness activities for the program or system include suppliers. (Satisfying this goal means that information sources about threats to key suppliers are monitored for the sake of the program or system.)

PANEL 7. MOVING FORWARD WITH UNMANNED SYSTEMS

Wednesday, May 11, 2022	
11:05 a.m. – 12:20 p.m.	**Chair: Paul Mann,** Deputy Assistant Secretary of the Navy – Research, Development, Test & Evaluation ***Uncrewed Maritime Systems: Navy Should Improve Its Approach to Maximize Early Investments*** Diana Moldafsky, US Government Accountability Office Larri Fish, US Government Accountability Office ***Systems and Cost Effectiveness Modeling of Unmanned Systems Product Lines for Acquisition*** Ray Madachy, Naval Postgraduate School John (Mike) Green, Naval Postgraduate School ***Reducing Asymmetry in Countering Unmanned Aerial Systems*** Capt. Christian Thiessen USMC, Naval Postgraduate School Douglas L. Van Bossuyt, Naval Postgraduate School Britta Hale, Naval Postgraduate School

Paul Mann—was appointed to the Senior Executive Service (SES) in 2010 and is the Department of the Navy (DON) Chief Engineer (CHENG) within the office of the Deputy Assistant Secretary of the Navy for Research, Development, Test and Engineering. He leads the Navy's engineering enterprise-wide efforts as a national expert in systems engineering to include development, integration and testing of complex Department of Navy (DON) warfare systems – in support of development, design, construction/fabrication, test and evaluation, operations, and life cycle support of all naval systems. Mr. Mann serves as the on-site technical/programmatic expert for acquisition-related Systems Engineering processes.

Prior to his role as the DON CHENG, Mr. Mann was Division Technical Director for Naval Surface Warfare Center, Port Hueneme Division (NSWC PHD), where he was responsible for the division's technical capabilities, program planning, technical authority, workforce development, and strategic investments.

Mr. Mann served as Acting Principal Deputy Director for the DoD Test Resource Management Center and led execution of statutory and regulatory responsibilities, including a Major Range and Test Facility Base capability assessment, strategic planning, congressional reports, Test and Evaluation (T&E) infrastructure investments and DoD T&E budget certification. He also completed a four-year assignment at White Sands Missile Range as the Executive Technical Director leading all Joint T&E responsibilities.

During his first SES role, he supported the Under Secretary of Defense for Acquisition, Technology, and Logistics as the Assistant Deputy Director for Land Warfare Portfolio of Major Programs. Prior, he was Joint Program Manager, leading procurement, fielding, and sustainment for the Mine Resistant Ambush Protected (MRAP) Vehicles Program at Marine Corps Systems Command, Quantico, Va. With an eventual of more than $44 billion, MRAP became the highest priority acquisition program in the DoD, successfully delivering more than 27,000 vehicles to two theaters of operation.

His decorations include the Army Meritorious Civilian Service Award, the Secretary of Defense Medal for Meritorious Civilian Service, a Joint Meritorious Unit Citation, the Rear Adm. Wayne E. Meyer Memorial Award for Acquisition Excellence, the David Packard Excellence in Acquisition Award for JPO MRAP, two Navy Superior Civilian Service Awards.

Mr. Mann earned his Bachelor of Science in mathematics, cum laude, from the University of La Verne and also holds a Master of Public Administration from the Key Executive Leadership Program at American University in Washington, D.C.

Uncrewed Maritime Systems: Navy Should Improve Its Approach to Maximize Early Investments

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Larri Fish—is a Senior Analyst with the U.S. Government Accountability Office. [fishl@gao.gov]

Abstract

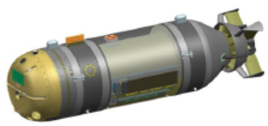
The Navy is in the process of re-examining its maritime strategy to respond to increased competition at sea from nations investing in new weapons and technology specifically designed to disrupt U.S. Naval advantages. In March 2021, the Navy published its Unmanned Campaign Framework which called for the development and fielding of a range of vehicles designed to operate on the surface and undersea without a crew or with a minimal crew to complement the Navy's existing fleet. The Navy's Framework describes a strategy for developing and improving these uncrewed maritime systems by leveraging technology that can be scaled across multiple platforms and domains. The Navy will need to invest significantly in order to develop the technologies necessary to enable these maritime systems to operate autonomously (or semi autonomously), as well as interact with the existing fleet. While the U.S. military has remotely operated uncrewed aerial vehicles for over 2 decades, uncrewed maritime systems are still in their infancy. As a result, the Navy is embarking on a robust effort intended to rapidly develop and field uncrewed system prototypes that can work with existing crewed vessels and solve technical issues prior to acquiring these systems in significant numbers. This paper will assess the extent to which the Navy's (1) strategic planning provide a sufficient basis to invest in uncrewed maritime systems; (2) leadership structure and processes are positioned to achieve its objectives and goals; and (3) prototyping approach is improving its knowledge prior to making purchase decisions.

Background

The Navy plans to introduce a number of uncrewed maritime systems into its fleet over the coming decades.5 While the Navy has previously operated some uncrewed systems including UUVs for missions such as oceanography and mine countermeasures, the Navy is currently developing a number of larger, more complex uncrewed systems. These include USVs—some approaching the size of a frigate or patrol ship—as well as UUVs—some approaching the size of small submarines. In addition to the vehicles, the Navy also needs to develop the software and digital infrastructure capabilities—such as data repositories and modeling and simulation—to operate these systems without a crew on board by developing artificial intelligence capabilities. While some of the software and other pieces will be unique to each vehicle, the Navy is planning for much of the digital infrastructure to be common to all of its major uncrewed maritime efforts.

Uncrewed Maritime Systems

The Navy has six large uncrewed maritime system prototype efforts underway. Four of these were initiated by the Navy's acquisition organization, specifically by the Program Executive Office for Unmanned and Small Combatants' (PEO USC) unmanned maritime system program office. The other two of the Navy's prototypes are being acquired by entities within the DOD's science and technology community, including by the Defense Advanced Research Projects Agency, the Office of the Secretary of Defense Strategic Capabilities Office, and the Office of Naval Research. These efforts have now been transferred to PEO USC. Figure 1 contains information about each of the systems.

Vehicle	Acquired by	Notable demonstrations/events	Prototype quantity	Potential missions
Sea Hunter/Seahawk Medium Displacement Unmanned Surface Vessel  Source: U.S. Navy/Petty Officer 2nd Class Thomas Gooley. | GAO-22-104567	Defense Advanced Research Projects Agency/Office of Naval Research	• June 2018 naval exercise with a reconnaissance payload • September 2020 exercise incorporating advanced autonomy and perception • April 2021 exercise with classified payload	2 delivered 0 planned	• Support MUSV and LUSV development
Overlord Unmanned Surface Vessel  Source: U.S. Navy Institute. | GAO-22-104567	Department of Defense Strategic Capabilities Office /Uncrewed Maritime Systems Program Office	• October 2020 and April 2021 mostly autonomous transits from Gulf Coast to West Coast for both available prototypes • December 2020 naval exercise with electronic warfare payload	2 delivered 2 scheduled for delivery by fiscal year 2023	• Support MUSV and LUSV development
Large Unmanned Surface Vessel (LUSV)  Source: U.S. Navy. | GAO-22-104567	Uncrewed Maritime Systems Program Office	• September 2019, Navy awarded six conceptual design studies worth $42 million • Following fiscal year 2021 budget, the Navy decided to delay procurement	0 delivered Plan to transition program to major capability acquisition	• Surface warfare
Medium Unmanned Surface Vessel (MUSV)  Source: U.S. Navy. | GAO 22 104567	Uncrewed Maritime Systems Program Office	• In July 2019, Navy awarded a $35 million fabrication contract to L3 Harris, with delivery expected in the second quarter of fiscal year 2023	0 delivered 2 planned Up to 7 on contract	• Multi-mission asset due to interchangeable payloads, such as surveillance and electronic warfare
Snakehead Large Displacement Unmanned Undersea Vehicle (LDUUV)  Source: U.S. Navy. | GAO-22-104567	Uncrewed Maritime Systems Program Office	• Initiated in 2012 as an acquisition program, but designated an accelerated research and development effort in 2017 • Government-led prototype to be delivered in fiscal year 2022 • Request for proposal for two industry prototypes issued in 2021	1 under construction 2 planned in short term	• Multi-mission asset due to interchangeable payloads, such as surveillance and electronic warfare • Planned to launch from a submarine
Orca Extra Large Unmanned Undersea Vehicle (XLUUV)  Source: U.S. Navy. | GAO-22-104567	Uncrewed Maritime Systems Program Office	• March 2017, Navy awarded a $274 million contract to Boeing • First XLUUV delivery delayed approximately 21 months until September 2022 due to ongoing production issues	0 delivered 5 under construction Up to 4 on contract Plan to transition program to major capability acquisition	• Modular payloads for seabed warfare

Source: GAO analysis of Navy documents. | GAO-22-104567

Figure 1. Selected Navy Uncrewed Maritime System Prototyping Efforts

Autonomy and Other Digital Infrastructure

The Navy plans to purchase a digital infrastructure that will enable it to operate uncrewed maritime systems autonomously by building its artificial intelligence capabilities over time.6 DOD and Navy officials describe autonomy as artificial intelligence (AI) "in motion," where autonomy is a set of behaviors such as obstacle avoidance that are enabled through the use of multiple capabilities including communications, sensing, and data management, among others. According to Navy officials, to develop an autonomy capability for uncrewed systems, the Navy state will need specialized tools, technologies, and computing infrastructure, such as:

- software models that can be used for simulation,
- software development processes for autonomy and mission planning,
- large data repositories with analytics and machine learning, and
- commercial software and technology that can be quickly purchased and incorporated into Navy systems.

To begin its efforts in this area, the Navy is establishing a set of rules for autonomy software development called the Unmanned Maritime Autonomy Architecture. This architecture is intended to ensure the Navy's software is compatible with other software, vehicles, and payloads provided by multiple contractors. In addition, the Navy is planning to establish the Rapid Autonomy Integration Lab, which is intended to support the testing and development of contractors' autonomy software. The Navy plans to use the lab, according to the program office, to build software updates quickly and model and simulate uncrewed vehicles prior to testing the software on physical prototypes in the water. According to Navy officials, in fiscal year 2022, the Navy plans to begin integrating the first uncrewed systems—the Overlord USVs—into the Rapid Autonomy Integration Lab software development process.

Prototypes in Acquisition Programs

Over the past 15 years, DOD and Congress have taken steps related to prototyping during the technology development phase of acquisition programs. In 2007, the Office of the Under Secretary of Defense for Acquisitions, Technology, and Logistics issued a memorandum on prototyping and competition expressing concern that DOD's decisions on acquisition programs were largely based on paper proposals that provided inadequate knowledge of technical risk and a weak foundation for estimating development and procurement costs.7 In 2018, DOD developed a guidebook with lessons learned from prototyping, which we refer to as DOD prototyping guidance.

In 2017, we examined several major acquisition programs that used prototyping and identified beneficial practices for prototyping based on information provided by the programs.8 Programs used prototyping to, among other things:

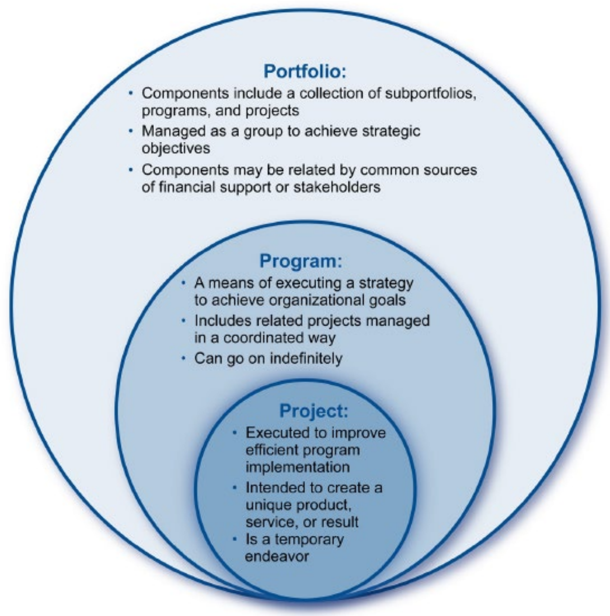
- reduce technical risk,
- investigate integration challenges, and
- validate designs.

We also reported that prototyping has the potential to provide a good return on investment by helping programs better understand key risks, requirements, the feasibility of proposed solutions, and cost. Further, we found that programs that scheduled prototyping efforts to yield results in time to inform key decisions helped to maximize the utility of the prototyping efforts.

We have also reported on the elements of DOD's prototyping strategies. In March 2013, we found that DOD often documented expectations for developing, demonstrating, delivering, and integrating technologies or stand-alone products.9 We found that, while these documents varied by program and could be tailored, they typically outlined technology and readiness metrics, such as cost, schedule, and performance parameters that the prototype must meet to trigger the end of prototyping and the beginning of the next phase. In addition, we have previously found that clear and objective metrics help sustain a stronger prototype effort by providing a formal way to track progress against requirements.

Portfolio Management

Portfolio management is a disciplined management approach that focuses on evaluating, selecting, prioritizing, and allocating limited resources to programs and projects that collectively best accomplish an organization's strategic objectives. The Project Management Institute, Inc., (PMI) has established standards for project, program, and portfolio management that are generally recognized as leading practices and used worldwide by private companies, nonprofits, and others.11 According to PMI, portfolio management is an approach for making a wide variety of decisions, including capability and funding trade-offs that allow an organization to achieve the optimal mix of capabilities for a given investment, as shown in figure 2.



Source: GAO analysis of information from Project Management Institute, Inc. | GAO-22-104567

Figure 2. Relationship between a Portfolio, a Program, and a Project, According to Leading Practices

We have previously reported on how large companies manage groups of linked investments and projects using portfolio management.12 In 2007, we reviewed the portfolio management practices of several large companies and found that they follow a disciplined process to assess costs, benefits, and risks of potential product alternatives across a group of linked investments. We also found that successful companies allocate resources to achieve a balanced portfolio that spreads risk across products, aligns with the company's strategic goals and objectives, and maximizes the company's return on investment. To ensure comparability across alternatives, companies require their projects' initial cost, benefit, and risk information to be developed in a transparent manner, to use specific standards, and to report estimates within certain levels of confidence or allowable deviations.

We also found that companies used portfolio management to assess and balance risk to help ensure that they were making investments that were not so risky that they could damage the company if they did not pan out or so conservative that the company could not compete in the marketplace. Companies emphasized that making tough go or no-go decisions, rather than pursuing every investment idea, is critical to keeping a balanced portfolio.

Navy Continues to Assess Effect of Uncrewed Maritime Systems on Shipbuilding Plans but Has Not Estimated All Known Costs

The Navy's strategic planning efforts examined the need for investments in uncrewed maritime systems, but the Navy is only beginning to assess their effects on existing shipbuilding plans. While the Navy has outlined a plan to spend $4.3 billion on uncrewed maritime systems in its shipbuilding plan, we found that this understates the costs associated with these systems because it does not account for all costs—specifically operations and sustainment, and the digital infrastructure necessary to enable them.

Navy Identified a Role for Uncrewed Maritime Systems and Is Currently Assessing Their Role in the Future Fleet

The Navy completed several studies examining the future of its fleet, concluding that uncrewed maritime systems are essential to address current and anticipated threats. In 2020, DOD and the Navy examined different options for modernizing the fleet to counter growing competition from peer adversaries in the maritime environment.13 The Navy brought together fleet operators and the intelligence and acquisition communities to analyze and war-game alternative fleet force structures—including varying levels of uncrewed maritime systems—within prescribed budgetary constraints. Following this study, in March 2021, the Navy published an Unmanned Campaign Framework, which called for the development and fielding of a range of uncrewed vehicles designed to complement the Navy's existing fleet. The Navy's Framework highlights the vital role that uncrewed maritime systems will play in the Navy's future capabilities and describes a strategy for developing and improving these uncrewed maritime systems by using technology that can be applied across multiple air and sea-based systems. In its framework, the Navy highlighted the need for these systems to be affordable.

Through its studies, the Navy determined that uncrewed systems could address capability gaps by enhancing the capabilities of crewed ships or operating independently. For example, the Navy examined the potential utility of LUSVs to meet existing unmet requirements. In doing so, the Navy found that an initial mission for a LUSV system would be to augment the capabilities of crewed surface ships by providing more missile capacity to strike enemy ships. The Navy also studied the use of MUSVs to augment the intelligence, surveillance, reconnaissance, and electronic warfare capabilities of the surface fleet by providing a less expensive, more disposable ship. Figure 3 shows the respective missions of the LUSV and MUSV and a notional control center, which could either be on another Navy ship or ashore. While uncrewed maritime systems may eventually have the potential to address a wide range of different missions, the Navy focused on meeting initial requirements for identified missions with as little technology development as possible.

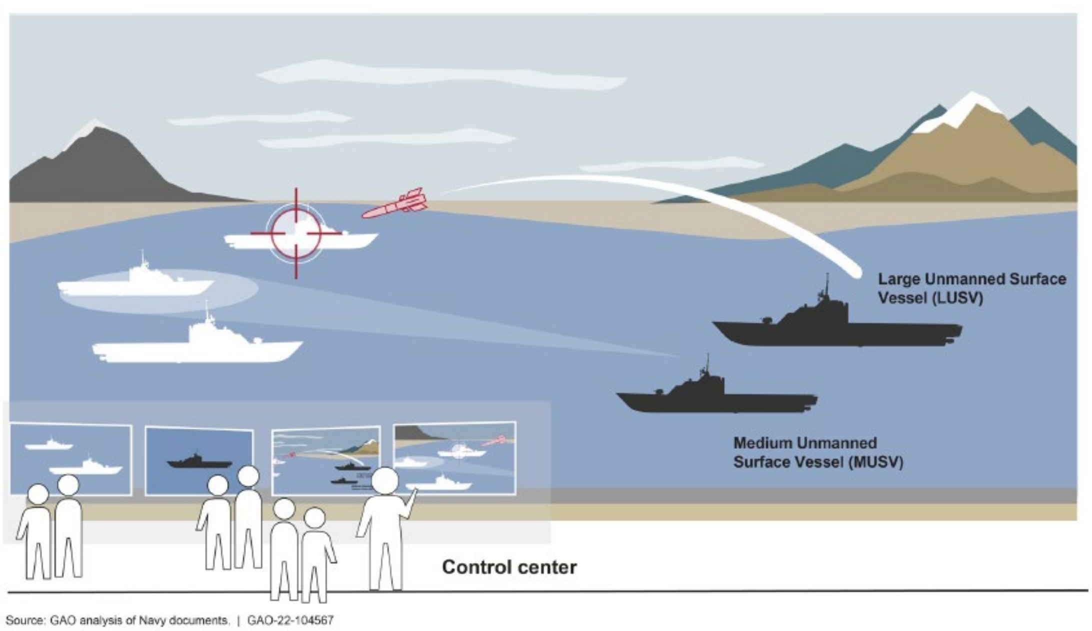


Figure 3. Notional Uncrewed Surface Vessel Operational View

In its studies, the Navy also examined the potential role of an XLUUV to fulfill existing unmet requirements. As such, the Navy plans for the initial XLUUV to be an autonomous, long endurance, pier-launched UUV for delivering payloads—such as mines—as shown in figure 4. According to Navy officials, using a UUV for this mission reduces the risk to crewed submarines.

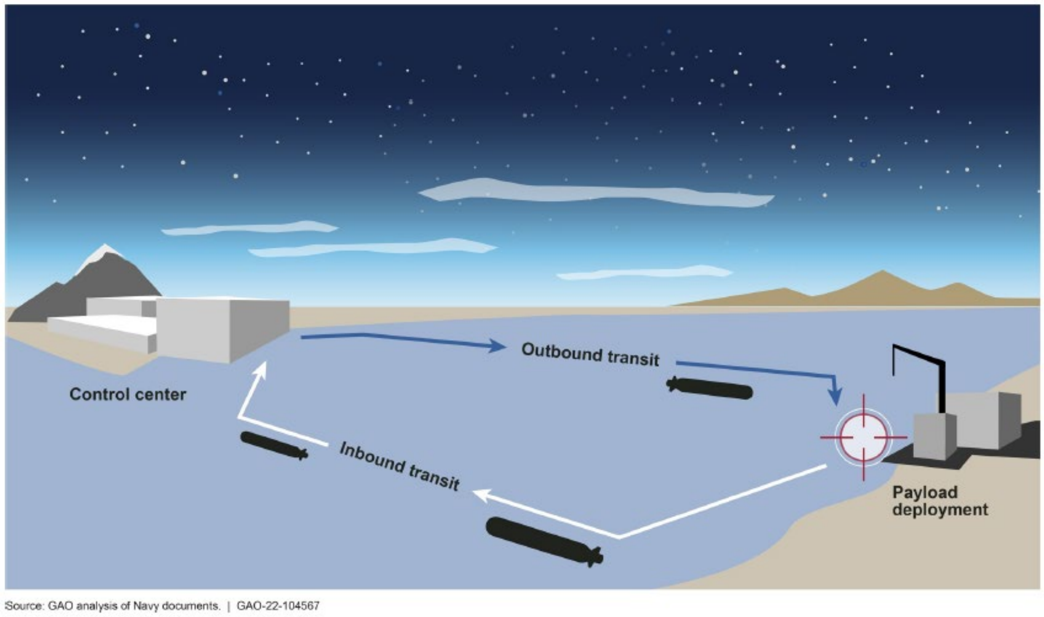


Figure 4. Notional Extra-Large Unmanned Undersea Vehicle Operational View

In addition, the Navy intends for LDUUV to be a long-endurance, multi- mission UUV that uses modular and reconfigurable payloads to increase the situational awareness of the crewed submarine that the Navy plans to launch it from, as shown in figure 5.

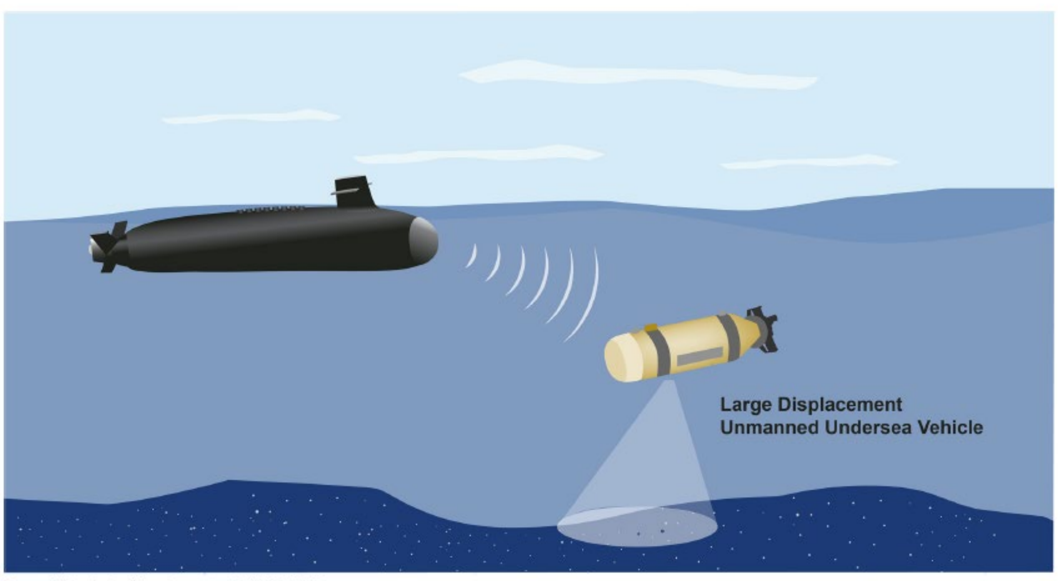


Figure 5. Notional Large Displacement Unmanned Undersea Vehicle Operational View

The Navy has a series of further analyses planned, which could address the effectiveness of uncrewed maritime systems in meeting identified missions to inform future tradeoffs. For example, the Navy initiated an Offensive Surface Fires Analysis of Alternatives to inform the LUSV effort after it was mandated to do so in the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021.14 This analysis will look at a variety of solutions—including uncrewed maritime systems— to provide a naval surface strike capability.

According to Navy officials, the Navy has yet to initiate any analyses to assess the effect that added capabilities of the XLUUV and LDUUV systems could have on the submarine fleet. However, after the Navy takes delivery of the XLUUV prototypes, it intends to complete a military utility assessment in 2024 to determine the effectiveness of XLUUV, which could inform other trade-offs. Finally, the Navy and DOD's Office of Cost Assessment and Program Evaluation are working on a number of efforts to assess the composition of the future fleet including continuing to assess options, as a part of the Navy's force structure review, which can inform the fiscal year 2024 shipbuilding plan. In doing so, a senior Navy official told us that the Navy remains committed to actively testing potential operational concepts for the uncrewed maritime systems.

Navy Is Budgeting for Uncrewed Maritime Systems but Has Yet to Estimate All Costs

The Navy is planning to spend billions of dollars on uncrewed maritime vehicles over the next 5 years. In December 2020, the Navy released a 30-year shipbuilding plan outlining a goal of acquiring 143 uncrewed maritime vessels and vehicles by 2045, as shown in figure 6.

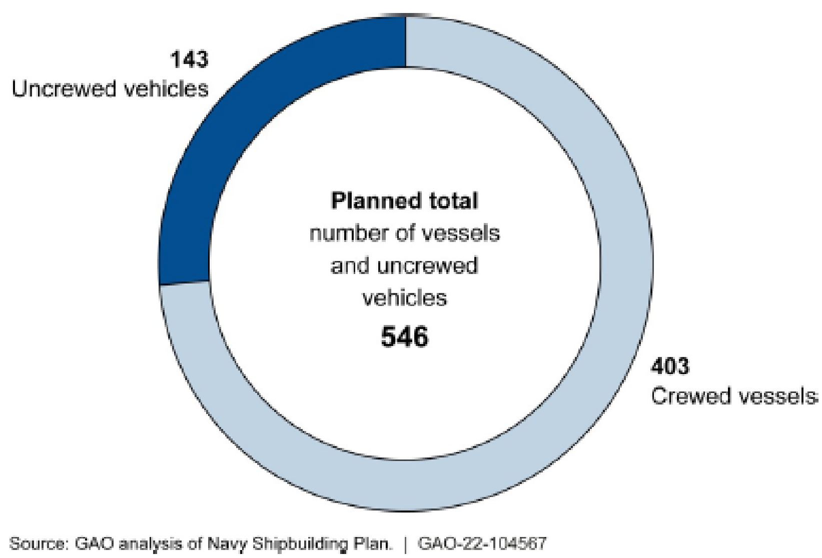


Figure 6. Total Vehicles and Vessels (Crewed and Uncrewed) in December 2020 Shipbuilding Plan

According to the December 2020 shipbuilding plan, the Navy plans to spend $4.3 billion over the next 5 years for 21 uncrewed vehicles, including $581 million planned in fiscal year 2022. According to the Congressional Budget Office's analysis of this plan, the Navy plans to spend an average of $1.2 billion per year for 30 years in fiscal year 2021 dollars, about 4 percent of the planned shipbuilding budget, on uncrewed maritime vehicles, as shown in figure 7.

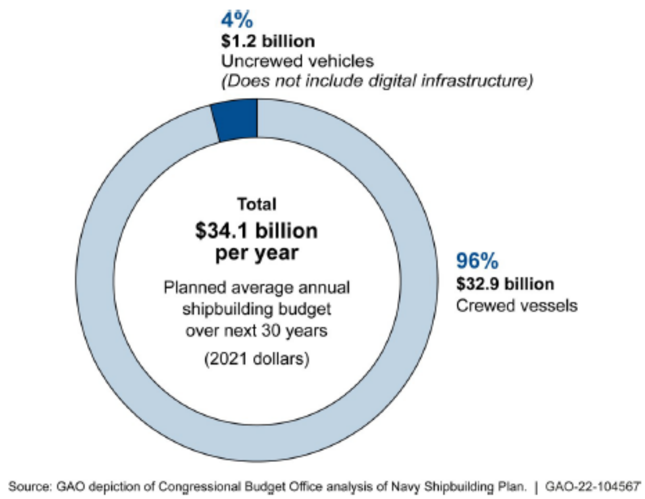


Figure 7. Navy's Planned Investment in Uncrewed Maritime Vessels and Vehicles

Overall, the Navy's December 2020 shipbuilding plan—including both crewed and uncrewed vessels—would require up to 50 percent more resources for shipbuilding than what the Navy has been receiving on average for the past 5 years, according to the Congressional Budget Office. Therefore, funding uncrewed maritime systems could come under pressure from the Navy's competing shipbuilding demands. The Navy subsequently published a shipbuilding plan in June 2021 to accompany its fiscal year 2022 budget request, but this plan only covered fiscal year 2022 rather than a 30-year forecast. While it did not include a future-year forecast for uncrewed maritime systems, it was consistent with the Navy's December 2020 plan in highlighting the importance of uncrewed maritime systems for the future fleet. Thus, we used figures reported in the December 2020 plan for this review as the best indication of the Navy's planned long-term level of investment for uncrewed maritime systems.

Based on our analysis of the Navy's December 2020 shipbuilding plan, we found that the Navy is underestimating the resources needed to acquire its uncrewed maritime systems. Specifically, the estimate does not encompass costs for: (1) operations and sustainment or (2) the digital infrastructure needed to enable and support these systems.

The December 2020 shipbuilding plan only includes operations and sustainment costs for the crewed fleet, and the June 2021 shipbuilding plan does not include operations and sustainment costs at all. According to Title 10, Section 231 of the U.S. Code, the annual shipbuilding plan must include estimated operations and sustainment costs for each vessel.15 In the December 2020 plan, the Navy stated that uncrewed maritime systems do not have a sufficient level of maturity and fidelity that would allow them to model operations and sustainment costs. We have previously reported that operations and sustainment costs for ship programs are a significant portion of a program's total cost.16 Given that operations and sustainment costs are such a large portion of a shipbuilding program's total cost, the Navy cannot fully assess the affordability of uncrewed maritime systems without an understanding of operations and sustainment costs, even if an estimate of these costs needs to be refined over time as more knowledge is gained through prototyping.

Further, while the removal of a crew onboard may present the opportunity for some operations and sustainment cost savings, these systems still require some crew to operate them either at onshore facilities or on board a crewed ship or submarine. The

Navy has yet to determine how many sailors will be required to operate uncrewed maritime systems in these roles, and according to Navy officials, is using prototyping to inform these crew requirements.

However, previous attempts by the Navy to reduce crew size by increasing automation did not go as planned. For example, in 2017 and 2021, we reported that the Navy's attempts to reduce crew sizes on crewed ships through increased automation, called optimal manning, resulted in large increases to maintenance costs when the automated systems failed to work as intended, ultimately leading the Navy to assigning additional crew to its ships.17 Given this trend, the Navy cannot fully assess the affordability of uncrewed maritime systems without understanding the extent to which the replacement of a crew on board with automated systems affects operations and sustainment costs.

The Navy's $4.3 billion estimate also does not include the costs associated with the digital infrastructure necessary to enable the uncrewed maritime systems to function without a crew on board. According to the Navy's initial prototyping plans, developing the digital infrastructure, including the Rapid Autonomy Integration Lab needed to enable uncrewed maritime systems, will require a significantly larger software development effort than is typical for shipbuilding programs. A senior Navy official in the Navy's Research, Development, and Acquisition office told us this digital infrastructure is still under development and the full extent of costs remain unknown, although they expect costs just for the digital infrastructure to run into the billions of dollars. However, the Navy did not include an estimate of the costs for developing the digital infrastructure in either the December 2020 or June 2021 shipbuilding plans, even as the Navy budgeted $293 million for digital infrastructure. Despite its criticality, Navy officials told us that developing this software capability has thus far not been as high of a priority as fielding vehicle prototypes. However, Navy officials also noted that the forthcoming fiscal year 2023 budget submission is expected to provide more funding for digital infrastructure.

The Navy attributes the incomplete cost estimates for uncrewed maritime systems to the unique nature of these efforts, as well as being prototyping efforts that are not typically included in shipbuilding plans. For example, Navy officials noted that the Navy does not produce program life-cycle cost estimates for prototyping efforts. However, the Navy often includes early estimates for ships that do not yet have program life-cycle costs, including the Light Amphibious Warship.

While there are some uncertainties with regard to uncrewed maritime systems, our cost estimating leading practices account for uncertainty in program costs. These practices state that, while programs tend to start with rough order of magnitude estimates, these estimates should be refined over time as more is understood about a program and as funding levels are expected to increase.18 Despite initial uncertainty, it is important to document planned costs as early as possible because initial cost estimates help to inform trade-off decisions among cost, schedule, and requirements, which increase a program's probability of success.19 Once completed, the Navy would benefit from updating these estimates as the uncrewed efforts gain knowledge over time in accordance with our cost estimating best practices.

The Navy highlights affordability as a significant reason for developing and acquiring uncrewed maritime systems in its Unmanned Campaign Framework. However, without even a rough cost estimate covering the full known scope of investment to acquire, operate, and sustain these systems, it cannot be certain that uncrewed maritime systems are the affordable solution for providing the capability that the Navy desires. A cost estimate, beginning with rough order costs that is refined over time, forms the basis for establishing and defending informed investment decisions and is integral to determining and communicating a realistic view of likely cost and schedule outcomes.21 By highlighting the affordability of these systems without analysis that accounts for all estimated costs, the Navy could potentially communicate unrealistic cost estimates and expectations for its uncrewed maritime systems. If uncrewed maritime systems turn out to be more expensive than anticipated, the Navy may not be able to buy as many ships—whether crewed or uncrewed—as currently planned, which could jeopardize its future force plans.

Navy Is Missing Opportunities to Better Manage Efforts to Achieve Its Uncrewed Maritime System Objectives

The Navy is not managing its individual uncrewed maritime system efforts and capabilities as a portfolio and, as a result, is missing opportunities to more efficiently achieve its strategic objectives and maximize its investments. Specifically, the Navy has not initiated key practices for its group of related investments on uncrewed maritime systems and capabilities:

1. clearly defining a portfolio that is linked to strategic objectives,
2. establishing clear metrics for judging the portfolio,
3. defining and appropriately empowering governance roles for the portfolio, and
4. identifying stakeholders and a stakeholder engagement plan for the portfolio.

By not establishing a portfolio and initiating these key steps, the Navy is reducing the likelihood that it will achieve its strategic objectives for uncrewed maritime systems.

Navy Has Not Established Uncrewed Investments as a Portfolio, Though It Identified Strategic Objectives

The Navy has not identified uncrewed maritime systems as a portfolio.22 A portfolio is a collection of projects, programs, subsidiary portfolios, and operations that should be managed as a group to achieve strategic objectives.23 According to PMI, a portfolio management approach creates a process for an organization to implement strategic objectives. Through portfolio management, organizations can make a wide variety of decisions—including capability and funding trade-offs—to achieve the optimal mix of capabilities for a given investment. According to PMI and our prior work, managing a group of linked investments as a portfolio is typically more effective than overseeing each effort individually because it, among other things, allows an organization to:

- ensure that investments match the organization's objectives,
- provide active and decisive leadership,
- clearly identify stakeholders and creates a stakeholder engagement plan, and
- improve risk management.

According to PMI's portfolio management standard, there are four phases in a portfolio life cycle: initiation, planning, execution, and optimization.24 The first of these phases—initiation—occurs when an organization establishes the approach and processes that define how it will manage the portfolio. See appendix II for a list of PMI's leading practices throughout the full life cycle of a portfolio.

Even though it has not established uncrewed efforts as a portfolio, the Navy published a collective set of strategic objectives for these individual efforts, which are highlighted in the March 2021 Unmanned Campaign Framework. These are:

- advance crewed and uncrewed teaming within the full range of Naval and joint operations,
- build a digital infrastructure that integrates and adopts uncrewed systems at speed and scale,
- incentivize rapid incremental development and testing cycles for uncrewed systems,
- disaggregate common problems, solve them once, and scale solutions across platforms and domains, and
- create a capability-centric and sustainable approach for uncrewed contributions to the Navy.

These strategic objectives for the Navy's uncrewed efforts illustrate the linkage between the various investments that share funding and expertise to solve similar issues—key criteria for a portfolio.

Instead of managing the various uncrewed maritime systems as a portfolio, senior Navy officials told us that the Navy divides its efforts between three different offices within the Office of the Chief of Naval Operations—surface, undersea, and warfare integration. These offices prioritize and allocate funding across the Navy's investments, which typically do not overlap. While this structure works for investing in individual surface and undersea vehicles, it does not facilitate collective efforts that span these areas, such as the digital infrastructure. Senior Navy officials told us that they opted for this approach to uncrewed maritime systems because they prefer having experts make trade-off decisions within their respective surface and submarine domains. However, without establishing a portfolio, the Navy does not have a mechanism by which it can collectively work together on shared aspects of its uncrewed maritime system efforts to optimize its ability to achieve its objectives.

Navy Does Not Have Clear Metrics That Link Uncrewed Maritime Efforts to Strategic Objectives

The Navy has also not established metrics that enable it to measure its progress towards achieving the strategic objectives established in its Framework. According to PMI, once an organization establishes a portfolio, it should develop objectives and metrics that allow it to track progress. While the Navy has established strategic objectives, it has not defined key terms to allow for measurement. For example, the Navy is currently:

- conducting naval exercises to better understand teaming between crewed ships and uncrewed maritime systems. However, the Navy has not established metrics that better define its goal of uncrewed teaming within the full range of naval operations, according to several senior Navy officials and the program office. Thus, the Navy cannot be sure it is on track to achieve its stated objective even as it conducts some initial teaming efforts at sea.
- planning to build the digital infrastructure needed to operate these systems. However, according to the program office, the Navy has not established metrics for building the digital infrastructure, such as measures to define speed and scale, and is not tracking its progress toward achieving this objective. However, establishing clear metrics— and refining them as more is learned—is a critical early step when the portfolio is initiated.

Navy program officials told us that it is too early in the program to measure progress against its objectives. However, PMI states that organizations should measure progress at the beginning stages of an effort. Without establishing metrics, the Navy cannot ensure that its progress is aligned with its strategic objectives.

Navy Has Not Established Governance with Authority for Uncrewed Maritime Systems

The Project Management Institute and our best practices state that organizations should have governance structures that appropriately empower leadership for its projects and portfolios.25 Further, effective portfolio management provides the space for organizations to responsibly innovate while also helping to ensure that the organization is setup to meet future goals and outpace competition by effectively balancing and prioritizing projects, as discussed by PMI and our prior work.26 However, the Navy does not have a governance structure with an empowered leader who has an understanding of the full uncrewed maritime system effort and can reprioritize the Navy's investments in this area as needed. Navy officials agreed that there is no senior leader with the responsibility for the collective decision-making process that determines how Navy investments in uncrewed maritime system efforts are oriented toward achieving its stated objectives.

The Navy attempted to build a common governance structure for uncrewed maritime systems, but its efforts were unsuccessful. In 2015, the Navy established a Deputy Assistant Secretary of the Navy for Unmanned Systems, but, according to officials who were in this office, it was disbanded in April 2018 in favor of managing uncrewed vehicles through the existing groups within the Office of the Chief of Naval Operations. According to officials in the Office of the Secretary of the Navy for Research, Development, and Acquisition, the Deputy Assistant Secretary of the Navy for Unmanned Vessels did not have the responsibility and authority needed to make research and investment decisions across the Navy's full uncrewed maritime system effort.

Senior Navy officials told us that they also established an office in 2015 within the Office of the Chief of Naval Operations focused on uncrewed systems including air, sea, and undersea. Both the office of the Deputy Assistant Secretary of the Navy for Unmanned Vessels and the uncrewed office within the Office of the Chief of Naval Operations were disbanded in fiscal year 2018. This was due to a lack of support from senior leadership for an organizational structure separate from its traditional warfare areas with its own resources, according to these officials.

Several organizations have also recognized the Navy's lack of governance of its uncrewed efforts. A provision of the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 required the Navy to designate an existing program executive officer as the lead official for acquiring and sustaining autonomous capabilities by February 2022. A program executive office can share some similarities with a portfolio management approach, in that these offices oversee the execution of a group of linked investments. However, the designation requirement addresses the acquisition of autonomous capabilities and not the entire uncrewed maritime system enterprise, including research, acquisition, and operations. A portfolio manager, as defined by PMI, would oversee all of these areas. As of December 2021, Navy officials told us that they are working on implementing this National Defense Authorization Act provision but have yet to decide on an approach.27

In addition, in 2021 the Center for Strategic and Budgetary Assessments recommended the Navy establish an Autonomy Project Office within the Navy with sufficient authority to coordinate resourcing and management of all of the Navy's uncrewed efforts across all domains. The Center for Strategic and Budgetary Assessments also recognized that the Navy does not have a governance structure that can unify various parts of the Navy who are working on autonomy-based projects. Further, while the Navy already has an autonomy program division within its research and development community, Navy officials said that they hope to formalize collaboration between the Office of Naval Research Autonomy office and the program executive office that is assigned responsibility for autonomy.

However, as of December 2021, Navy officials stated they had yet to complete their efforts to establish formal relationships between these offices. Without formalizing unified leadership for a single portfolio for uncrewed maritime systems, the Navy could have multiple leadership positions responsible for autonomy. This could, among other things, result in inefficient investments and multiple autonomy-based projects attempting to solve similar problems without coordinating their efforts.

Senior Navy officials confirmed that it is difficult to gain support for investments in developing the digital infrastructure compared to purchasing vehicle prototypes because digital infrastructure is not a tangible deliverable like a ship. Further, Navy officials did not identify an appropriately empowered Navy official who has the responsibility for leading the digital infrastructure through the Navy's investment process. In line with one of its objectives and how Navy governance is setup, the Navy program office and offices with the Chief of Naval Operations have been prioritizing purchasing uncrewed maritime vehicle prototypes and getting them to the fleet as quickly as possible to prove that the uncrewed concept can work in the field.

However, the digital infrastructure to support uncrewed systems has not kept pace with vehicle investment. Of the approximately $1.9 billion in total funding that the Navy has spent on uncrewed maritime systems since 2015, the Navy only requested a fraction of this amount, $293 million, to develop the digital infrastructure, even though the vehicles will be much less effective without it. In addition, the Navy's Seahawk, Sea Hunter, Overlord and XLUUV efforts do not conform to the planned Unmanned Maritime Autonomy Architecture for digital infrastructure, which could result in costly retrofits. Senior scientists within the Office of Naval Research told us that building the digital infrastructure to develop and test capabilities before building whole vehicles is the preferred way to rapidly develop and execute uncrewed maritime system efforts. Further, AI experts from DOD and external organizations agree that DOD must have the necessary digital infrastructure in place to develop, acquire, and scale AI effectively for weapon systems.

As a result, the Navy risks purchasing vehicles and software that cannot be easily updated, reconfigured, or maintained, which would result in assets that will not meet the Navy's needs. Without defining a portfolio with a governance structure and assigning leadership, the Navy is missing opportunities to more effectively manage its uncrewed maritime system efforts. Less effective management could result in the Navy suboptimally utilizing investment dollars, which would delay its achievement of uncrewed maritime capabilities.

Navy Has Not Identified Roles and Responsibilities for Key Stakeholders

The Navy has not clearly defined the roles and responsibilities of the numerous stakeholders that have some responsibility for developing and acquiring uncrewed maritime systems. There are many key stakeholders for these efforts from two large communities within the Navy—the science and technology community within the Office of the Chief of Naval Operations, and the acquisition community within the Assistant Secretary of the Navy for Research, Development, and Acquisition. In 2015, we highlighted what happens when these two stakeholder communities do not actively collaborate with one another on transitioning technologies into acquisition programs and solving problems.28 Specifically, in 2015, we reported that the scientific community often does not develop technologies to a level of maturity that provides substantially less risk to the acquisition program. This report looked at 10 case studies and found that, in all five cases where a successful technology transition occurred, active collaboration between science and technology research and acquisition efforts was crucial to success.29

The Navy's uncrewed maritime efforts have, so far, resembled a hand-off from the science and technology community to the acquisition offices, rather than a collaborative effort. For example, according to Office of Naval Research scientists, even after years of development by the Office of Naval Research and others, uncrewed maritime undersea vehicles require additional development by the acquisition program office to achieve necessary endurance capabilities. In 2013, we found a range of management tools used by transition programs to support communication and collaboration among stakeholders, such as informal agreements, which can help organizations work together to solve technical problems during uncrewed system development. Specifically, we found that "good faith" agreements that document the expectations for developing, demonstrating, delivering, and integrating technologies helped to formalize collaborative prototyping efforts.30 However, according to DOD science and technology officials we spoke with, the scientific community does not have these or similar agreements for the uncrewed maritime system prototypes.

Lastly, Navy acquisition officials told us that they are working closely with subject matter experts in the science and technology community to facilitate the continued development of uncrewed maritime systems. However, we found that the roles and responsibilities of each group going forward on this effort are largely informally defined. Accordingly, Navy scientists, engineers, and program managers, among others, have to self- organize and coordinate across organizational boundaries to solve problems or move programs forward.

The Navy is considering a number of organizational changes to help manage its uncrewed maritime efforts, but these changes do not yet address the core organizational issues that are preventing more formal collaboration between the science and technology and acquisition communities. For example, the Navy stood up a task force on uncrewed maritime systems in 2021 with stakeholders from across the Navy to help coordinate day-to-day management of its uncrewed maritime systems. Navy officials told us they also recently began discussing efforts to stand up an Unmanned Campaign Council to coordinate strategic decision making, including the resourcing of uncrewed maritime systems, but the roles and responsibilities of this organization have yet to be established.

According to Navy officials, this organization would potentially coordinate the efforts of the surface and undersea warfare resource sponsors for uncrewed maritime systems, including the necessary digital infrastructure. However, senior Navy officials told us that this group will primarily be charged with identifying existing commercial technologies that the Navy can potentially use to provide needed capabilities instead of developing new technologies. As of January 2022, senior Navy officials told us that the Navy had yet to document the roles and responsibilities of this group. Specifically, the Navy has yet to define whether these new organizational bodies will coordinate between Navy stakeholders, including the science and technology and acquisition communities. Since portfolios often cross organizational boundaries, according to PMI's guidance, organizations should formally identify stakeholders and develop a plan for how they should coordinate when a portfolio is initiated. Without defined roles and responsibilities for key stakeholders, the Navy's process for problem solving through prototyping and incorporating these lessons into future acquisitions is ad hoc and relies on the unofficial and voluntary collaboration of officials working across bureaucratic divisions.

Current Prototype Approach Does Not Ensure That the Navy Is Building Knowledge Prior to Making Decisions

The Navy's prototyping plan for uncrewed maritime systems has the potential to reduce risk before significant investments are made, but it lacks several key strategies for successfully transitioning the efforts to acquisition programs that are highlighted in DOD guidance and our prior work.31 Specifically, the Navy has not:

- documented clear evaluation criteria to inform readiness of prototyping efforts to transition to acquisition programs;
- developed prototyping schedules to help ensure that knowledge is gained in time to inform key decisions; or
- detailed the technology maturation process and other development milestones, such as the achievement of safety certifications in prototyping plans.

Without incorporating these strategies into its prototype planning, the Navy will not maximize its significant investments in prototyping these systems.

Navy Does Not Have Measurable Criteria for Evaluating Prototyping Efforts

We reviewed all of the Navy's available prototyping documents, including test strategies and prototyping plans, and found that the Navy does not have evaluation criteria to determine the readiness of each prototype to move to the next phase. DOD prototyping guidance states that an example of a best practice is to establish evaluation criteria that specifically outlines milestones and metrics that describe when a prototype is ready to move to the next phase.32 The guidance also states that the purpose of prototyping is to reduce technical risk to support the next phase of the effort. Tailored evaluation criteria is important because each prototyping effort is designed to meet a different set of missions.

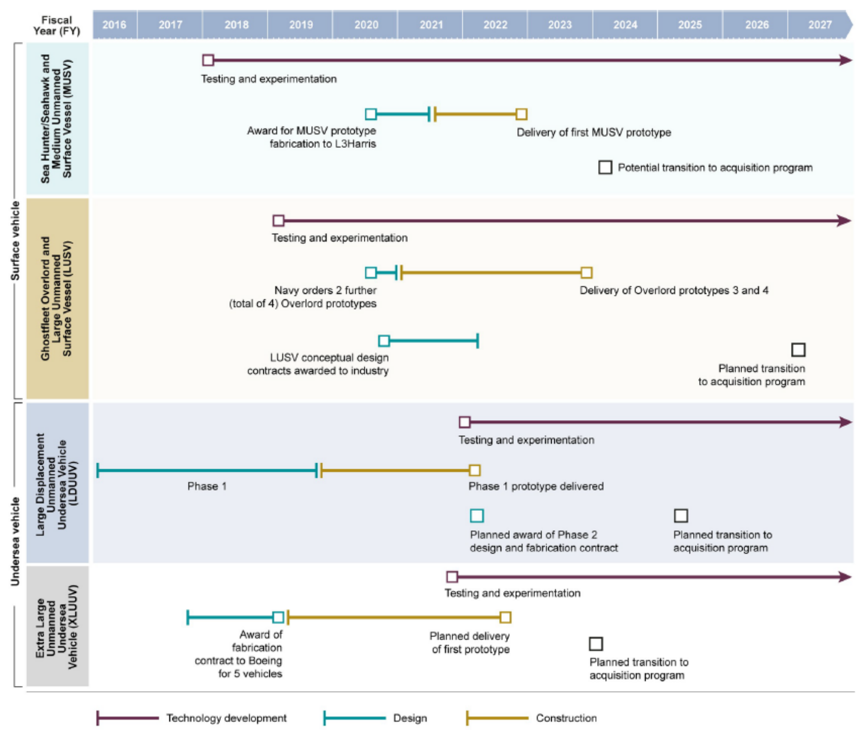
Navy officials responsible for the uncrewed maritime prototypes told us that it is too early to establish measurable evaluation criteria for the Navy's prototypes. Project officials also said that further assessment of the progress and status of the Navy's prototypes will determine if the prototypes receive additional funding. As of January 2022, the Navy has yet to complete more detailed capability descriptions. However, DOD prototyping guidance recommends that transition planning should begin in the first year of the prototyping effort. The Navy's prototyping efforts for MUSV, XLUUV, and LDUUV have each been underway for almost 3 years. Further, even though the Navy has delayed the LUSV prototyping effort, it has received two Overlord USV prototypes from DOD's Strategic Capabilities Office and ordered two more without developing evaluation criteria. In addition, the Navy has also been operating the Sea Hawk and Seahunter to inform the MUSV program since fiscal year 2020 without evaluation criteria.

Without metrics and milestones to evaluate the prototypes, the Navy will not know when it has achieved its objective of lowering the risk of acquiring these systems before committing to significant investments. As a result, the Navy may transition these programs into the acquisition process before they are ready, potentially leading to concurrency between the technology maturation, design, and building stages of the program. As we have previously reported on multiple Navy shipbuilding programs over the last 10 years, concurrency often results in cost growth, schedule delays, and performance issues.

Navy Has Yet to Develop Schedules for Aligning Uncrewed Maritime System Efforts

The Navy has yet to develop schedules that align its uncrewed maritime vehicle prototypes and the related digital infrastructure to help ensure that its prototyping milestones align with key investment decisions. We requested an integrated schedule for the uncrewed maritime system prototyping efforts, but the most detailed schedules that the Navy provided to us only included a limited number of events illustrated on a single briefing slide for each prototyping effort. Therefore, we could not determine if knowledge from prototyping events would be available when the Navy plans to make investment decisions, such as buying additional vehicles. Further, as of January 2022, the Navy was unable to provide schedules for the digital infrastructure development efforts and did not have a schedule that integrated these efforts with its vehicle prototypes. The most recent schedules, which accompanied the Navy's fiscal year 2022 budget request, provided limited future information rather than a long-term schedule, and the schedules did not demonstrate how the Navy plans to gain knowledge prior to making decisions or how all of the efforts are integrated.

In the absence of an integrated schedule from the Navy, we analyzed the information provided to us and developed a depiction of the schedule for all of the Navy's uncrewed system prototypes, including when the Navy plans to transition them to acquisition programs. Figure 8 depicts the schedule information that we could determine from analyzing available documents.



Source: GAO analysis of Department of Defense and Navy prototyping documents. | GAO-22-104567

Figure 8. GAO Depiction of Uncrewed Maritime System Prototype Schedule

We found that there is potentially significant overlap between ongoing prototyping efforts of uncrewed surface vehicles and the Navy's plan to acquire follow-on prototype vehicles. For example, the Office of Naval Research recently provided the Navy with two medium uncrewed vessel prototypes—Sea Hunter and Seahawk—that the Navy is beginning to use for experiments. The Navy's schedules do not clearly outline when the

Navy plans to gain knowledge from its prototypes and how the timing of this knowledge aligns with when the Navy needs to make decisions about forthcoming investments. Although the Navy delayed the LUSV effort by 5 years, its schedule is not detailed enough to understand when the Navy plans to gain knowledge from prototyping Overlord—the precursor to the LUSV. Thus, without an integrated schedule, the Navy cannot demonstrate how Overlord prototyping aligns with LUSV design, requirements, and transition to acquisition or how this effort supports planned investments for the MUSV and digital infrastructure.

The Navy is pursuing common elements for all of the prototyping efforts—especially between USVs and UUVs—such as information technology standards, autonomy and endurance capabilities, and other key technologies and certifications for the uncrewed systems. For example, the Navy expects that endurance improvements for an undersea prototype like the XLUUV are applicable to the LDUUV. The same concept applies to the surface prototypes, where reliability improvements, such as an automated lube oil system, contributes to both the LUSV and MUSV. There are also interdependencies between the information technology and autonomy portions of the systems. For instance, the standards that the Navy is developing to guide autonomy (Unmanned Maritime Autonomy Architecture) are common across all four efforts, as is the planned Rapid Autonomy Integration Laboratory. Without a schedule that states how the Navy plans to align the development of these common efforts, the Navy risks inefficient and out-of-sequence work as it tries to develop uncrewed maritime capabilities.

GAO's scheduling best practices state that a master schedule should identify interdependencies between subprograms, which help programs manage risk and can be tailored to the maturity level of the program.34 In addition, in 2017, we found that prototyping efforts should be structured so that they can be completed in time to inform key decisions.35 Further, the Project Management Institute states that one advantage of portfolio management is that organizations can gain a better understanding of the schedule interdependencies between its efforts, which improves the organization's ability to manage and invest in these efforts.

However, project officials told us that they do not have schedules because their prototype efforts are early and have already been subject to numerous schedule changes based on changes to their budget and other delays. While the Navy's efforts are early, our scheduling best practices state that even a basic integrated schedule of key milestones provides a time sequence for the duration of a program's activities and helps stakeholders understand both the dates for major milestones and the activities that drive the schedule.36 If the Navy does not develop schedules that account for interdependencies between prototype efforts and update the schedules as progress is made, the Navy cannot manage these efforts to ensure that knowledge gained from prototyping will inform future purchasing decisions and designs.

Navy Prototyping Documents Provide Little Detail on Technology and Certification Development

The Navy has yet to document: 1) how it plans to develop technologies to achieve its uncrewed maritime system requirements and 2) how it will use prototyping to advance systems towards developing certification standards prior to making investment decisions.

Prototyping Documents Lack Detail on Technology Development Process

Each of the Navy's uncrewed maritime system efforts has prototyping documents for the current phase of each effort. However, these documents contain little information about how the Navy plans to use the prototypes to achieve its top level requirements. The

Navy has established top level requirements for each of its uncrewed maritime system prototypes that specify, among other things, the range, endurance, and speed the Navy believes it must achieve for the systems to be militarily useful. However, the Navy's current prototyping plans generally focus on how it will execute experimentation with prototype vehicles, instead of how technology development milestones link to top level requirements.

Specifically, none of the Navy's prototyping documents that we reviewed identify the technologies and planned technology development milestones necessary for progressing the prototypes to a point where they meet the top-level requirements. For example:

- In spring 2019, the Navy declared the MUSV to be a rapid prototyping project and created a prototyping plan. The prototyping plan identifies several requirements related to endurance, reliability, and autonomy. However, the plan does not include key details on the current status of the technologies needed to achieve these requirements and the process for maturing these technologies through prototyping.
- In December 2016, the XLUUV prototyping document identified performance risks associated with endurance, autonomy, and reliability. In addition, the XLUUV used a technology assessment completed by a similar program to identify current technology readiness levels. However, the technology maturation plan in XLUUV prototyping documents does not identify actions that are planned for maturing the technologies through prototyping. The XLUUV plan states that project officials will track technology development in industry and the scientific community, but we found that technologies matured by the Navy scientific community differ from technologies used in the XLUUV.

DOD's prototyping guidebook states that one of the main purposes of prototyping is to reduce technical risk prior to beginning the next phase of the effort. Also, in 2017, we found that successful prototyping efforts gathered information on technology maturity, potential costs, and the achievability of planned performance requirements.37 Lastly, our technology readiness assessment guide states that early technology development efforts should identify what technologies a project aims to mature and the associated milestones and risks.38

Navy program officials acknowledged that they need to revise their plans to document the steps necessary to progress the prototypes towards meeting top-level requirements but have yet to take action. Without documenting the key milestones it plans to achieve during the prototype experimentation process, the Navy cannot be certain that it is on track to reduce technical risk prior to transitioning the effort to an acquisition program.

Prototyping Documents Lack Detail on Certification Development

The Navy has yet to document in its prototyping plans how it will develop safety and proficiency standards for uncrewed maritime systems, called certifications. Certifications generally establish the basic functional standards for safe operation of a Navy vessel and can vary widely depending on the type of ship. For example, the certification for safe operations differ significantly between a diesel-powered frigate and a nuclear-powered submarine because of where these vessels operate and how they are powered, among other differences. Critical systems, the crew, and the flight deck (among many other things)—have an associated certification process that a person or system must pass for the vessel to be approved for operational use by the fleet. According to

Navy guidance, the Navy uses certification as a tool to help ensure that ships and sailors are ready to safely and effectively operate vessels.

A key effort for uncrewed maritime systems is converting certifications previously completed by the crew into certifications that are executed by software before the vehicles can be used for military operations, according to Naval engineers. Navy officials told us that there is ongoing work to develop certifications for uncrewed maritime systems, but it will take several years to complete these efforts. While Navy officials told us that they are working to develop the certifications, they added that gathering data from the operation of current prototypes is necessary to inform this process.

However, we found that the prototyping plans for the systems do not include the level of detail needed to inform this process. For instance, in the MUSV prototyping plan, the Navy describes the various certifications the system will need, such as transportation, safety, and information assurance, among others. Yet, the plan provides no additional detail on how the Navy will use the prototypes to work toward developing these certifications. Similarly, in a LDUUV prototyping document completed April 2021, the Navy stated that it will leverage certification expertise gleaned from similar programs and projects, but this document does not identify any specific milestones related to certification development. In addition, the prototype document recognizes the need for certifications related to cybersecurity and safe integration with a submarine but does not identify how the Navy will develop the identified certifications or other components for the LDUUV related to autonomy. Without an understanding of all needed certifications or how the Navy plans to use the LDUUV prototypes towards meeting and developing certifications, there could be a delay in progressing the LDUUV because of unplanned work.

By reflecting additional details on safe and effective prototype operations in the prototyping plans for the uncrewed maritime systems, the Navy can better understand how prototyping can inform certification development and better ensure that it will have the knowledge it needs before making design and fabrication decisions that rely on these details. For example, if Navy engineers must make changes to a system to meet a certification requirement after fabrication is complete, these changes could delay uncrewed maritime systems' availability to the fleet. Further, if the Navy does not know what safety standards it needs to meet, it will not be able to use valuable prototyping time to work toward achieving these developmental milestones.

Conclusion

The Navy has identified uncrewed maritime systems as an important affordable capability for future warfare. However, the Navy has yet to develop a basic cost estimate for these capabilities and, therefore, does not know how these efforts fit in with future ship planning. This is critical as the Navy is likely to face continued budget pressure as it attempts to build up its fleet. Portfolio management offers the Navy an approach to optimize its uncrewed maritime systems by balancing resources across multiple efforts and linking its efforts to its strategic objectives. However, if the Navy maintains its current approach of managing these systems through its divided portfolios that were not intended to share resources, it will likely continue to make investment decisions that minimize the importance of the digital infrastructure necessary to operate these vehicles. This divided approach is also unlikely to help the Navy achieve the collective objectives it set for its uncrewed maritime system efforts.

Moreover, the Navy is unlikely to fully realize the benefits of prototyping because it has yet to develop: (1) evaluation criteria to measure the readiness of prototypes to enter into acquisition, (2) schedules that demonstrate how prototype efforts align with key investment decisions, and (3) prototype plans that illustrate how the Navy intends to mature technology and achieve certifications. If the Navy does not implement these practices, it may not get the most of the billions of dollars it is investing in these prototypes and would also likely begin future uncrewed acquisitions with more risk than planned.

Recommendations for Executive Action

We are making the following seven recommendations to the Department of the Navy:

- The Secretary of the Navy should provide Congress with a cost estimate that includes the full scope of known costs to develop and operate uncrewed maritime systems—including estimated costs for operations and sustainment as well as the digital infrastructure—and develop an approach to refine this estimate over time as part of its next shipbuilding plan. (Recommendation 1)
- As the Secretary of the Navy considers potential reorganization of the management of uncrewed maritime systems as required by law, it should establish an uncrewed maritime systems portfolio and assign an entity with the responsibility for overseeing this portfolio in line with portfolio management best practices and define the role of key stakeholders. (Recommendation 2)
- The Secretary of the Navy should provide details about how it intends to achieve its uncrewed maritime system strategic objectives. Such information should include measures and metrics, as well as a planned process to assess the Navy's progress toward achieving its stated objectives in line with portfolio management best practices. (Recommendation 3)
- The Secretary of the Navy should develop evaluation criteria for assessing each uncrewed prototype effort's readiness to transition to an acquisition program. (Recommendation 4)
- The Secretary of the Navy should develop a master planning schedule to include each uncrewed maritime system effort. This schedule should establish when the Navy plans to purchase and prototype each vehicle as well as when it plans to achieve desired capabilities, including the digital infrastructure. (Recommendation 5)
- The Secretary of the Navy should revise the prototyping plans for each uncrewed maritime system to incorporate how it plans to use its prototyping efforts to mature technologies to achieve top level requirements. (Recommendation 6)
- The Secretary of the Navy should revise its prototyping plans for each uncrewed maritime system to incorporate how it plans to use information gained from prototyping to develop certifications that apply to uncrewed maritime systems prior to investment decisions. (Recommendation 7)

Agency Comments and Our Evaluation

We provided a draft of our report to the Navy for comment. The Navy's written comments are reprinted in Appendix III of this report. The Navy generally concurred with all seven recommendations, but some of the actions that it plans to take in response to three recommendations would not fully address the issues that we discuss in this report. GAO maintains that fully implementing all recommendations is warranted.

In response to our first recommendation, the Navy agreed to develop a full cost estimate. Further, the Navy stated that uncrewed maritime systems should not be included in the battle force inventory of ships.

We interpret the Navy's response to mean that it does not plan to provide an estimate of the full costs of uncrewed maritime systems in shipbuilding plans. As the Navy's response states, it does not plan to complete a cost estimate until it is required to do so by acquisition policy. As such, the cost of the Navy's uncrewed maritime portfolio will remain unaccounted for in shipbuilding plans in the near term because the Navy has yet to establish a timeline for transitioning these efforts to acquisition programs. Regardless of whether uncrewed ships are a part of the battle force inventory, the Navy's shipbuilding plan is required to have an estimate of the operations and sustainment costs, among other costs, for the ships that will be delivered under the plan. Given that operations and sustainment costs are such a large portion of a shipbuilding program's total cost, the Navy cannot fully assess the affordability of uncrewed maritime systems without an estimate of these costs.

In response to our second recommendation, the Navy stated that it has designated the Unmanned and Small Combatant program executive office as the executive agent responsible for the acquisition of autonomy, as required.

However, the Navy's response does not address gaps in the governance of the entire uncrewed maritime system enterprise, including research, acquisition, and operations, as discussed in the report. Specifically, the Navy's uncrewed maritime programs remain divided across the surface, undersea, and warfare integration offices within the Office of the Chief of Naval Operations—since these are the offices that determine how the Navy allocates resources. Further, the Navy did not address how the Unmanned and Small Combatant Program Executive Office will improve collaboration with the science and technology community. As we discuss in the report, an essential element of portfolio management is empowering a governance structure that is responsible for the collective decision-making process and can direct Navy investments in uncrewed maritime system efforts to ensure that they achieve their collective objectives. The Unmanned and Small Combatant office, even as the executive agent for autonomy, still will not have the ability to make decisions and direct investments for the entire portfolio of uncrewed maritime efforts.

In response to our third recommendation, the Navy requested that we remove the recommendation because, stating that it overlaps with our fourth through seventh recommendations.

We disagree with the Navy's response because the third recommendation focuses on the Navy's strategic objectives, as outlined in its Unmanned Campaign Framework. The Navy's proposed actions are focused on each separate effort rather than the collective whole. As we discuss in the report, a key element of managing a portfolio is establishing strategic objectives and measuring progress towards achieving them for the entire uncrewed maritime effort. Without measuring its progress towards its strategic objectives, the Navy will likely continue to miss opportunities to manage risk and allocate resources across its uncrewed maritime portfolio.

The Navy agreed with our fourth through seventh recommendations.

DOD and the Navy also provided technical comments that we incorporated as appropriate.

Systems and Cost Effectiveness Modeling of Unmanned Systems Product Lines for Acquisition

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Abstract

This research investigated the systems and cost-effectiveness of unmanned system product lines to improve both the acquisition processes and warfighter's capabilities. Historically defined as the probability that a system can successfully meet an operational demand within a given time when operated under specified conditions, system effectiveness is the ability of a system to do its intended job. Traditionally applied to a single system acquiring DoD systems with overlapping capabilities are most economically acquired as integrated product lines. Therefore, more relevant measures are needed to evaluate product lines and similar systems of systems. Cost-effectiveness measures a system in terms of the cost of system effectiveness and its ability to fulfill the intended mission and total lifecycle cost (LCC). The LCC can be expressed in different ways depending upon specific mission or system parameters under evaluation. The "constructive product line investment model framework" (COPLIMO) applies to performing product line cost estimation and investment analysis. Initially oriented for software product line development, it is now a general framework for system product lines consisting of software, hardware, or combined elements. The Cost model is adaptable for different product types, processes, and estimation relationships necessary to cover unmanned systems. The cost model accomplishes this by employing product-specific parametric cost models to improve estimation fidelity versus using average assumptions. The overall model sums the software and hardware component estimates derived from their detailed cost models. The results of a student capstone report are the focal point of the paper.

Executive Summary

This research investigated the systems and cost-effectiveness of unmanned system product lines to improve both the acquisition processes and warfighter’s capabilities. Historically defined as the probability that a system consistently meets an operational demand within a given time when operated under specified conditions, system effectiveness is the ability of a system to do its intended job. Traditionally applied to a single system acquiring DoD systems with overlapping capabilities are most economically acquired as integrated product lines. Therefore, more relevant measures are needed to evaluate product lines and similar systems of systems. Cost effectiveness measures a system in terms of the cost of system effectiveness and its ability to fulfill the intended mission, and total lifecycle cost (LCC). The LCC can be expressed differently depending upon specific mission or system parameters under evaluation. The constructive product line investment model framework (COPLIMO) applies to performing product line costs estimation and investment analysis. Initially oriented for software product line development, it is now a general framework for system product lines consisting of software, hardware, or combined elements. The cost model is adaptable for different product types, processes, and estimation relationships necessary to cover unmanned systems. The cost model employs product-specific parametric cost models to improve estimation fidelity versus using average assumptions. The overall model sums the software and hardware components estimates derived from their detailed cost models.

By way of background, unmanned underwater vehicles (UUVs) are advanced, versatile systems procured by the U.S. Department of the Navy (DoN) for use by forward-deployed forces. During and in conflict regions, UUVs are deployed singularly or within Smart Warfighting Array of Reconfigurable Modules (SWARM) configurations. Missions requiring UUVs can vary from surveillance of an area to an area-specific payload delivery. Missions may be conceptually different but still require similar capabilities. For example, in a surveillance mission, the UUV must be able to navigate to the point of interest. This requirement is also true when delivering a payload to the point of interest. Likewise, the requirement to autonomously navigate to a specific location is true across both missions. Designing system requirements for reusability across different missions yields increasing savings in systems engineering (SE) labor by including more missions in the reuse portfolio. If the baseline UUV mission SE requirements incorporate design for reuse, the initial labor investment will increase. However, the Constructive Systems Engineering Cost Model (COSYSMO) shows that if enough requirements and interfaces are reusable across different missions, this initial investment will have a high return (ROI) return.

Interest in UUV platforms is expanding as technologies advance while resources become increasingly constrained. Identifying and implementing SE artifact reuse across UUV missions is critical in determining potential cost savings. COSYSMO provides an industry-validated means to compare program SE LOEs while incorporating the reuse of SE artifacts. The student work investigated multiple essential system requirements and interfaces to identify and provide ROI estimates for support across district missions by UUVs developed via a product line approach to SE. The investigation of reusable system requirements and interfaces for UUVs identified efficiencies in applying a product line method to the SE process across different missions. The research determined, employing COSYSMO analysis, whether it is advantageous to develop reusable requirements and interfaces for an initial UUV mission and then reuse or delete those requirements for follow-on missions. Metrics for this analysis are in terms of SE labor. Ultimately, calculating an ROI for reuse versus independent development efforts determined if the investment was lucrative or not.

The DoN requires nine primary missions: Intelligence, Surveillance, and Reconnaissance (ISR); Mine Countermeasures (MCM); Anti-Submarine Warfare (ASW); Inspection and Identification (INID); Oceanography (OO); Communication or Navigation Network Node (CN3); Payload Delivery (PD); Information Operations (IO); and Time Critical Strike (TCS).

The initial step was to identify and compare requirements for each mission for similarity across missions. A systems modeling approach defines the necessary actions and interfaces required for each mission. MBSE System Modeling Language (SysML) diagrams created using Innoslate MBSE software (Innoslate) represent each independent UUV mission's action, inputs, outputs, and requirements. From the models created, requirements and interfaces will be defined and input into COSYSMO. Outputs from COSYSMO will contain the total level of effort (LOE) needed, in person-months (PM), to perform the SE for each mission. COSYSMO will provide LOEs for independent and reuse mission SE artifact development. ROI assessment enables an informed decision on whether to invest more initially to receive savings later. COSYSMO results provided data for ROI. Program managers and sponsors can use ROI values to make informed investment decisions to develop cross-program and ultimately DoN-wide cost savings. Implementation of SE artifact reuse does not have to stop with the DoN but can expand to include all DoD UUV mission development efforts.

The students referenced the COSYSMO output against current programs of record for accuracy, and the person-month labor estimates were found to be in the correct range. Based on the COSYSMO analysis, the students recommended investing extra labor during the first mission's SE process to design all requirements and interfaces for reuse. Further, they recommend using the ISR mission as the base design reference mission. UUV missions contain similar system requirements and interfaces across the portfolio of missions. For example, UUVs must inherently be deployable, autonomous navigators, situationally aware, capable of communications, recoverable, and replenishable. Finally, the students recommend further investigation into alternate baseline missions. The students believe that analyzing each mission as a baseline could lead to more significant ROIs. For example, utilizing the mission with the most significant number of system requirements as a baseline may lead to greater reuse of requirements. Conversely, the students note that the result could increase deleted requirements. Developing a COSYSMO 2.0 analysis with each mission as the baseline would yield potential alternate results or further solidify the philosophy of using ISR as the reuse baseline.

Research Focus

The research investigates the potential benefits of using a product line approach for the SE of the nine main UUV missions in [3]. The specific questions this research intends to address are: 1. What are the activities, interfaces, and requirements of each of the nine UUV missions? 2. What are the complexities of the identified requirements and interfaces? 3. What is the optimal baseline mission for SE artifact reuse? 4. What is the reusability of the baseline mission's SE artifacts for the remaining missions? 5. What are the LOEs for each mission's development using traditional and reuse methods? 6. What is the ROI for applying a product line approach to the UUV mission SE efforts? 7. Does operational modularity duplicated across UUV missions save on SE labor costs when the original system is designed for reuse, while still satisfying UUV demands?

Thesis Methodology

Nine UUV missions will be evaluated from the Concept of Operations (CONOPS) statements in [3]. The process will begin with modeling each mission in Innoslate to generate MBSE diagrams. The architecture model will follow SysML, which is a common language used in support of illustrating hierarchies and ontologies [8]. The MBSE diagrams will consist of activity, interface, and requirement diagrams of key mission-driven systems for all nine UUV missions. Comprehensive requirements will be derived from the activity and interface diagrams. The requirements and interfaces will be classified as one of three defined complexities, *Easy, Nominal, Difficult*, and input to COSYSMO to determine the LOE required to develop the SE artifacts for each mission using the traditional siloed development approach. The architecture breakdown of mission profiles will support classifying each and every requirement and interface within a mission [5]. Then the ISR mission will be selected as the reuse baseline. SE artifacts will be categorized into defined reuse levels: *New, Designed for Reuse, Modified, Deleted, Adopted, Managed* [6]. All ISR mission SE artifacts will be designated as *Designed for Reuse*. SE artifacts will be compared across missions and duplicates identified. For example, for a reconnaissance or a bottom survey mission, the sensor package, propulsors, and material types will be cross-utilized to provide a common cost and product line solution for both missions. The resulting database of classified requirements and interfaces will be input into version 2.0 of COSYSMO producing values that can be compared with those for traditional development. The resulting LOEs will be used in ROI calculations determining the benefit of utilizing the identified reuse relationships across the nine UUV missions. The primary deliverable for this research is the analysis that identifies a cumulative ROI showing the additional benefit gained from each mission added to the portfolio.

Thesis Assumptions

The following assumptions were held throughout this thesis and supporting research and analysis. They served to both bound the analysis and provide a stable base of reference in a diverse and dynamic space. Their presentation order implies neither importance nor significance.

- The CONOPS provided in [3] describe the UUV missions with uniform accuracy, depth, and detail.
- The SysML diagrams capture all required activities, systems, and interfaces from the CONOPS.
- Requirement extraction from the SysML diagrams was consistent across missions.
- Interface definition was consistent across missions.
- Requirement and interface classification for both complexity and reuse was consistent across missions.
- SE artifact complexity does not change from mission to mission.
- All missions are performed by a medium class UUV.
- The ISR mission is the best reuse baseline for the nine-mission portfolio.
- COSYSMO will reasonably predict UUV program development efforts.
- The CONOPS in [3] were generalized such that decomposition of the extracted requirements to the “sea level” [9] would introduce an unreasonable level of subjectivity in the requirement definition and classification.

Reducing Asymmetry in Countering Unmanned Aerial Systems

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Abstract

Current Counter Unmanned Aerial Systems (C-UAS) rely heavily on low-efficiency techniques such as broadband radio frequency (RF) jamming and high-intensity lasers. Not only do such techniques come at the cost of second and third order effects—such as collateral jamming risks to operational systems, a large RF footprint, and high energy use—but they also present an asymmetry between threat and response. Many commercial, off-the-shelf UAS devices are inexpensive compared to the C-UAS systems historically under focus in Department of Defense (DoD) acquisition. This work argues for leveling that asymmetry by exploring C-UAS autonomy-on-autonomy options by using cyberattack payload capabilities residing on a UAS. By reducing the attack surface to focus on a particular target, these cyber techniques provide scalpel-edged control to the operator, reducing risk to own systems, RF footprint, and collateral damage.

Keywords: UAS, C-UAS, electronic warfare, cyber, secure acquisitions, advancement of military operations

Introduction

In the past decade, unmanned aircraft systems (UAS) have proliferated on the battlefield, giving technologically inferior combatants an advantage over their more sophisticated and numerically superior competitors. This was never more evident than in 2014 when ISIS used consumer UASs to surveil and target coalition forces during fighting in Raqqa, Syria (Almohammad & Speckhard, 2017). Then in the 2017 battle to retake the city of Mosul, the terrorist group leveraged their Facebook and Twitter presence to record and post jaw-dropping videos of their ambushes using UASs retrofitted with grenades (Warrick, 2017). Several years later, the 2020 Nagorno-Karabakh War between Armenia and Azerbaijan further demonstrated the need for robust short-range air-defense to counter-unmanned aircraft systems (C-UAS) when the numerically inferior Azeri military dismantled the Armenian army and destroyed over 350 armored vehicles (Sukhankin, 2021a, 2021b). More recently, Ukraine achieved remarkable success against the Russians using the same tactics and equipment as the Azeris (Perrigo, 2022). These examples show how poor and technologically inferior combatants can employ inexpensive technology in a sophisticated manner to negate an opponent's center of gravity.

This is telling given what is known about asymmetric warfare: By engaging in a war of asymmetry, where an actor's interests and political vulnerability are inversely proportional, strong actors are more likely to lose opposite approach interactions (Arreguin-Toft, 2005). Taking the lessons from Ivan Arreguin-Toft's research as well as the initial results of the American war in Afghanistan, it is clear that the best way for a stronger combatant to counter asymmetry is by taking an indirect approach of their own.

		Weak Actor Strategic Approach	
		Direct	Indirect
Strong Actor Strategic Approach	Direct	Strong Wins	Weak Wins
	Indirect	Weak Wins	Strong Wins

Figure 13. Strategic Approach Model. (Arreguin-Toft, 2005; Figure 3)

In this work, we consider the current C-UAS approach and technologies and assert that instituting a constellation of aerial security patrols tasked with UAS interdiction will provide installation commanders a more robust method for countering the asymmetric threat posed by UASs. Networking stand-in electronic warfare (EW) and cyber-attack devices provides a layered perimeter to augment the current systems with persistent deterrence that mimics the security patrols used in modern defensive operations.

This paper will begin with a discussion on what makes a modern defense-in-depth approach successful, then move onto a more technical discussion on electronic warfare and cyber-attack methods. Additionally, this paper will cover the countermeasures currently in procurement by the Department of Defense (DoD) and the Department of Homeland Security (DHS). Finally, this paper will conclude with two example scenarios in which this framework could be adopted by the DoD and DHS acquisition communities to create the most effective means of countering unmanned aircraft.

Defense-in-Depth

Marine Corps Warfighting Publication 3-01, *Offensive and Defensive Tactics*, defines a defensive operation as "an operation conducted to defeat an enemy attack, gain time, economize forces, and develop conditions favorable to offensive or stability operations" (U.S. Marine Corps, 2019). Defensive operations create the conditions that allow a friendly force to recover and regain operational initiative by denying an enemy's access to vital areas or by eroding an enemy's ability to concentrate firepower in an attack. While there are myriad defensive positions to analyze, they are designed to defend-in-depth using a main engagement area, a support area, and a security area where forward positioned troops gather information and interdict the enemy. In the example shown in Figure 1, the defenders use the perimeter defense to give 360-degree coverage of a vital asset, which in the case of C-UAS would be the defense of a military base or installation.

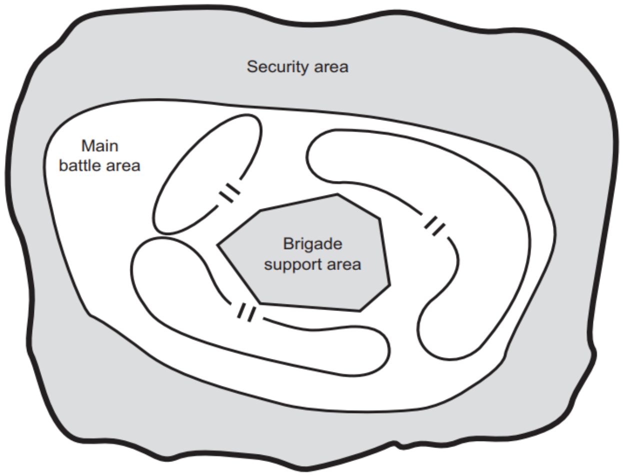

Figure 14. Sample Perimeter Defense (Figure 9-1; U.S. Marine Corps, 2019)

Defensive operations are characterized by maneuver, preparation, flexibility, mutual support, and surprise to disrupt an adversary's attack momentum. In a defense-in-depth, this is achieved by engaging the enemy at the earliest opportunity with security forces as well as moving reserve and fire support units to a position of advantage (U.S. Marine Corps, 2002). This gives the defense a buffer against an attacker's main thrust, ensuring the attacker commits their forces in piecemeal fashion, and preventing them from massing firepower where they intend.

In the context of defending infrastructure against adversarial UAS, the goal of the defense is to maintain normal operations without interruption or degradation from an attack. Given that most bases and critical infrastructure in the continental United States have defined physical perimeters with restricted operating zones for aircraft to fly in and out of, the main engagement area in the C-UAS fight becomes a matter of procedure based on local environmental restrictions (Air Land Sea Application Center, 2019). In defensive operations, this engagement area development establishes control measures and trigger lines to outline specific weapons and actions to be taken given a set of circumstances. These escalation of force procedures are well-defined for human incursions onto a military facility, yet they remain immature in the C-UAS fight.

In the planning process for carrying out defense-in-depth, the Marine Corps teaches its officers seven steps of engagement area development (U.S. Marine Corps, 2017). One of the first actions taken is to gain depth in the battle space by launching security patrols to interdict would-be attackers. These security patrols are designed to increase the situational awareness of the ground force commander and are given with several guiding principles: observe, report, and protect against enemy infiltration or ambush (U.S. Marine Corps, 2000). This may, or may not, require a security patrol to engage the enemy kinetically, making it an essential tool for the successful execution of a ground commander's mission.

This begs the question, why is there not a similar process for defending U.S. bases and infrastructure against adversarial UASs? We believe the answer is that there has yet to be a serious incursion or multi-wave attack using only unmanned systems. The current method for defending military installations and critical infrastructure from UAS incursions mirrors the static defense of forts and castles rather than the maneuverable defenses of the 21st century. If defensive positions are supposed to be designed for maneuver and flexibility, a defense in the current C-UAS landscape is anything but. Instead of adhering to traditional escalation of force procedures, the current C-UAS architecture uses the most capable weapons first, like the CACI Skytracker (Pitsky, 2021) and Anduril Sentry Tower (Anduril, 2021) first. As a metaphor for defensive operations, this is more akin to opening fire with crew-served weapons instead of beginning an engagement with security patrols and harassing fires. Ultimately, the lack of defensive layers allows an attacker increased mobility to target the defender's most lethal assets.

With an understanding of the current systems and how they match, or do not match, customary planning guidance, the DoD and DHS should incorporate the concept of aerial security patrols into the C-UAS framework. To fully realize this, friendly unmanned platforms can be terrestrially or aerially deployed to act as patrols, giving installations a forward presence to assist in the full gamut of C-UAS kill-chain actions. Because many of the kill-chain functions can be offloaded and stripped away to the main sentry tower, these C-UAS devices can be modular and customizable enough to meet the form, fit, and function of the host device.

Electronic Warfare in the C-UAS Kill-Chain

To limit collateral damage and to increase effectiveness in countering unmanned systems, the DoD and DHS have focused their efforts on the non-kinetic electronic warfare technology built by Anduril, CACI, Sierra Nevada Corporation, and Lockheed Martin. Electronic warfare has three subcomponents: electronic attack, electronic support, and electronic protection, the first two being the most important to the purpose of this paper. Electronic support in C-UAS consists of the techniques conducted in the first three steps of the kill-chain, "Detect, Track, and Identify," while electronic attack consists of the techniques to "Mitigate" an adversarial UAS. This section will primarily focus on the electronic attack techniques contained within radio frequency (RF) jamming.

RF jamming is designed to sever the communication link between a UAS and its ground control station (GCS) by injecting substantial amounts of electromagnetic energy, referred to as noise, into a receiving antenna (Parlin et al., 2018). Uplink jamming disrupts the receiving antenna of the target UAS, while downlink jamming interferes with the receiving antenna of the GCS (Lichtman et al., 2016). Uplink and downlink jamming can be accomplished by two types of jammers: stand-off and stand-in. Stand-off jammers are devices that exist among friendly forces, typically employed as terrestrial or aerial platforms (e.g., the MADIS and EA-18G Growler). Stand-off jammers are notorious for consuming copious amounts of power to overcome the free-space path loss associated with their use. Stand-in jammers exist amongst their targets but must be located closer to their target, requiring a host-device or person to decrease the distance to their target (Brown et al., 2007).

RF jamming, also referred to as noise jamming, uses a jamming carrier signal modulated with a random noise waveform to disrupt the communication by inserting Gaussian noise into the receiver. The bandwidth of the jamming signal can be as wide as the entire spectrum width used by the target or as narrow as a single channel (Poisel, 2011). The former refers to broadband, full-band, or barrage jamming to place noise energy across the entire width of the frequency spectrum used by the target. This technique is useful against all communications by placing the jammer between an adversary's communication links. To mitigate fratricide, directional antennas are used to avoid interference with friendly communications in the same frequency band (Stutzman & Thiele, 2013). Because broadband jamming generates a signal like broadband noise, the jamming power is lowered to meet the needs of the entire frequency band. Additionally, since broadband jamming raises background noise levels, it can attack the synchronization and tracking processes of the communication scheme it is going after (Poisel, 2011). It may be obvious, but the primary limitation with broadband jamming is its inefficient consumption of power, which necessitates a large system size, and the likelihood to inflict unintentional collateral damage to adjacent communication systems.

Communications engineers are constantly designing and employing techniques to lower the probability of communications detection (LPD), interception (LPI), and exploitation (LPE), while expanding access to multiple users (Sklar, 2001). This led engineers and system designers to spread spectrum signal modulation techniques through two primary techniques: Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS; Sklar, 2001). Both FHSS and DSSS are considered “anti-jam” communications schemes because they vary the frequencies used, use time hopping, and implement narrow-beam antennas to put the jammer at a significant disadvantage.

However, just because the signal has anti-jam properties does not mean the signal is impervious to disruption. This is due to the notion that the intelligibility of information transfer can be sufficiently degraded by partial jamming (e.g., jamming only 30% of a voice transmission degrades the transfer; Poisel, 2008). Therefore, to negate anti-jam properties, a jammer can use an unmodulated carrier signal centered on the transmitting frequency that can be modulated with tone signals or with a variable-bandwidth noise signal. These tones are placed on specified frequencies identified from prior target knowledge to raise the noise floor and prevent signal reception (Poisel, 2011).

The goal of jamming a communications signal is no trivial matter. In seeking to deny reliable connection between two hosts, there are significant tradeoffs made with the jamming device’s size, power, antenna, and development cost. To make matters harder, the spread spectrum techniques seek to create jam-resistant waveforms to “force a jammer to expend its resources over a wide-frequency band, for a maximum amount of time, and from a diversity of sites” (Sklar, 2001).

The most efficient means of jamming FHSS signals is with a follower jammer where only a portion of each dwell is jammed, meaning the jammer must ascertain the newly detected energy and determine if it is the correct signal to jam (Poisel, 2011). A follower jammer is best employed with a specific protocol in mind and with significant reverse engineering of the intended signal. *Protocol aware* or *smart jamming* algorithms then become the most effective way to jam a signal without deleterious effects to the surrounding environment by disrupting portions of a digitized signal based on their necessity to deny the intended communications link. This requires extensive synchronization and knowledge about the target signal to track the timing and phase of the transmitted signal. Another major limitation in protocol aware jamming is the time delay from initial signal acquisition to predicting the next frequency the signal hops to—this is done in milliseconds, and the frequency hopping pattern can be non-deterministic (Poisel, 2011).

Historically, RF jamming has been the most common C-UAS mitigation technique and is limited by terrain, weather, equipment cost, and potential disruption of friendly and civilian devices (Wang et al., 2021). Due to the clutter in the frequency bands where most UAS communicate, RF detection and mitigation becomes incredibly complicated. The LPD, LPI, and LPE characteristics of FHSS and DSSS signals enable them to hide amongst the background clutter, making it harder for attackers to identify and disrupt signals of interest. Many modern devices are hardened against rudimentary RF jamming techniques, which has led to new jamming techniques and high-power consumption that increase complexity of the C-UAS device.

It should be reiterated; regardless of which RF jamming technique is used, there is a requirement for substantial amounts of power which increases the physical parameters of a system. This has a detrimental effect on the form, fit, and function of a modular payload to interface with other systems. Additionally, RF jamming has negative effects on the other sensors integrated on a host aircraft. Because of the collateral damage and SWaP considerations, integrating RF jamming on manned and unmanned aircraft becomes a more complex problem to solve (Brown et al., 2007). As drones continue to operate in commonly utilized frequency bands and in urban environments, high power output and digital signal processing will continue to be the norm.

Profiling Current C-UAS Technology

Size, weight, power, and development cost are among the many constraints that companies developing C-UAS technology have to contend with. These companies must design systems that not only work properly—a technological feat in and of itself—but they must also contend with societal and legal limitations as well. In a 2019 survey on current drone technologies, the authors identified 537 C-UAS technologies designed to counter unmanned aircraft through kinetic or non-kinetic actions (Michel, 2019). Despite the market density, the main trend of this study showed that unmanned countermeasures are getting increasingly bulky and expensive to procure and sustain, while the targets they are supposed to thwart are only getting smaller and more expendable. The asymmetry in threat versus countermeasure is much like the asymmetry in tactics and strategy. Thus, where such asymmetry exists, reducing asymmetry can be achieved through rethinking the problem. This leads to an inflection point where the SWaP requirements of a host device and non-kinetic electronic warfare and cyber-attack techniques can be utilized to mitigate threats from small UASs.

Figure 15. C-UAS Kill Chain (Figure 3-1; Patel & Rizer, 2019)

For the purposes of understanding the C-UAS kill-chain, the technology used in detecting, locating, and classifying UAS can be parsed separately from the mitigation measures. The digital signal processing required for the first three-quarters of the kill-chain are the most complex problems for C-UAS companies to tackle because of a UAS's low-energy output physical characteristics that make them appear as small birds. Companies like CACI and Anduril have created robust platforms to meet the needs of the first three-quarters of the kill-chain by building target libraries to help in building digital signal processing and computer-vision algorithms for their sensor packages.

Static, ground-based C-UAS sites are typically employed aboard military bases, secure facilities, and other strategic points of interest. Because they have access to shore power, they contain the most robust suite of countermeasures, integrating most sensor types with several mitigation methods. Additionally, these systems can have an autonomous mode that allows the platform to move through the kill-chain with a human-on-, -in-, or -out-of-the-loop. Unfortunately, these platforms require enormous amounts of shore power to operate the various sensor packages onboard (Wang et al., 2021). Additionally, because they are in static positions, they become easier targets for adversaries to attack or sabotage. Lastly, because the sensors on fixed and terrestrial sites use the high-end solutions, they are extremely expensive to acquire, maintain, and sustain throughout their product life cycle (Wang et al., 2021).

Ground-based, mobile platforms are designed to be mounted on vehicles and operated while moving. Depending on the transportation vehicle, they can be very capable in austere environments by carrying a modest amount of power and sustainment before needing to return to base for rest and refit. However, despite their mobility, these C-UAS systems like the Marine Air Defense Integrated System (MADIS), built by Sierra Nevada Corporation and Lockheed Martin, have several glaring limitations (Barrett, 2019). First off, they are human operated which requires extensive operator training on the system. Second, because they are general-purpose EW systems, the ground-based mobile systems require significant amounts of power that have a large RF signature. This power consumption means that the ground-based, mobile C-UAS cannot conduct persistent sensing without nearby resupply. Third, they are extremely expensive. The MADIS is a $150 million program of record, and as it seeks to bring in more capabilities, it will increasingly become more expensive (Missile Defense Advocacy Alliance, 2020). Finally, because the MADIS is expensive, bulky, has significant power requirements, and contains sensitive equipment, it must be carefully protected. Loss of such an aerial defense system could itself be catastrophic, such as the fate of the Russian surface-to-air missile convoy under Ukrainian Bayraktar TB-2 attack (Ukraine Armed Forces, 2022).

Handheld C-UAS systems are operated by a single individual or team of individuals. The Dedrone DroneDefender is a good example of a lightweight handheld system that resembles a small arms weapon with highly directional antennas (Dedrone, n.d.). The handheld devices are cheaper than the fixed, mobile, or UAS-based devices. Additionally, the low power and portability of these systems gives another advantage over their larger counterparts; handheld systems can jam an entire frequency band with minimal collateral damage to friendly communications farther afield because of signal attenuation over longer distances. However, there are downsides to the lower power settings. Namely, they only operate on one or two frequency bands and lack a smart library, necessitating a broadband jam of the 2.4 or 5.8GHz frequency bands. They are only effective over shorter distances to a target, and the broadband jamming can lead to the unintended disruption of friendly or civilian communications nearby. Thus, in high-density electromagnetic spectrum environments like airports and border crossings, using the DroneDefender becomes precarious. Finally, even though they are more portable than their mobile or fixed counterparts, handheld systems are still bulky and unwieldy; Dedrone's DroneDefender weighs 15.8 lb, making it a cumbersome piece of gear for operators to carry for sustained periods of time. The DroneDefender is a fine piece of equipment for the close-in fight where collateral damage does not matter, but at high altitudes, it fails to be effective against adversarial aircraft.

Table 1. Pros and Cons of Current C-UAS Technology

	Current Systems	Current C-UAS Pros	Current C-UAS Cons
Ground to Air	MADIS Compact Laser Weapon DroneDefender CACI Skytracker Anduril Sentry Tower Shotguns	Mobility Small Form Factor Handheld Purpose-Built for COTS UAS Exquisite AI Backbone Close-Range	High-Power Consumption Easily Disrupted BBN Jamming Only Fixed Position Expensive Potential Fratricide
Air to Air	Nets Anduril's Anvil Explosives	Capture Target Kinetic Kill w/o Fratricide Target Destruction	Short-Range Extensive Flight Path Metrics Damages Friendly Device

By and large, the current systems procured have met the needs of the DoD and DHS for the initial wave of UAS usage. The systems have proven records of operational success around the world and will continue to work well against singular incursions like the ones experienced over the past decade. However, as this section has noted and Table 1 summarizes, there are serious limitations associated with the current technology. Therefore, it is necessary to look to the past to the initial stages of aerial warfare and how we might introduce the same lessons learned to countering unmanned aircraft.

Cyber

Cyber mitigation measures are the ultimate complement to traditional electronic attack mitigation measures like RF jamming. Instead of putting broadband noise into the ether like broadband noise jamming, cyber-attacks offer a scalpel's edge approach to C-UAS. Because UASs operate using the same digital modulation principles as terrestrial information systems, they are also vulnerable to the same attacks conducted over the past few decades. While there are inherent technical limitations to each cyber-attack technique, this methodology typically requires less power because of the *a priori* knowledge about an information system. Second, cyber-attacks lower the risk of collateral damage to surrounding infrastructure. And finally, because there are lower SWaP requirements in comparison to RF jamming, delivering cyber-attacks against adversarial UASs from a friendly UAS becomes reality. This section will discuss cyber-attack techniques that gained prominence in the past two decades and how the attacks can be used to target UASs.

A Man-in-the-Middle (MITM) occurs when an adversary intercepts the communication between two communicating devices, allowing the attacker to alter or obtain information in the exchange (Conti et al., 2016). This attack compromises the integrity, confidentiality, and access control of a given security scheme without ever notifying the server or the client. By subverting access controls and intercepting the communications, an attacker can subsequently alter and manipulate the information transmission between devices at their discretion – including hijacking a target or spoofing Global Navigation Satellite System (GNSS) navigation (Common Attack Pattern Enumeration and Classification [CAPEC], 2021). Figure 4 represents an impersonation attack where Eve maliciously spoofs messages (i.e., sends forged messages to Bob, who believes he is speaking with Alice). Meanwhile, Alice cannot regain connection to Bob because Eve has blocked her ability to communicate.

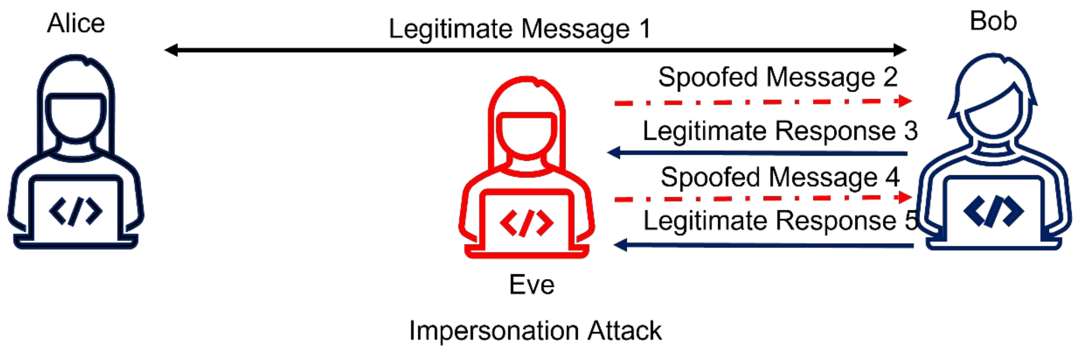

Figure 16. Impersonation Attack

According to the CAPEC, a cyber-attack community resource operated by the government-contracted MITRE Corporation, a MITM has the following prerequisites: first, two entities must be communicating with insufficient cybersecurity protections, allowing an attacker to eavesdrop on the communication exchange with or without the target's knowledge. Second, there is a lack of sufficient mutual authentication between the targets giving way to attacker interposition. From this point, an attacker can subsequently manipulate the actions of its target (CAPEC, 2021). Given that a MITM is reliant upon the exploitation of protocol or system vulnerabilities, it can be viewed as more of an end state vice an attack vector, as seen in Figure 4. In this figure, Eve is the MITM seeking to intercept the network traffic between Alice and Bob. Once Eve can establish a network connection either between her targets or spoofing one to the other, she can then conduct a variety of attacks, including the hijacking of the network traffic.

While much different from a MITM, Denial-of-Service (DoS) protocol attacks such as UDP (CERT Division, 1997) and TCP/SYN floods (CERT Division, 2000) or deauthentication (Bellardo & Savage, 2003) attacks can be an integral part of achieving that end state. Both the UDP and TCP/SYN flood are examples of DoS attacks that are more effective when multiple systems are used as sources of attack traffic (Douligeris & Mitrokotsa, 2004). This creates a Distributed-DoS (DDoS) using computers and other networked devices to create a surreptitious botnet that prevents normal communications from occurring as planned (Mirkovic & Reiher, 2004). Both flood attacks are easy to carry out using open-source tools like Low-Orbit Ion Cannon (Nagpal et al., 2015) or hping3 (Sanfilippo, 2006) to flood a target server with TCP or UDP packets to disrupt the service connection. DDoS attacks gained particular prominence in the late 2000s and early 2010s when the hacktivist group Anonymous used these vulnerabilities to shut down the service connections at Visa and Mastercard after the payments companies removed their support for the WikiLeaks website (Olson, 2012). The DDoS is particularly sinister if implemented properly, as this type of attack is unpreventable and can only be mitigated through firewall strengthening and filtering protections.

GNSS spoofing is an attack method where a spoofer generates a counterfeit signal for each authentic signal received to distort the relative true location of a target in favor of a counterfeit location that is more favorable for the spoofer (Kerns et al., 2014). For an attacker to sufficiently exert control of a target device via GNSS spoofing, the attacker must capture the GNSS signal of interest dynamically or through *a priori* knowledge. GNSS spoofing requires the insertion of a MITM but can be especially effective in negating an adversary's use of waypoints for UAS movement and control.

The cyber-attack techniques outlined in the preceding paragraphs provide a baseline for attack vectors against adversarial UASs. To make this a fully realized effort, a library of attacks is needed specifically designed to mitigate the threats posed by commercial UASs and integrated with a menu of options on a user interface. This interface could be fully automated, giving the operator-on-the-loop a common operating picture of local threats and actions taken that the operator needs to be alerted to.

While this was only lightly touched on in the introduction, cyber-attacks notably consume less power than RF jamming. Each attack type exploits a different protocol vulnerability than the other and, while some can be patched easily, many UAS manufacturers continue to design and build UASs with known vulnerabilities. For many consumers, a fully optimized product at a low price point is more important than data privacy and security. The cyber-attack techniques discussed in this section are not meant to be a one-size-fits-all approach like RF jamming, but instead they are meant to give a variety of attack solutions for escalation of force procedures in countering unmanned systems.

Progression of Counter-Aerial System Development

In aerial defense for standard enemy aircraft, there has been a historic progression where ground-based anti-aircraft artillery was avoidable by aircraft use of the wider airspace (obstacles or altitude) until aerial interdiction patrols were introduced to either intercept the enemy or force them into lower altitudes and the kill-zone. The flexibility afforded by aircraft designed for air-combat extended the effectiveness of a defense.

Thus, it is easy to extend this same natural progression to aerial combat with unmanned systems. Whereas we currently use centralized, ground-based systems, the right type of friendly UASs using low-SWaP payloads could make aerial interdiction patrol and improved airspace control a reality. Instead of designing only general-purpose EW platforms like the MADIS, Sentry Tower, and Skytracker, the DoD and DHS can develop a suite of aerial interdiction platforms designed for purpose-built EW and cyber-attacks. Just as aircraft have specific mission sets, the same should be said for C-UAS. There is a reason the A-10 does not do the job of the F-22 or vice versa. While the A-10 can fight against an aerial threat, it does not have the speed, maneuverability, or weaponry like the F-22 to fight effectively. Similarly, the F-22 is not designed for the close-air support afforded by the A-10's 30mm Gatlin gun (Air Combat Command, Public Affairs Office, 2020).

The maneuverability afforded by decentralization of technology is essential to counteract the current centralized methods. Instead of static towers with limited or no mobility, networking a family of mobile devices designed to tackle each subset of the C-UAS problem leads to maneuverability. For example, an airborne C-UAS device designed to fit in the payload bay of a fixed-wing Group 2 UAS can effectively mitigate enemy UASs for over 24 hours by overcoming the signal attenuation that occurs in ground-to-air systems like the Sentry Tower, MADIS, and DroneDefender.

Case Study – Defending a Hydro-Electric Power Facility

Example Scenario

Consider the following case study of defense of a hydro-electric power facility on the Pacific west coast as the target.

Begin Scenario

At the hydro-electric facility, the guard on watch receives notification from the northeast tower's radar sensor that there is a 95% chance of the presence of multiple UASs moving at 20 miles per hour towards the tower. A few seconds later, the guard receives another notification, this time of 10 UASs flying at 25 miles per hour[15] directly at the southwest tower located on the dam's primary entryway. The guard has a system of typical and current mitigation measures available at his disposal via a display. The display shows a heterogeneous swarm operating on the 2.4 GHz band. Due to the swarms' rapid speed and multi-directional attack, the guard chooses to jam the entire 2.4 GHz band using the northeast and south tower's omnidirectional antenna suites.

The jamming effect causes the UAS devices to act as if they have hit an invisible wall – a few collide and drop out of the sky, and the swarm stops in place and continues to hover. At this point, several more UASs self-land. Meanwhile, back at the command center, the guard receives an updated situation report from his heads-up display, showing the targeted UASs returning to their point of origin, causing the guard to assume that the system is working. As the jamming system resets and the guard is about to send in a report on the attack, the tracking system identifies another UAS swarm approaching the southwest tower, this time operating on the 5GHz band. Since the system is resetting, the guard is unable to re-start the broadband jam, and the UAS deliver shape charge after shape charge to the walls of the dam, causing explosions along the dam's center. As the guard contacts local authorities to inform the need for evacuation, the dam bursts, and tens of thousands of tons of water pour out.

The dam finally disintegrates, and power immediately goes out in the nearby metropolitan city as well as significant parts of the surrounding region because of their reliance on the power generated by the dam. Airplanes trying to land in the city airport lose connection with the air traffic control station, and while the ground crews work to get the backup generators operational, many flights are diverted. The larger aircraft can make it to other airports, but smaller planes with dwindling fuel supplies are forced to find open clearings for emergency landings in the heavily wooded Pacific Northwest.

After the UAS attack, large-scale physical infrastructure damage is identified, including roads, power grids, buildings, and the dam itself. Power loss disrupted businesses, transport, and security systems. Moreover, back-up generator functionality does not cover the months needed to restabilize power, leading to power grid blackouts and interruptions in normal operations. In comparison, the entire attack was executed by low-cost commercial devices.

Example Scenario (New Version)

In the ensuing scenario, we will revisit the same attack, but the C-UAS protections are enhanced with a security patrol of UASs armed with drone hijacker devices.

Begin Scenario

At the hydro-electric facility, each tower was augmented with a new type of UAS security patrols: drone hijackers ("Alphas"). This was a significant upgrade in the defense as the Alphas are deployed forward of the sentry towers on a patrol schedule and can receive mid-flight updates from the towers to guide their attack methods. Additionally, given their

[15] Data-sheet for Intel Drone Light Shows states current max speed up to 17 m/s (38 mph; Intel, 2021)

small form-factor and low power consumption, the Alphas can patrol for an hour apiece, giving the watch officers a persistent presence to augment the sentry towers.

The guard on watch receives notification from the northeast tower's radar sensor that there is a 95% chance of the presence of multiple UAS moving at 20 miles per hour towards the tower. A few seconds later, the guard receives another notification, this time of 10 UASs flying at 25 miles per hour directly at the southwest tower located on the dam's primary entryway. The guard's display shows a heterogeneous swarm operating on the 2.4 GHz band. Due to the swarms' rapid speed and multi-directional attack, the guard chooses to deploy the Alphas against the approaching swarm for mid-air interdiction. The guard reserves the capability to jam the entire 2.4 GHz band using the northeast and south tower's omnidirectional antenna suites as a back-up.

The Alphas begin to issue a flood of UDP packets and deauthentication frames. As with the centralized system, the two swarms function as if they have hit an invisible wall and a few drop out of the sky, and the swarm stops in place and continues to hover. Several more UASs begin to-self land.

Meanwhile, back at the command center, the guard receives situation updates from his heads-up display showing several UASs dropping out, and the guard assumes the system is working. As the guard is about to send in a report on the attack, the tracking system identifies another UAS swarm approaching the southwest tower. The guard sends an updated instruction set to the Alphas before activating the jamming system, sending RF noise out of the tower's omnidirectional antennas to broadband jam the entire 5 GHz band. The new UAS swarm stops, and the Alphas take a forward position for preemptively mitigating any new incoming threats. In the ensuing 10 minutes, a ground team is dispatched and captures five suspects on all-terrain vehicles carrying several large briefcases filled with small UASs and explosives.

Framework Comparison and Conclusion

In summary, the current framework, while sufficient for the C-UAS fight in the late-2010s and early 2020s, will likely be outpaced by emerging drone technologies in the coming decades. More specifically, when drone swarms become more readily available, they will increasingly be a threat to critical infrastructure and military installations. The proposed ground-to-air C-UAS systems under development by Northrup Grumman (2020) and other defense industrial base companies may be necessary additions for the high-end C-UAS fight. However, there are inherent technical limitations to overcome using terrestrial systems, creating an opportunity to use UASs as aerial interdiction platforms. Designers of aerial C-UAS systems should focus on the technological advancements of the past three decades and develop low-size, weight, and power (SWaP) EW and cyber-attack techniques for UAS mitigation. While we recognize (and Table 2 represents) the limitations with UASs as stand-in EW and cyber-attack platforms, these aerial systems offer flexibility and maneuverability on the battlefield with a targeted interdiction to overcome the limitations of ground-based technologies. Finally, the lack of interference from telephone poles, trees, and buildings affords aerial systems the ability to extend the operational range of non-kinetic countermeasures. With an aerial variant, this operational range is only limited by the output power of the transmitting C-UAS device, which can be varied by using host power or its own power source.

Table 2. Pros and Cons of Future C-UAS Technology

	Future Systems	Future C-UAS Pros	Future C-UAS Cons
Ground to Air	AFRL NINJA	Reliability, Fully Funded	Bulky
	MADIS/FWS	Mobility	High-Power Consumption
	Inter-Networked Systems	Small Form Factor	Easily Disrupted
	mmWave Directed Energy	Handheld	BBN Jamming Only
Air to Air	Autonomous Stand-in Hijackers	Usurp Control of Target	Requires Target RE
	Cryptographic Protocol Attacks	Precision	Requires Target Profile
	DDoS Attacks	Effective against Swarms	Spreading Complexity
	Stand-in GNSS Jammers	Easier to Implement	Attack Profile Modification
	Stand-in RF Jammers	Close Proximity to Target	Potential Communication Fratricide

Current systems and methods for countering UAS have found many successes in the past decade. However, because the Sentry Tower, Skytracker, and MADIS are terrestrial systems, they only provide limited robustness and depth as a solution set. Additionally, the research and development of C-UAS emerging technologies fails to address the asymmetry posed by UAS threats. Instead of getting smaller and cheaper, tomorrow's directed energy weapons and lasers are increasingly expensive to build, manufacture, and sustain over the product life cycle.

Thus, reconsideration of C-UAS methods and how such systems are procured and integrated within the DoD and DHS is advised. By developing a family of networked systems that focuses on cyber-attack methodologies, the current systems on hand will be able to withstand a multi-wave and multi-frequency attack. The use of UASs during the ISIS insurgency, in the Nagorno-Karabakh war, and in the Ukrainian conflict prove that any state, or non-state, actor with modest funding can build an air force to cripple their adversary. The framework proposed herein seeks to address and mitigate that asymmetry by leveraging the technological expertise and intelligence of the defense industrial base.

References

Air Land Sea Application Center. (2019). *Multi-service tactics, techniques, and procedures for air and missile defense*. https://armypubs.army.mil/epubs/DR_pubs/DR_d/ARN15491-ATP_3-01.15-000-WEB-1.pdf

Air Combat Command, Public Affairs Office. (2020, December). *A-10C Thunderbolt II*. Air Force. https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104490/a-10c-thunderbolt-ii/

Almohammad, A., & Speckhard, A. (2017). *ISIS drones: Evolution, leadership, bases, operations and logistics* (ICSVE Research Reports). International Center for the Study of Violent Extremism. https://www.icsve.org/isis-drones-evolution-leadership-bases-operations-and-logistics/

Anduril. (2021). *Anduril—sentry tower* [Defense technology]. https://www.anduril.com/hardware/sentry/

Arreguin-Toft, I. (2005). *How the weak win wars: A theory of asymmetric conflict*. Cambridge University Press.

Barrett, B. (2019, July 22). The Marines' new drone-killer aces its first test. *Wired*. https://www.wired.com/story/iran-drone-marines-energy-weapon-lmadis/

Bellardo, J., & Savage, S. (2003, May 16). *802.11 Denial-of-service attacks: Real vulnerabilities and practical solutions*. 12th USENIX Security Symposium, USENIX Security 2003, Washington, D.C. https://www.usenix.org/legacy/events/sec03/tech/full_papers/bellardo/bellardo_html/

Brown, K., Drake, S., Mason, K., Piotrowski, A., & Swierkowski, L. (2007). A distributed stand-in EW hunter-killer system. *2007 10th International Conference on Information Fusion*, 1–8. https://doi.org/10.1109/ICIF.2007.4407985

CERT Division. (1997). *CA-1996-01: UDP port denial-of-service attack* (CERT Advisory REV-03.18.2016.0; 1996 CERT Advisories). Carnegie Mellon University Software Engineering Institute. https://resources.sei.cmu.edu/asset_files/WhitePaper/1996_019_001_496172.pdf#page=123

CERT Division. (2000). *CA-1996-21: TCP SYN flooding and IP spoofing attacks* (CERT Advisory REV-03.18.2016.0; 1996 CERT Advisories). Carnegie Mellon University Software Engineering Institute. https://resources.sei.cmu.edu/asset_files/WhitePaper/1996_019_001_496172.pdf#page=123

Common Attack Pattern Enumeration and Classification (CAPEC). (2021). *CAPEC-628: Carry-off GPS attack* (CAPEC Report CAPEC-628). The MITRE Corporation. https://capec.mitre.org/data/definitions/628.html

Conti, M., Dragoni, N., & Lesyk, V. (2016). A survey of man in ththeiddle attacks. *IEEE Communications Surveys Tutorials*, *18*(3), 2027–2051. https://doi.org/10.1109/COMST.2016.2548426

Dedrone. (n.d.). *Data sheet—DroneDefender counter-UAS device*. Retrieved January 3, 2022, from https://gdmissionsystems.com/-/media/General-Dynamics/Ground-Systems/PDF/Counter-UAS---Dedrone/DroneDefender-DataSheet.ashx?la=en&hash=516300C425D3CDA5C69CBAD29C1886EEFD9EA54A

Douligeris, C., & Mitrokotsa, A. (2004). DdoS attacks and defense mechanisms: Classification and state-of-the-art. *Computer Networks*, *44*(5), 643–666. https://doi.org/10.1016/j.comnet.2003.10.003

Intel. (2021). *Intel drone light show premium fact sheet*. https://inteldronelightshows.com/wp-content/uploads/sites/3/2021/01/Intel-Drone-Light-Show-Premium-Fact-Sheet-23112020.pdf

Kerns, A. J., Shepard, D. P., Bhatti, J. A., & Humphreys, T. E. (2014). Unmanned aircraft capture and control via GPS spoofing. *Journal of Field Robotics*, *31*(4), 617–636. https://doi.org/10.1002/rob.21513

Lichtman, M., Jover, R. P., Labib, M., Rao, R., Marojevic, V., & Reed, J. H. (2016). LTE/LTE-A jamming, spoofing, and sniffing: Threat assessment and mitigation. *IEEE Communications Magazine*, *54*(4), 54–61. https://doi.org/10.1109/MCOM.2016.7452266

Michel, A. H. (2019). *Counter-drone systems* (2nd ed.). Center for the Study of the Drone, Bard College. https://dronecenter.bard.edu/files/2019/12/CSD-CUAS-2nd-Edition-Web.pdf

Mirkovic, J., & Reiher, P. (2004). A taxonomy of DdoS attack and DdoS defense mechanisms. *Association of Computing Machinery*, *34*(2). https://doi.org/10.1145/997150.997156

Missile Defense Advocacy Alliance. (2020, July 8). *Marine air defense integrated system (MADIS) – Missile Defense Advocacy Alliance*. Missile Defense Advocacy Alliance: U.S. – Air Defense, Intercept. https://missiledefenseadvocacy.org/defense-systems/marine-air-defense-integrated-system-madis/

Nagpal, B., Sharma, P., Chauhan, N., & Panesar, A. (2015). DDoS tools: Classification, analysis and comparison. *2015 2nd International Conference on Computing for Sustainable Global Development (INDIACom)*, 342–346.

Northrup Grumman. (2020, July 8). Defining possible against unmanned aerial systems [Defense contractor]. *Counter Unmanned Aerial Systems (C-UAS)*. https://www.northropgrumman.com/what-we-do/land/counter-unmanned-aerial-systems-c-uas

Olson, P. (2012). *We are anonymous: Inside the hacker world of LulzSec, Anonymous, and the global cyber insurgency*. Little, Brown. https://books.google.com/books?id=ncGVPtoZPHcC

Parlin, K., Mahtab Alam, M., & Le Moullec, Y. (2018). Jamming of UAV remote control systems using software defined radio. *2018 International Conference on Military Communications and Information Systems (ICMCIS)*, 1–6.

Perrigo, B. (2022, March 1). Ukraine's secret weapon against Russia: Turkish drones. *Time*. https://time.com/6153197/ukraine-russia-turkish-drones-bayraktar/

Pitsky, P. (2021). *SkyTracker® technology suite* [Defense contractor]. CACI. https://www.caci.com/sites/default/files/2021-06/F424_2106_Corian%20Flyer.pdf

Poisel, R. (2008). *Introduction to communication electronic warfare systems* (2nd ed.). Artech House, Inc. http://pws.npru.ac.th/sartthong/data/files/Introduction%20to%20Communication%20Electronic%20Warfare%20Systems.pdf

Poisel, R. (2011). *Modern communication jamming principles and techniques* (2nd ed.). Artech House, Inc.

Sanfilippo, S. (2006). *Hping*. Hping. http://www.hping.org/documentation.php

Sklar, B. (2001). *Digital communications: Fundamentals and applications* (2nd ed.). Prentice Hall Professional Technical Reference.
Stutzman, W. L., & Thiele, G. A. (2013). *Antenna theory and design* (3rd ed.). John Wiley & Sons, Inc.
Sukhankin, S. (2021a). The Second Karabakh War: Lessons and implications for Russia (Part one). *Eurasia Daily Monitor*, *18*(2). https://jamestown.org/program/the-second-karabakh-war-lessons-and-implications-for-russia-part-one/
Sukhankin, S. (2021b). The Second Karabakh War: Lessons and implications for Russia (Part two). *Eurasia Daily Monitor*, *18*(7). https://jamestown.org/program/the-second-karabakh-war-lessons-and-implications-for-russia-part-two/
Ukraine Armed Forces. (2022, February 27). Байрактари в роботі. Наші оператори ювелірно криють колони ворожих військ. Знищено російський БУК в районі Малина Житомирської області. Бійтеся, вороги! Не буде вам спокою на нашій землі! Https://facebook.com/100068564836091/posts/257372956558197/ https://t.co/dH2UEUbKST [Twitter]. *@ArmedForcesUkr*. https://twitter.com/ArmedForcesUkr/status/1497997019515961347
U.S. Marine Corps. (2000). *Marine Corps warfighting publication 3-11.3: Scouting and patrolling*. Headquarters Marine Corps.
U.S. Marine Corps. (2002). *Marine Corps warfighting publication 3-1: Ground combat operations*. Headquarters Marine Corps.
U.S. Marine Corps. (2017). *Rifle platoon in the defense B3J0435XQ student handout*. The Basic Officers Course, Marine Corps Training Command.
U.S. Marine Corps. (2019). *Marine Corps warfighting publication 3-01: Offensive and defensive tactics*. Headquarters Marine Corps.
Wang, J., Liu, Y., & Song, H. (2021). Counter-unmanned aircraft system(s) (C-UAS): State of the art, challenges, and future trends. *IEEE Aerospace and Electronic Systems Magazine*, *36*(3), 4–29. https://doi.org/10.1109/MAES.2020.3015537
Warrick, J. (2017, February 21). Use of weaponized drones by ISIS spurs terrorism fears. *The Washington Post*. https://www.washingtonpost.com/world/national-security/use-of-weaponized-drones-by-isis-spurs-terrorism-fears/2017/02/21/9d83d51e-f382-11e6-8d72-263470bf0401_story.html

PANEL 8. CONTRACTING STRATEGIES FOR DIVERSE NEEDS

Wednesday, May 11, 2022	
12:30 p.m. – 1:45 p.m.	**Chair: Major General Cameron G. Holt, USAF,** Deputy Assistant Secretary, Contracting, Office of the Assistant Secretary of the Air Force for Acquisition, Technology and Logistics ***Challenging Industry to Innovate! How the Government Can Apply Transparency, Collaboration, Unencumbered Communication, and Dynamic Engagement Through Challenge-Based Acquisition*** Vanessa McCollum, Defense Information Systems Agency Justin Raines, MITRE Corporation Ryan Novak, MITRE Corporation Kasey Pugh, DISA Citizens' Broadband Radio Service Adam Bouffard, MITRE Corporation Craig Carlton, Defense Information Technology Contracting Office ***Emergency Contracting: Themes from Agencies' Disaster and Pandemic Response Efforts*** Janet McKelvey, US Government Accountability Office Marie Mak, US Government Accountability Office Meghan Perez, US Government Accountability Office ***DOD Has Increased Its Use of Fixed-Price Incentive Contracts, but Is It Getting Better Outcomes?*** Julie Clark, US Government Accountability Office

Major General Cameron G. Holt, USAF—is the Deputy Assistant Secretary for Contracting, Office of the Assistant Secretary of the Air Force for Acquisition, Technology and Logistics, Washington, D.C. He is responsible for all aspects of contracting relating to the acquisition of weapon systems, logistics, and operational support for the Air Force and provides contingency contracting support to the geographic combatant commanders. He leads a highly skilled staff of mission-focused business leaders supporting warfighters through $825 billion of Space, Global Power/Reach and Information Dominance programs. He also oversees the training, organizing and equipping of a workforce of some 8,000 contracting professionals who execute programs worth more than $65 billion annually.

Prior to this assignment, General Holt served as the Commander, Air Force Installation Contracting Agency, Office of the Assistant Secretary of the Air Force for Acquisition, Wright-Patterson Air Force Base, Ohio. He led an over 700 personnel agency with a total contract portfolio of $55 billion. In this capacity, he directed enterprise-wide installation strategic sourcing efforts for the Air Force and oversaw $9.1 billion in annual obligations for mission and installation requirements.

General Holt received his commission through the ROTC at the University of Georgia in 1990. He has experience in the full spectrum of acquisition and contract management across four major commands, Headquarters U.S. Air Force, U.S. Air Forces Central Command and the Joint Staff. General Holt is a joint qualified officer with multiple deployments in support of Operation Enduring Freedom.

Challenging Industry to Innovate! How the Government Can Apply Transparency, Collaboration, Unencumbered Communication, and Dynamic Engagement Through Challenge-Based Acquisition

Vanessa McCollum—is DISA's Chief, Emerging Technologies, Special Interest Contracts and Pricing Division, where she leads a division of 70 contracting professionals and oversees a contract portfolio exceeding $13 billion. Vanessa served in the Air Force for 22 years and holds a bachelor's degree in management from Park University and a master's in procurement and acquisition with a minor in computer resources and information management from Webster University. She is Contracting Level III certified, holds a certified professional contract manager certification from NCMA, and is Level II cyber procurement certified. [vanessa.a.mccollum.civ@mail.mil]

Justin Raines—is a Principal Decision Analyst at the MITRE Corporation, where he assists government teams to develop effective acquisition strategies. His work focuses on developing innovative capability and industry communication in order to improve product delivery and meet national priorities. He is a former Air Force acquisition program manager with extensive experience in nontraditional procurement strategies, challenge-based acquisition, market research, and strategic planning. Justin holds a bachelor's from the United States Air Force Academy and a Master of Public Policy from the University of Maryland. [jraines@mitre.org]

Ryan Novak—is currently an Acquisition and Contracting Strategist with over 24 years of achievement and leadership experience in the areas of contracting, acquisition, negotiation, strategic purchasing, consulting, project and program management, and innovation. He has achieved acquisition success and executed acquisitions for 20+ civilian agencies, the DoD, and the intelligence community. Novak is a 1996 USAFA graduate and a former contracting officer with unlimited warrant. He has DAWIA Level III certification, an MBA, a master's in strategic purchasing and project management, and is co-department head for MITRE's Center for Acquisition and Management Sciences Acquisition Department. [rnovak@mitre.org]

Kasey Pugh—is the Lead Systems Engineer for the DISA Citizens' Broadband Radio Service (CBRS) program and responsible for the effective execution of the DISA 3550-3650 MHz Transition Plan. He has extensive experience working within standards bodies collaborating with a wide variety of commercial companies. Through the TARDyS3 initiative, he has established a DSO DevSecOps software factory enabling rapid, secure software development and deployment. Kasey holds a bachelor's in electrical engineering from the University of Central Florida. [Kasey.A.Pugh.civ@mail.mil]

Adam Bouffard—is a Group Leader and Lead Contracts and Acquisition Analyst for MITRE. He has over 16 years of experience in acquisition and contracts supporting multiple DoD and civilian government agencies. Prior to joining MITRE in 2015, he worked as a civilian supporting Naval Sea Systems Command and Office of Naval Research. He has a master's in systems engineering from The George Washington University and has multiple contracts certifications. [abouffard@mitre.org]

Craig Carlton—is an Other Transaction Authority (OTA) Agreements Officer and a Contracting Officer with the Defense Information Technology Contracting Office (DITCO), located at Scott Air Force Base, IL. He serves as the OTA Team Lead for the Defense Information Systems Agency (DISA). His duties include the obligation, issuance, and administration of DISA's complete portfolio of OTA agreements. Craig also serves as an advisor to DITCO's Chief of Emerging Technologies, Special Interest Contracts & Pricing Division on OTA-related initiatives. [craig.j.carlton.civ@mail.mil]

Abstract

The Defense Information Systems Agency (DISA) Telecommunications Advanced Research and Dynamic Spectrum Sharing Systems (TARDyS3) program demanded new ideas and novel approaches for sharing electromagnetic spectrum between the Department of Defense and commercial industry. To solve this problem, DISA created an acquisition structure that focused on

building transparency, collaborating, and actively communicating with industry across the entire acquisition. This focus on dynamically engaging vendors and encouraging innovation allowed DISA to rapidly deploy high-quality and user-approved capabilities. Dynamic engagement involves a two-way exchange of ideas, listening to industry by seeking input, and conveying the government's ideas and motivations to potential vendors, while innovation centricity consists of encouraging vendors to solve problems with unique solutions, providing a framework for future acquisitions. Dynamic engagement, coupled with innovation centricity, powerfully engages the vendor community to solve hard problems. Combining innovation with communication creates a vendor community that is motivated to meet the government's needs, and it accelerates risk mitigation. Furthermore, it can improve product quality and shortens delivery time lines at a reasonable price. For these reasons, future programs should consider incorporating dynamic engagement and innovation-centric approaches at the core of their acquisition strategies.

Introduction

Government acquisition can be slow, arduous, and illogical at times. While information expands and technology evolves exponentially, U.S. acquisition processes generally cannot keep pace with advances in technology. This is the classic problem. When government agencies follow the standard acquisition processes, often by the time they field a solution, the capability has already become outmoded. The enemy has adapted to the capability involved, the threat has changed, and/or the technology has advanced past this late-to-the-field capability. As Vice Admiral Jeffrey Trussler has stated,

> I don't think we keep up with the industry opportunities. We write requirements and we send them out, let industry compete. But boy, that's an unsatisfying process sometimes when we have trouble taking advantage of and seeing opportunity because we didn't identify it as a requirement. (Tadjedeh, 2021)

Challenge-Based Acquisition (ChBA), as guided by the ChBA handbook, offers a better way to meet government and end user needs (Roe et al., 2020).

From an innovation perspective, government acquisition processes generally lack dynamic engagement; that is, other than the occasional question-and-answer session, they often involve little meaningful exchange of ideas between the government and industry. Moreover, acquisitions can fail to motivate vendors to bring their best innovations to bear on the government's problems. Steve Blank (2019) stated, "These processes reduce risk to an overall organization, but each layer of process reduces the ability to be agile and lean and—most importantly—responsive to new opportunities and threats." He is right on this point.

In many acquisitions, vendors read the government-authored solicitation that often stipulates all aspects of the solution to be built through a tightly confined performance work statement (PWS) or statement of work (SOW). The government selects the best builder on paper, not the vendor with the best, most innovative, highest impact solution; often, vendors simply regurgitate the government-authored SOW in their proposals to increase their likelihood of award. This standard acquisition process often represents an exercise that reflects who can best follow directions, offer a predictable method of building the pre-articulated solution, and show success in past projects. This is not how we acquire goods and services in our private lives; it should not be how the government acquires solutions for complex defense problems, either. Consider how most people purchase a vehicle. They want to understand the options available and get the opinions of others who own similar cars—that is, conduct market research. They would take a test drive—that is, try out the vehicle in an operational environment—and evaluate how well it meets their needs.

The same applies to defense acquisitions. The Department of Defense (DoD) needs an acquisition model that focuses on dynamic engagement and innovation, allowing the government not only to balance risk but also see the full span of solution sets. The DoD needs to be able to test drive solutions. The Telecommunication Advanced Research and Dynamic Spectrum Sharing Systems (TARDyS3) program, leveraging ChBA and dynamic engagement, offers an example of how to do this.

This paper describes the TARDyS3 project, its innovations, and its unique acquisition approach in a way that enables other programs to emulate TARDyS3. After describing the basics of the TARDyS3 project, the authors discuss acquisition strategy enablers that set the baseline for success. The paper then provides nine detailed methodologies that supported TARDyS3 dynamic engagement and innovation outcomes. In addition to providing a model for the future, this paper also provides discrete actions that can be taken by any program to enhance its dynamic engagement and innovation-centric approach.

Sharing Spectrum: DISA's Unique Need

In TARDyS3, the Defense Information Systems Agency (DISA) needed to devise a way for the DoD to actively share electromagnetic spectrum with commercial fixed and mobile broadband network operators in the 3550–3650 megahertz (MHz) band without modifying the DoD systems already operating in that band. Moreover, the DoD solution needed to integrate with the efforts of the commercially driven Citizen Broadband Radio Service (CBRS), which incorporated other external systems for managing commercial spectrum operations. Specifically, TARDyS3 needed to provide the tools that permit complex sharing arrangements, thereby enabling DoD to schedule operations and conduct interference analysis and resolution activities. This work was unprecedented within DoD. Given the complex spectrum sharing ecosystem, DISA needed a radically new set of tools to deconflict, manage, and predict spectrum interference. Thus, before acquiring a solution, DISA needed to better understand both the problem space and potential solution sets. Industry-driven innovation was critical to overall acquisition success. Dynamic communication made it happen.

TARDyS3: An Innovation Theory

DISA's unique spectrum sharing needs consciously drove an engagement-focused and innovation-centric acquisition approach. Before initiating any acquisition activity, DISA hypothesized and envisioned an acquisition that dynamically engaged industry partners and encouraged innovation by being transparent with and by actively collaborating with industry. To test this hypothesis, DISA drove these themes of *dynamic engagement*, which involves both listening to industry by seeking input and communicating with industry to express DISA's views, and *innovation centricity*, which involves encouraging vendors to solve problems by applying unique solutions into every facet of the acquisition.

The TARDyS3 acquisition team started by defining what the team wanted to avoid. Often, the acquisition process leaves industry guessing when solicitations will be released, the type of contract vehicle the government will use, the final requirements, and how the government will evaluate bids. Industry scrambles to solve the problem when the government releases the solicitation. TARDyS3 sought to break this cycle with industry and be as open as possible regarding the requirements, the program goals and intentions, the chosen acquisition process, and the chosen solution. The goals included (1) ensuring that industry would be well informed so it could deliver the best possible solution and (2) giving industry the maximum freedom to innovate.

From Theory to Reality

With TARDyS3, DISA took informed risks to try a new approach and test its hypothesis regarding dynamic engagement and innovation centricity. The TARDyS3 team resolved to remain entirely open throughout the acquisition and clearly communicate changes, challenges, and expectations. The team wanted vendors to clearly understand the government's priorities and to help vendors understand how they could compete to win. This led the team to make three initial proposals. First, DISA would conduct an extensive pre-solicitation market engagement campaign that sought industry's technical ideas, informed industry of DISA's plans, and sought industry feedback on DISA's proposed approaches. Second, DISA would solicit for a prototype other transaction (OT) to seek innovative solutions and "fail fast" if the outcomes were disappointing. Third, DISA would use a ChBA to focus the vendor selection process on risk-balanced innovation. In other words, DISA's strategy focused on using transparency and innovation to build trust and understanding. These three proposals became the enablers of success.

The TARDyS3 team implemented a multi-phased ChBA strategy that encouraged innovative solutions through openness and incentivized reasonable pricing through competition. The multi-phased approach emphasized continuous competition that kept offerors focused on improving and maturing their proposed solutions right up until the final award.

Phase 0: Comprehensive Market Engagement

Market research informed the government's decision to use a multi-phased ChBA OT and helped refine the TARDyS3 requirements. Phase 0 began with an abbreviated request for information (RFI) that published the government's proposed TARDyS3 plans and requirements; it requested answers to specific programmatic questions in a white paper format (see Figure 1). The RFI responses established a broad TARDyS3 vendor community, highlighted key risks, challenged the government's assumptions, and highlighted technical uncertainties. Continuously focused on dynamic engagement, the government invited selected vendors whose RFI responses included innovative or interesting ideas to discuss those concepts in virtual one-on-one meetings.

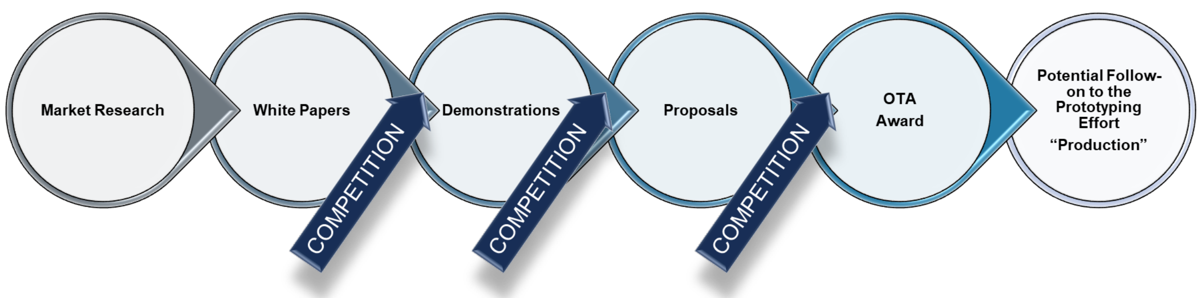

Figure 17. TARDyS3 Competition Process

Also, in the spirit of openness, the government team invited vendors to an "Ask Me Anything" event at which the government program manager fielded vendor questions about the technical and acquisition specifics. At this stage, the government recognized the broad set of skills needed to successfully complete TARDyS3 and used the "Ask Me Anything" session to encourage vendors to begin exchanging contact information. Throughout the market engagement process, the government updated the RFI with additional information, changes, and ideas to assist the vendor community. Twenty-six vendors participated in market engagement.

Phase I: Request for White Papers

The request for white papers (RWP) formally initiated the TARDyS3 solicitation. The RWP included a Statement of Need as the base requirements document to articulate the government's vision of the TARDyS3 end state. (The PWS would be collaboratively built later.)

The RWP deliberately failed to specify an anticipated solution set. Additionally, the RWP included a thorough description of the complete acquisition process, expectations, evaluation criteria, and draft Phase II demonstration scenarios. Thirteen vendors submitted white papers, and as a result of a rapid evaluation, the government invited the most highly rated six vendors to participate in the subsequent phase: challenge demonstrations.

Phase II: Challenge Demonstrations

The selected vendors provided capability demonstrations for six ChBA scenarios. This phase focused on mitigating risk, understanding vendor-driven innovations, and ensuring vendors could deliver workable solutions. The demonstrations asked vendors to address risks that the government identified in white paper responses, articulate a product roadmap, demonstrate software development capabilities, showcase spectrum expertise through a tabletop exercise, demonstrate affordability, and convey other transaction authority (OTA) compliance. Prior to the demonstration days, the government hosted a planning session with industry that allowed the government to describe the ChBA process in detail, enabled vendors to check their technical systems, and invited vendors to ask questions of the government representatives. Following demonstrations, the government invited two vendors to participate in the subsequent project proposal phase.

Phase III: Request for Project Proposals

The final phase invited two vendors to submit project proposals and draft PWSs for evaluation and review. This phase focused on value—ensuring the government could procure the right technical solution at the right price. The government invited vendors to one-on-one collaborative meetings, where they could refine their PWSs and proposal elements. This enabled the two vendors to better understand government concerns and expectations. Evaluations resulted in selection of a single vendor and award of a prototype OT following final negotiations. The government awarded the OT agreement with the expectation that a multiyear production effort could be negotiated with and awarded to the successful vendor upon successful prototype completion.

Enabling Success

Dynamic engagement and industry-driven innovation permeated each acquisition phase, as the government remained open about changes, expectations, and perceived risks. Moreover, dynamic engagement kept the government receptive to industry ideas and technical innovations. The team leveraged three enablers that formed the framework of success and garnered the best possible outcome for TARDyS3: innovative market research, a multi-phased ChBA approach, and OTA agreements.

Innovative Market Engagement Enabler

Market research is essential to acquisition, but it typically involves a "check the box" paper drill with few actionable results. The TARDyS3 dynamic engagement hypothesis drove a completely different market research approach: one focused on transparency, collaboration, and open communication with industry. This involved using RFIs, one-on-one engagements, and multi-vendor meetings to identify acquisition and technical risks, understand the realm of the possible, and seek vendor input on DISA's plans. Moreover, dynamic engagement required DISA to share incomplete plans and discuss ideas even while they were not fully formed. This opened the lines of communication and helped DISA build a rapport with industry that would permeate the process all the way through to award. Information gathered during dynamic engagement helped DISA formulate its acquisition documentation and helped potential vendors better plan their responses to the government's requirement.

Guidance for the Future

- Create a vendor community through market research by actively communicating and developing a common purpose among the large number of interested companies
- Move beyond paper-based market research and talk to vendors; ask questions and let vendors ask the government representatives questions as well
- Focus on program risks, dependencies, and opportunities; let vendor expertise and inputs help the government shape its acquisition
- Share the government's acquisition plans and requirements, even if they are incomplete, and let vendors identify unforeseen risks and incorporate government plans into their response strategies

Multi-Phased ChBA Enabler

The multi-phase down-select process continued to build trust with industry after market research by remaining clear about expectations and making it as easy as possible for vendors to participate. Describing exactly what the government was expecting freed vendors to focus on their technical innovations. The multi-phased approach had the unique advantage of enabling each phase to inform the subsequent phase. Thus, risks identified in one phase could be addressed in the next phase; each down-select gave vendors an opportunity to improve their technical solutions. Instead of leaving vendors to guess what the government really wanted, DISA used this multi-phased approach to communicate clear expectations, objectives, and requirements to vendors. Moreover, the multi-phased down-select maintained a focus on competition, incentivizing vendors to propose their best technical solutions at the most reasonable price.

Guidance for the Future

- Emphasize competition among vendors throughout the acquisition process and provide a constant incentive for vendors to deliver their best technical approaches at reasonable prices
- Communicate expectations of what constitutes a good proposal and how vendors can use their technical insights and innovations to gain a competitive advantage

Other Transaction Agreement Enabler

The TARDyS3 project outcomes were unprecedented within the DoD, and innovative solutions that leveraged new ideas, concepts, tools, and processes were needed. Consequently, the ChBA multi-phased approach resulted in awarding a prototype OT agreement for the TARDyS3. The OT construct required participation from nontraditional defense contractors, which naturally brought innovative thinking into every proposed solution. OTs also had the benefit of adding flexibility and speed to the acquisition process, freeing the DISA team to focus on risk. While maintaining fairness amongst the vendor pool was one of DISA's paramount concerns, the OT framework relieved the government team of the burdens inherent in a standard procurement and enabled rapid vendor down-selects. Finally, the short horizon (in the case of TARDyS3, 1 year) of a prototype OT enabled the government to quickly evaluate success after vendor performance began. As an off-ramp, if needed, DISA could quickly identify a prototype failure and conduct a separate capability acquisition with minimal loss of schedule and resources.

Guidance for the Future

- Use prototype OTs, when appropriate, to inspire vendor innovation, focus government evaluations on risk, and accelerate the acquisition process

The results of the TARDyS3 prototype have direct relevance to enhancing the mission effectiveness of warfighter systems. Without TARDyS3, interference between CBRS and DoD warfighters cannot be predicted, prevented, or mitigated, and mission-critical DoD systems will fail to function, resulting in both training and operational mission degradation. A successful TARDyS3 tool suite prevents mission failures due to spectrum use conflicts and minimizes the impact of spectrum sharing on DoD systems within the affected spectrum band. DISA implemented the acquisition approaches described in the following sections to make it a reality.

Applying Dynamic Engagement and Innovation Centricity

Ultimately, TARDyS3 focused on continuous competition and continuous government/industry engagement. By the time of award, the selected vendor had developed a deep understanding of the TARDyS3 problem space, had matured an innovative solution to the TARDyS3 problem, and had demonstrated a proven capability to deliver products that met the TARDyS3 requirement. Additionally, the government had the confidence that the vendor understood and addressed TARDyS3 risks. DISA applied the following discrete methodologies to TARDyS3, which have broad applicability to future acquisitions.

Building the Right Acquisition Team

Often, acquisitions do not have the luxury of picking the personalities, leadership, and skill sets that make up the team. TARDyS3 did not have this luxury either; however, the team consciously fostered a group of government and Federally Funded Research and Development Center (FFRDC) subject matter experts that functioned as a true partnership. The team consisted of experts with a broad array of skill sets that included innovation, contracting, acquisition, program management, spectrum engineering, software development, cybersecurity, and systems engineering; collectively, this team possessed in-depth knowledge of the government's needs relative to TARDyS3. Moreover, this broadly skilled team could assess a wide scope of industry innovations, which increased the team's willingness to seek and evaluate new technical and process ideas. Team members exchanged constant internal communications through emails, phone calls, and recurring stand-ups. Effective leadership and internal communication ensured members shared a common view of the acquisition's status, understanding of its ultimate goals, knowledge of next steps, and a clear understanding of responsibilities. Furthermore, the team used risk-driven agendas to drive core considerations at each meeting and leveraged peer reviews from external personnel to improve decisions and final documentation as it pushed forward. An evolving risk map drove the team's prioritized workflow. Stated generally, the team had the right people, leadership, and culture. The members thrived on working together, figuring out problems together, and working with one another. This brought success.

<u>Guidance for the Future</u>

- Build a broad technical and functional team that can understand and assess the risks and opportunities driven by industry innovations
- Lead regular synchronization meetings with the acquisition that use risk-based agendas; avoid internal confusion that will often translate into stakeholder and industry confusion

Reducing Risk Across the Program

Throughout the entire acquisition process, to include the market research, the TARDyS3 acquisition team focused on identifying, characterizing, and mitigating programmatic risk. Specifically, in the early market research phases, the team issued an RFI seeking primarily to identify vendors with software development expertise in specific areas relevant to the TARDyS3 requirement. Once it had identified those vendors, the team performed individual one-on-one engagements to discover the key risks that would likely impact the TARDyS3 prototype development. Over the course of the market research phase, the team communicated openly with industry to ensure the TARDyS3 requirement was well understood before DISA issued a formal solicitation.

Following the market research phase, the ChBA process for TARDyS3 offered a dynamic method for the government to evaluate each proposed solution more thoroughly by presenting potential vendors with carefully constructed challenges, asking questions, and engaging in a real-time dialogue to gain a more complete understanding of the proposal and the offeror's ability to meet the technical requirements. It also gave the government an opportunity to see the vendors in action and how each of the vendor teams functioned in both demonstrating against the scenario and answering questions in real time. This identified some vendor teams as very knowledgeable with a deep understanding of the problem space, while showing that others lacked demonstrable understanding beyond what they could capture in a white paper response. This risk-focused approach elevated more-capable vendors.

Additionally, the entire acquisition process provided greater transparency and opportunities for meaningful collaboration between the government and vendors. In particular, during challenges the government was equipped to ask pertinent questions about vendors' solutions, observe how vendors would perform during different scenarios, and provide feedback on the proposed aspects of the solution. Ultimately, the vendors determined to propose the best solutions at the conclusion of challenge events could draw on the government feedback to enhance the final prototype solution, thereby further reducing programmatic risk.

Guidance for the Future

- Collaborate with industry to identify, characterize, and mitigate risk throughout the acquisition
- Structure the acquisition strategy to assess and mitigate identified programmatic risks
- Leverage open discussions in market research to broadly identify and characterize risk

Continuous Acquisition Improvement

Many acquisitions force the procuring agency to specify the complete solution when releasing the initial solicitation. While TARDyS3 defined the high-level outcomes and expectations in its initial RWP, the multi-phase ChBA processes, coupled with dynamic engagement, provided meaningful latitude to improve the acquisition process as it proceeded. DISA learned from one phase to the next, clarified requirements and expectations, and dynamically assessed risks.

The Statement of Need was a living document that DISA continually updated throughout the acquisition process. In particular, DISA learned a great deal about the "art of the possible" after reviewing the innovation-driven white paper submissions. Informed by risk assessments of innovative solutions, active communication with vendors, and consultations with subject matter experts, the TARDyS3 team updated the Statement of Need with important information at the conclusion of challenge demonstrations, vendor collaborations, and the final down-select. These updates significantly increased the likelihood of producing a successful prototype, and they took TARDyS3 to the next level with respect to meeting warfighter needs in this space.

DISA used the Statement of Need to develop evaluation criteria for each phase of the OTA process. Understanding that vendors had considerable leeway to propose unique solutions that would widely vary from vendor to vendor, the Statement of Need and evaluation criteria used in each phase of evaluations allowed the government team to evaluate proposed solutions fairly and equitably. Like the Statement of Need, the evaluation criteria were informed by previous acquisition stages and by the dynamic engagements in those stages. DISA evaluated risks that became apparent in white papers in subsequent phases to drive down its risk exposure. Additionally, the government highlighted the specific areas of evaluation in its communications to the vendors to incentivize risk mitigation throughout the acquisition. By the time the government received final proposals, most of the meaningful technical and business risks had already been addressed and mitigated.

DISA communicated the challenge scenarios early, as drafts in the RWP phase, for offerors to review and get a sense of the acquisition process flow, downstream requirements, and what the government would ask of them. DISA marked these scenarios as drafts, with the intention of modifying them over the course of the acquisition. DISA clearly communicated this to the vendors up front and then used the risks identified in white papers to craft modified challenges. While some scenarios evolved from draft to final, DISA added other scenarios that addressed newly identified risks. To solidify the challenge approach, the team led a transparent back-and-forth question-and-answer (Q&A) session with the vendors in order to answer questions, receive feedback, and modify and/or inject additional information into the scenarios. This enabled the vendors to provide input to the challenge process and enhance their buy-in.

While the government improved its Statement of Need, evaluation criteria, and scenarios as the acquisition proceeded, DISA also gave vendors the opportunity to enhance and refine their solutions through each phase. The flexibility of both the ChBA process and the OTA procurement approach made this possible. The open collaboration between the government and industry, including the clear articulation of risks and opportunities that the government identified in proposed solutions, injected key feedback that enabled vendors to improve their submissions. This directly mitigated risk at each acquisition phase and helped enhance product quality.

In the final stage of the acquisition process, the government held collaboration days with the vendors selected to move forward from the challenge demonstration. The primary goals for these collaboration day events were to refine the work statement that would be used to guide the prototype OT and to ensure that the contractual requirements would enhance, rather than constrain, the vendors' technical approach. During these events, the vendors and the government discussed how each vendor would envision execution of the OTA, and the government worked with the vendors to identify methods of meeting the government's statutory requirements for oversight without constraining the vendors' approach. The vendors and the government continued to discuss and work through programmatic risks during this final stage of the acquisition process. To maintain fairness, DISA gave both vendors an equal opportunity at these collaboration day events to guide the conversation and ask the government as many questions as time would allow. DISA tailored these collaboration days to each vendor, and these events proved critical to ensuring that the contractual requirements written into the prototype OTA enabled program success.

Guidance for the Future

- Use statements of need to encourage outcome-driven innovation
- In multi-phased acquisitions, use the knowledge gained during one phase to inform the subsequent phases; give vendors an opportunity to improve their solutions while the government improves acquisition documents and expectations
- Recognize that transparent and timely communication (e.g., draft documents, expectations of the government are critical to building trust and accelerating the acquisition)
- Communicate risks and opportunities to vendors as often as practicable; give vendors the opportunity to address risks without detracting from the positive elements of their solutions
- Conduct two-way verbal communication and collaboration sessions with industry to reduce risk and improve the acquisition

Requirements Clarification

Clear requirements played a critical role in the overall success of the TARDyS3 multi-phased down-select process and in the prototype development effort to date. DISA communicated clearly and openly with the vendors throughout the entire process so that they could create the best solution possible that met or exceeded the government's needs. The TARDyS3 acquisition demonstrated the importance of effectively communicating the government's selection process and expectations as well as the overall goals of the acquisition. In communicating with vendors, the TARDyS3 team focused on the problem the vendors were trying to solve and the high-level objectives they were seeking to meet with any of the solutions offered.

To provide requirements clarity, the government must have a coherent approach to the acquisition. The TARDyS3 team had to have a full understanding of its goals and the processes ahead. Unless the government fully understood its goals and its method for achieving them, it could not clearly identify the innovative acquisition process flow and the requirements for TARDyS3. This process began with the government writing the OTA authorization form for TARDyS3. While this is a typical part of the process when a government agency considers using an OTA, it represents an outstanding forcing function to assemble the necessary expertise, staff, resources, and so forth, and to clearly articulate the government's objectives.

When beginning communications with industry, DISA answered industry's questions promptly and held logistics days to clearly stipulate expectations as well as one-on-one collaborative sharing sessions. Unlike the typical arms-length relationship, the government and the vendors exchanged free-form questions, sharing their goals, objectives, preferences, and views. The government clearly described the acquisition process and all three phases to the competing vendors from the start so that the vendors knew the detailed process from Phase I through Phase III and the expectations throughout. This type of collaboration and transparency, again, was critical to a successful TARDyS3. DISA set this tone from the very beginning.

Guidance for the Future

- Communicate simply, clearly, and often across the government team and with industry to set expectations and align the effort to the government's objectives
- Engage with industry to allow loosely structured back-and-forth Q&A that builds trust and collective knowledge, since more information and trust improve proposed and delivered solutions

Maintaining Clear Expectations/Early and Consistent End User Engagement

The logistics approach taken for the TARDyS3 OTA effort, from pre-award through post-award was unique in a variety of ways. Generally speaking, industry has longed for much more clarity from the government in the solicitation process, particularly in the area of RFIs and other market sourcing initiatives. In contrast, a highlight of this acquisition was the lucidity in the communications and logistics process. The subsequent paragraphs will note how this approach and methodology maximized the efficiency of the government's use of time and resources with respect to employment, technique, and benefits.

In recent years, stakeholders and shareholders have expressed an ever-increasing frustration with lack of communication about planning, knowledge, areas of responsibility, and expectations during the federal acquisition cycle. The TARDyS3 OTA project employed a methodology that leveraged real-time interaction between the government technical evaluation team and the vendors, rather than the limited communications normally associated with traditional practices. This manifested itself in the multiple forums that the government held with industry throughout the acquisition process. These logistics days allowed the government team to set expectations with industry, communicate changes (such as schedule modifications), and answer questions from industry about the acquisition process.

During the market intelligence gathering process of the OTA procurement, DISA handled meetings with potential vendors in a very open-ended fashion, frequently using events to engage private industry such as “Ask Me Anything” and one-on-one sessions and other activities to promote communications, transparency, and clarity.

The opportunities that vendors gained in pursuing partnerships present perhaps the clearest example of end user engagement during the TARDyS3 OTA procurement process. Even as the team approached Phase II challenges, which were considered the later part of the competition, vendors still had a chance to partner with new nontraditional defense contractors and produce a capability that could potentially serve the best interests of the government. This approach resulted in healthy interaction between parties and increased competition, resulting in a more quality end product.

The ChBA process provided for an efficient use of time and prioritization for both aspiring vendors and the government. From the vendor’s perspective, the open communication between the vendors and the government team allowed industry to convey just enough information about the intended proposed solution, while not compromising the proprietary rights needed to maintain business continuity and competition. At the same time, this approach afforded the government the unique flexibility to configure draft problem sets that it could release to vendors in an open fashion at relatively low operational and informational risk. As a result, the technical evaluation team could tier its assessments appropriately, while vendors could offer their best solutions.

<u>Guidance for the Future</u>

- Notify industry early about the acquisition direction and objectives
- Inspire innovation by configuring the requirement in terms of solving a problem or achieving an outcome. This incentivizes technological advancement and enables agile and adaptable contracting procedures
- Focus on establishing a common understanding with industry on knowledge and best practices. Avoid a high-minded perch that the government holds exclusive expertise. Always look to open pathways for fruitful and worthwhile engagement in both directions

Stimulating Innovation Through Vendor Partnerships

From the beginning, the TARDyS3 team wanted to ensure that the most innovative ideas and approaches were applied to the TARDyS3 requirements. Furthermore, the team wanted to make sure that companies enhanced their solutions with well-rounded partnerships. Specifically, during market research it became clear that many spectrum vendors lacked experience in DevSecOps software development, whereas the software vendors knew little about spectrum management.

The TARDyS3 team created a secure “Match Making” website to help niche and nontraditional vendors present their capabilities to the entire TARDyS3 vendor community. The site allowed companies to register, submit information about their organization, and then review potential partners. Industry was encouraged to use the site to learn about companies that could be potential partners for success in response to the white paper phase of the ChBA multi-phased process. In essence, it allowed those niche and nontraditional companies to publicize their capabilities to other vendors and to identify the teaming arrangements or partnerships to improve their bids. The TARDyS3 team wanted to ingrain in all participating vendors that the government would help to foster collaboration within industry and to provide a bridge in communications. This was one of the first steps taken in making sure the OTA awardee represented a well-rounded team with multiple skill sets.

Guidance for the Future

- Encourage vendors to speak to one another early in the market research process; provide a forum that consciously encourages partnerships among the vendor community

Acquiring Vendors With Multiple Skill Sets

The TARDyS3 acquisition approach focused on and incentivized performance in two areas of expertise. First, vendors would have to apply complex spectrum management skills and a detailed understanding of the operating environment and regulatory framework. Second, vendors would have to apply modern software development approaches that enabled test-driven development, user-centric design, and DevSecOps product delivery.

The team plainly stated these desired outcomes to the vendor community. During market research, the government specifically told vendors that DISA needed both spectrum and software expertise and would evaluate bidders on that basis. To further support these objectives, the government established the website described in the previous section, which focused on enabling vendors to learn each other's capabilities and team with one another.

After DISA received white papers in Phase I of the acquisition, it took two specific steps to ensure that the selected vendor could successfully deliver the requisite skills in spectrum and software. First, the team applied evaluation criteria that focused on the vendors' ability to demonstrate why they would succeed in the next phase: challenge demonstrations. This allowed the team to eliminate vendors that did not show a viable path to applying both spectrum and software knowledge. Second, the government provided specific feedback to vendors that advanced to challenge demonstrations. The team specifically told them about the opportunities and risks that the government had identified and asked them to mitigate those risks in the challenge demonstration phase. This approach allowed vendors with a viable path to applying spectrum and software expertise to refine their approaches and overcome any shortfalls in their applied expertise (through additional partners, changes in their team, etc.).

DISA constructed ChBA scenarios for which demonstrations centered on separate spectrum management and software development challenges. This approach incentivized vendors to build well-rounded teams and innovate in their technical solutions, knowing that successful award would depend on an ability to successfully demonstrate expertise in both areas. In the challenge demonstration phase, vendors exercised those skill sets through their demonstrations and answered questions from the government team that tested their in-depth knowledge of spectrum management and software development. Successful vendor demonstration teams were able to respond to the demands of both scenarios.

Vendors that formed well-rounded teams successfully demonstrated their capabilities. The successful vendors entered into partnership agreements and teaming arrangements that emphasized the strengths of each partner. In effect, this approach allowed the TARDyS3 ChBA to identify and mitigate risks that would result from an inability to apply both spectrum and software expertise. This early focus on risk poised TARDyS3 for development of a successful prototype.

Guidance for the Future

- Identify the key skill sets and expertise necessary to succeed; incentivize performance and mitigate risk early by evaluating identified skill sets separately
- Communicate early and often with industry what the key skill sets might be; ensure vendors know that they must address them during the evaluation phases of the acquisition

Controlling Costs

TARDyS3 applied a robust price analysis structure that evaluated just enough price information at each stage to inform risk without delaying the selection process. It did so by communicating the intent of price evaluations at each phase, and delving into core details of vendor price proposals, instead of assessing affordability as a pass/fail. In the end, this ensured that the government understood vendor solutions, the vendor understood the government's core considerations, and that the chosen solution was affordable across the entire acquisition life cycle.

In the market research phase, DISA asked the vendors to provide rough order of magnitude estimates, highlighting cost drivers and uncertainties for the government. This price focus enabled the TARDyS3 team to better understand risks, dependencies, and unknown elements from a vendor perspective. The team used this information to clarify and refine requirements for the RWP. Following this phase, the solicitation initially asked for a price estimate, with the expectation that the vendors would provide additional justification later in the acquisition process. This approach helped ensure that prices proposed in Phase I were reasonable, without incurring a high proposal development or evaluation burden. The high-level evaluations at this stage cast light on the most viable competitors by highlighting gaps in vendor solutions, solutions with insufficient levels of effort, unaffordable solutions, vendor uncertainties, and additional risks to be mitigated in Phases II and III. DISA clearly communicated its findings to the vendors.

Following Phase I, during the invitation to the Phase II challenge demonstrations, the government revealed its cost estimate to the vendor community. Once proposed solutions were understood during the white paper phase (Phase I), the TARDyS3 team provided vendors with feedback, including a list of risks and a list of positively evaluated features and attributes. This communication helped vendors refine their technical solutions while still staying within the government's price targets. The challenge demonstrations required vendors to provide oral presentations on how their proposed solution enhanced project affordability, increasing clarity about the vendor decision-making process.

DISA asked each of the two vendors that were promoted to Phase III, project proposals, to provide detailed cost estimates of its work, including the buildup of fully burdened labor rates. An in-depth understanding of proposed labor rates and milestone prices highlighted vendor uncertainties and price reasonableness. The vendor with higher labor rates had to justify those rates; similarly, the vendor with higher labor hours had to justify the risks and the tasks that drove those hours.

OTAs are widely known for their flexibility and speed. Robust price analysis may seem inconsistent with these characteristics; however, price analysis can provide the government with exceptional insight into technical solutions without creating additional hurdles in execution. With an OTA, a program can progress rapidly while being thorough. In a ChBA, the government rarely compares the same technical solutions. Thus, a focused price analysis becomes critical to creating an equitable understanding of disparate solutions. The price analysis creates a framework for understanding proposed solutions in terms of risk and gives the government the tools to ensure technical suitability.

<u>Guidance for the Future</u>

- Inform vendors that the government intends to use high-level price analyses to highlight technical risks, dependencies, and uncertainties
- Use multi-staged acquisitions to focus on lowering costs through iteration
- Consider releasing the government cost estimate to better scope vendor solutions

Cultivating Innovation

The nature of ChBA supports vendors in applying innovative problem solving, developing innovative solutions, and identifying the full solution space for meeting the government's needs. Demonstrations of the vendors' proposed solutions took place in an operational-like environment and allowed the vendors to build solutions tailored to the government's problem. Again, the government did not prescribe a solution but instead stated its problem more broadly and asked for help in solving the problem. This fostered innovation.

Per the ChBA handbook, "ChBA is based on the concept that Government agencies can best perform acquisitions if they present the solution to be acquired as a need (the challenge) and potential providers are free to propose innovative solutions that fill the need" (Roe et al., 2020). Following the guidelines provided in this document, a well-crafted challenge, accompanied by clear, transparent, and effective assessment methodologies and appropriate contracting vehicles, leads to successful acquisitions.

Furthermore, the ChBA handbook describes requirements flexibility:

> In traditional acquisition, the government communicates its needs in a specification (such as a statement of work). … The fundamental flaw in this process is the failure to recognize that the government-dictated specification drives design constraints and possibly limits the government's ability to obtain the best solution to address its need. To avoid these problems and implement ChBA successfully, the government must allow industry to innovate within a well-defined performance-based framework. (Roe et al., 2020)

TARDyS3 used all of the above principles to guide ChBA and OTA, particularly in the demonstration instructions and evaluations that asked for innovative solutions. Innovation was a priority. While the products and processes differed between vendors, as DISA expected, they were graded according to the same criteria that focused on innovation. In other words, through its non-limiting statement of need and innovation-focused evaluation criteria, the TARDyS3 acquisition sought and incentivized innovation and unique concepts to solve the problem.

Guidance for the Future

- Use dynamic engagement via a set of open objectives (rather than a prescribed solution) and transparency in executing vendor demonstrations in operational-like environments; this strongly encourages innovation in the solution space

Outcome of the TARDyS3 Investigation

The TARDyS3 acquisition's focus on dynamic engagement and innovation represented a conscious departure from the typical acquisition processes used to solve spectrum sharing problems. It became very clear early in the process that communication and innovation benefited the government through enhanced vendor engagement and better technical solutions. At the time of award, both the chosen vendor and government had a deep understanding of the requirements and the proposed solution. Moreover, the government and vendor had built trust and a working relationship before award through open communication, and they could effectively transition from pre-award discussions into productive collaboration on prototype development. The TARDyS3 focus on innovation ensured that the delivered solution represented the best possible technology that the government and industry team could collaboratively develop.

As an example of how effectively the TARDyS3 process functioned, the vendor deployed its minimum viable products 4 months after beginning the OT. Moreover, combining the thematic elements of collaboration, communication, and transparency accelerated the entire acquisition process and enhanced the quality and effectiveness of the prototype. TARDyS3 reflected spectrum scheduling capabilities that gained the praise of users less than 11 months after DISA released its initial solicitation.

The result of the successfully completed prototype will be a minimum viable capability release (MVCR) enabling spectrum scheduling, interference assessment, and interference resolution in the 3550–3650 MHz band. At the time this paper was published, the prototype developed under this effort was being tested, evaluated, and refined in preparation for a potential future production effort; all indications continue to show that the government's focus on dynamic engagement in the acquisition enabled the fielding of a highly successful TARDyS3 prototype.

A Framework for Future Implementation

As demonstrated by the TARDyS3 example, dynamic engagement and innovation centricity can generate powerful acquisition outcomes. While no two acquisitions are identical, the underlying themes, enablers, and core activities apply broadly to a wide range of future acquisitions.

From an acquisition strategy standpoint, success in TARDyS3 depended upon applying innovative market engagement, a three-phased ChBA down-select process, and use of a prototype OT. Each of these core strategy elements focused on communicating actively and inspiring vendors to apply new, interesting solutions to the government's requirement. Generally speaking, any future acquisition program should interweave dynamic engagement into the chosen strategy and discover what vendors have to offer. Acquisition teams should not blindly accept all vendor recommendations, given that vendors have different motivations from the government team; however, teams should carefully consider vendor inputs. Vendors often have staff with powerful ideas that the government can leverage to its benefit.

Market engagement should focus on building trust with the vendor community. The government should be willing to share information and be open about its unknowns and its plans. Acquisition programs should move beyond paper-based approaches and emphasize verbal communication that focuses on risks, uncertainties, and new ideas. They should maintain this philosophy throughout the solicitation process and, while maintaining fairness between competitors, communicate openly and in a timely manner.

The government should build an acquisition strategy that keeps competitive pressures on vendors and gives vendors an incentive to deliver their best approaches at reasonable prices. In an outcome-oriented way, acquisition teams should communicate what innovations and ideas the government seeks and inform vendors how the government expects them to build on their competitive advantages. The government should also clearly articulate how the evaluation team will determine value.

Acquisition programs should consider using statements of need to communicate outcome-based needs, provide guide rails to assist vendors in solving a problem, and let proposers innovate inside that space. Programs can use multi-phased acquisitions to iteratively assess and address risks generated by this innovation-focused approach. Moreover, multi-phased acquisitions give vendors an opportunity to iteratively enhance their approaches and refine their price.

ChBA can represent a formidable tool to minimize risk and to inspire innovative solutions. It is particularly useful for developing new technologies, solving difficult problems, and mitigating risks early in the acquisition process. For TARDyS3, ChBA naturally fit the need, and the multi-phased down-select process enabled the government to iteratively understand and mitigate risks. The chosen vendor gained the government's confidence through demonstrations.

Prior to any key acquisition event such as a white paper due date, a challenge demonstration, a proposal due date, or a negotiation session, the acquisition team should consider having a conversation with the vendor community. The team should use open dialogue to allay industry concerns and learn new perspectives—seek knowledge from potential vendor partners and incorporate it into the acquisition approach. In the end, vendors and the government team will have tightly aligned incentives to deliver capability and value to the warfighter; dynamic engagement and innovation centricity can maximize this value.

Conclusion

The TARDyS3 program team built transparency, openly communicated, and incentivized innovation throughout the acquisition. Injecting those core concepts improved the outcomes:

- At time of award, the vendor already deeply understood the TARDyS3 problem and had a technical team engaged in solving that problem. Additionally, the government possessed a detailed understanding of every aspect of the vendor's solution. That understanding enabled a rapid transition to prototype development and fielding.
- The trust built during early acquisition stages carried over to the execution phase, enabling a rapid progression to productive, trust-based performance.
- The government's risk-based acquisition approach mitigated many uncertainties and threats to performance prior to award.
- DISA's approach spurred industry innovation while ensuring the chosen vendor demonstrated a capability to deliver the needed product.

Each of these attributes helped ensure the TARDyS3 program quickly developed and deployed high-quality products. These principles are broadly applicable to future acquisitions, whether or not they follow the TARDyS3 acquisition model. As demonstrated by the TARDyS3 prototype experience, dynamic engagement and a focus on innovation enhance acquisition outcomes.

References

Blank, S. (2019, October 7). Why companies do "innovation theater" instead of actual innovation. *Harvard Business Review*. https://hbr.org/2019/10/why-companies-do-innovation-theater-instead-of-actual-innovation

Roe, S., Novak, R., Raines, J., Staresina, P., Zaharee, M., Kattman, J., & Lee, M. (2020). *Challenge-based acquisition* (5th ed.). The MITRE Corporation. https://www.mitre.org/sites/default/files/publications/pr-20-0745-challenge-based-acquisition-version-5.pdf

Tadjedeh, Y. (2021). Just In: Navy information warfare leader says IT adoption too slow. *National Defense Magazine.* https://www.nationaldefensemagazine.org/articles/2021/4/21/just-in-military-must-speed-up-it-acquisition-process

Emergency Contracting: Themes from Agencies' Disaster and Pandemic Response Efforts

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Abstract

The federal response to the rising number of natural disasters coupled with other emergency response efforts, such as those for COVID-19, have illustrated the important role that federal contracts have in providing life-saving and life-sustaining goods and services. However, contracting during an emergency can pose a unique set of challenges as contracting officials face significant pressure to provide these services as quickly as possible. Leveraging several U.S. Government Accountability Office (GAO) reviews of emergency contracting issues, this paper examines (1) contract and agreement mechanisms agencies used to facilitate response efforts; (2) challenges planning and executing contracts in an emergency environment; and (3) how tracking contract obligations and contracting lessons learned can inform future response efforts.

Report Objectives, Scope, and Methodology

The GAO has conducted a number of reviews in recent years that examine agencies' use of contracts and agreements when responding to emergencies such as the COVID-19 pandemic, hurricanes, and wildfires. Details on the scope and methodology underpinning these reviews are available in methodology section of each of the reports listed at the end of this paper.

Summary

Contracts play a critical role providing life-saving and life-sustaining goods and services in response to emergencies such as COVID-19, hurricanes, and wildfires. The GAO has conducted a number of reviews examining the federal contracting response during emergencies, and challenges that contracting officials may face. Through these reviews, the GAO has examined contract and agreement mechanisms that agencies can use to facilitate emergency response efforts, along with a variety of challenges agencies encounter when contracting during an emergency. The GAO has also made observations about tracking contract use for emergencies, and collecting and sharing contracting lessons learned.

Contract and Agreement Mechanisms

Agencies can use a variety of contract and agreement mechanisms to assist in responding quickly during an emergency, including:

Advance Contracts: The Post-Katrina Emergency Management Reform Act of 2006 required the Federal Emergency Management Agency (FEMA) to establish advance contracts—which are established prior to disasters and are typically needed to quickly provide life-sustaining goods and services in the immediate aftermath of disasters. According to FEMA's advance contracting strategy, the agency will maximize the use of advance contracts to the extent they are practical and cost-effective, which will help preclude the need to procure goods and services under unusual and compelling urgency. Other agencies—such as the U.S. Army Corps of Engineers (USACE)—have also awarded advance contracts as a preparedness measure. These contracts are typically indefinite delivery contracts, which allow the agency to place orders against an existing contract vehicle when needs arise.

Other Transaction Agreements: Certain agencies—such as the Departments of Defense (DoD), Homeland Security (DHS), and Health and Human Services (HHS)—have received legislative authority to award other transaction agreements, which are not subject to the Federal Acquisition Regulation (FAR). Other transaction agreements are not required to include terms and conditions that are typically required when using procurement contracts subject to the FAR. They enable agencies and companies to start with a "blank sheet of paper" to negotiate contractual terms and conditions specific to the agreement. This flexibility may help agencies address concerns from nontraditional contractors—entities that do not typically do business with the federal government such as start-up companies—about requirements that apply to federal procurement contracts.

Undefinitized Contracts: To help meet urgent needs, agencies can also use undefinitized contracts to authorize contractors to begin work and incur costs before reaching final agreement on contract terms and conditions. Before these contracts are finalized, they are called undefinitized. In contrast, a definitized contract is one in which all terms and conditions, including price, are agreed to by the parties to the contract at the time of contract award.

Government Purchase Cards: In addition to awarding contracts during emergency response and recovery, agencies can use government purchase cards to acquire goods and services, either under an existing contract vehicle or directly from merchants. Purchase cards can provide a convenient and often faster alternative to using a contract in a disaster response environment, particularly for certain lower dollar thresholds, such as purchases below the micro-purchase threshold.[16]

[16]The micro-purchase threshold is generally $10,000, however agencies are generally able to increase the micro-purchase threshold to $20,000 when an emergency or major disaster is declared under the Robert T. Stafford Disaster Relief and Emergency Assistance Act.

Challenges Planning and Executing Contracts in an Emergency Environment

The GAO's prior work has identified a variety of challenges agencies may face when awarding contracts during an emergency. The GAO made recommendations to a variety of federal agencies to address each of these challenges. In most cases, the agencies agreed with the recommendations, and the agencies have either addressed them or are in process of doing so.

Acquisition Planning and Requirements Development: The GAO's prior work identified challenges in FEMA's acquisition planning for certain advance contracts. In December 2018, the GAO found shortfalls in FEMA's acquisition planning resulted in a number of bridge contracts (GAO, 2018). Specifically, the GAO found that at least 10 of the advance contracts FEMA used in response to Hurricanes Harvey, Irma, and Maria and the 2017 California wildfires were bridge contracts.[17] Bridge contracts can be a useful tool in certain circumstances to avoid a gap in providing products and services. However, the GAO has previously reported that when non-competitive bridge contracts are used frequently or for prolonged periods, the government is at risk of paying more than it should for products and services (GAO, 2015).

The GAO also identified challenges with requirements development related to the award of contracts in response to disasters. In April 2019, the GAO reported that contracting officers responsible for selected FEMA contracts received requirements packages that were lacking in technical specificity or were otherwise deficient (GAO, 2019). At the time of our review, FEMA had begun to address this challenge through the use of portfolio managers to provide templates and guidance to program officials on acquisition documents and by hosting informal training sessions for program officials, so the GAO did not make a recommendation at that time.

Determining Contractor Responsibility: The FAR requires that no purchase or award be made from a prospective vendor unless the contracting officer has made an affirmative determination of responsibility, and contracting officers rely on a variety of resources—including government databases and private sector resources—to assess prospective vendors. In July 2021, the GAO identified limitations in the guidance and resources available and communicated to HHS contracting officials for assessing prospective vendors during the COVID-19 emergency, which posed challenges to HHS contracting officials when working with new vendors to respond to the COVID-19 pandemic (GAO, 2021).

In July 2021, the GAO also found that some agencies involved in contracting for the COVID-19 response—such as HHS and the U.S. Department of Agriculture—had not typically been involved in contracting for other recent disasters and emergencies (GAO, 2021). However, the GAO reported that government-wide emergency acquisition guidance intended to provide federal agencies with best practices they can consider when contracting

[17] In October 2015, the GAO established the following definition related to bridge contracts: an extension to an existing contract beyond the period of performance (including option years), or a new, short-term contract awarded on a sole-source basis to an incumbent contractor to avoid a lapse in service caused by a delay in awarding a follow-on contract. See *Sole Source Contracting: Defining and Tracking Bridge Contracts Would Help Agencies Manage Their Use* (GAO, 2015).

during an emergency provided limited information on resources for assessing prospective vendors, and had not been updated since 2011.

Acquisition Workforce: The GAO has also found that agencies have varied in their efforts to plan for disaster contracting activities and assess contracting workforce needs. In April 2019, the GAO reported that FEMA identified workforce shortages as a continuing challenge for disaster response and recovery following the 2017 hurricanes and California wildfires, but had not assessed its contracting workforce—including staffing levels, mission needs, and skills gaps—since 2014 (GAO, 2019).

In November 2020, the GAO reported that the efforts of selected agencies—specifically USACE, the U.S. Coast Guard, and the Department of Interior—to plan for disaster contracting activities and assess contracting workforce needs varied (GAO, 2020). For example, the GAO found that USACE and the Coast Guard assigned clear roles and responsibilities for disaster response contracting activities, but neither had assessed contracting workforce needs specifically for disaster response.

Purchase Card Fraud Risks: The use of government purchase cards for smaller purchases can reduce the government's administrative costs and increase its flexibility to meet its needs. However, if not properly managed and controlled, the use of purchase cards can also expose the government to significant risk, particularly during a disaster when officials may have a higher fraud risk tolerance due to the urgent need for products and services. In November 2020, the GAO found that USACE, the Coast Guard, FEMA, the Environmental Protection Agency, and the U.S. Department of Agriculture's Forest Service had not assessed or documented how their purchase card fraud risk might differ in a disaster response environment (GAO, 2020).

Tracking Contract and Agreement Obligations and Collecting Lessons Learned

Maintaining accurate procurement data and establishing methods to collect, analyze, and share contracting lessons learned can help to inform agencies' future emergency response efforts. The GAO has made recommendations to a variety of federal agencies on the importance of these efforts. The agencies generally agreed with the recommendations, and have either addressed them or are in process of doing so.

Tracking Contract and Agreement Obligations: Contract actions and associated obligations can be tracked in the Federal Procurement Data System (FPDS) using National Interest Action (NIA) codes.[18] However, the GAO has identified inconsistencies in establishing and closing these codes following previous disasters or emergencies. In April 2019, the GAO reported that the full extent of post-disaster contracting related to the 2017 disasters was unknown due to DHS's inconsistent implementation of the criteria for closing a NIA code (GAO, 2019). Further, in September 2020, during the federal response to COVID-

[18]The NIA code data element in FPDS was established following landfall of several major hurricanes in 2005 to enable consistent tracking of emergency or contingency-related contracting, and the General Services Administration, DoD, and DHS are jointly responsible for determining when a NIA code should be established and closed.

19, GAO reported on concerns with the criteria that DHS and the DoD rely on to determine whether to extend or close a code, and whether the memorandum of agreement the agencies use to inform their decisions meets the needs of high visibility events, and of users, such as other agencies and Congress (GAO, 2020).

The GAO's prior work has also identified challenges related to tracking the use of other transaction agreements for COVID-19 in FPDS. In January 2021, the GAO found that HHS misreported its other transaction agreements related to COVID-19 as procurement contracts, including about $1.5 billion in other transaction agreements obligated for Operation Warp Speed and other medical countermeasures (GAO, 2021). Further, in July 2021, the GAO reported that the DoD and DHS did not accurately identify certain other transaction agreements as COVID-19-related in FPDS (GAO, 2021).

Contracting Lessons Learned: Collecting and sharing lessons learned—both positive and negative—allows agencies to communicate knowledge more effectively and to ensure that beneficial information is factored into planning, processes, and activities. However, the GAO's prior work has identified shortfalls in agencies' lessons learned processes. In April 2019, the GAO found that while FEMA had taken steps to identify interagency lessons learned following the 2017 hurricanes and California wildfires, USACE and the Coast Guard lacked processes for formally gathering and incorporating input and lessons learned and communicating this information to FEMA's interagency group (GAO, 2019).

The GAO has also identified opportunities to assess contracting lessons learned in relation to border wall construction during a national emergency. Specifically, in June 2021, the GAO found that, following a 2019 Presidential Declaration of National Emergency, USACE awarded more than $4 billion in noncompetitive contracts and used undefinitized contract actions to quickly start construction and maximize the miles of border panels it could build on the southwest border (GAO, 2021). By focusing on expediency, the government risks paying higher costs, but USACE had not developed plans to examine its overall acquisition approach and identify lessons learned.

The GAO also identified challenges collecting and sharing lessons learned related to contracting in response to COVID-19. In July 2021, the GAO reported that selected agencies were collecting lessons learned from the response, but that the lessons learned processes at HHS and FEMA did not include contracting personnel or contracting observations (GAO, 2021).

Further, in July 2021 the GAO reported that despite the extensive interagency coordination that occurred during the response to the COVID-19 pandemic, contracting officials at the DoD, HHS, and DHS were not always aware of, or involved in, government-wide efforts to collect and share interagency lessons learned (GAO, 2021). Without a process to ensure that contracting lessons learned are incorporated into interagency lessons learned efforts, federal agencies risk missing an opportunity to memorialize contract and coordination practices that were successful, as well as those that were not, for future emergencies.

In summary, the GAO identified a variety of challenges and opportunities for improvement related to emergency contracting over the past five years. Implementation of the GAO's recommendations in these areas will improve the federal government's response to future emergencies.

References

GAO. (2015, October 14). *Sole source contracting: Defining and tracking bridge contracts would help agencies manage their use* (GAO-16-15). https://www.gao.gov/products/gao-16-15

GAO. (2018, December 6). *2017 Disaster contracting: Action needed to better ensure more effective use and management of advance contracts* (GAO-19-93). https://www.gao.gov/products/gao-19-93

GAO. (2019, April 24). *2017 disaster contracting: Actions needed to improve use of post-disaster contracts to support response and recovery* (GAO-19-281). https://www.gao.gov/products/gao-19-281

GAO. (2020, September 21). *COVID-19: Federal efforts could be strengthened by timely and concerted actions* (GAO-20-701). https://www.gao.gov/products/gao-20-701

GAO. (2020, November 24). *Disaster response: Agencies should assess contracting workforce needs and purchase card fraud risk* (GAO-21-42). https://www.gao.gov/products/gao-21-42

GAO. (2021, January 28). *COVID-19: Critical vaccine distribution, supply chain, program integrity, and other challenges require focused federal attention* (GAO-21-265). https://www.gao.gov/products/gao-21-265

GAO. (2021, June 17). *Southwest border: Schedule considerations drove Army Corps of Engineers' approaches to awarding construction contracts through 2020* (GAO-21-372). https://www.gao.gov/products/gao-21-372

GAO. (2021, July 26). *COVID-19 contracting: Actions needed to enhance transparency and oversight of selected awards* (GAO-21-501). https://www.gao.gov/products/gao-21-501

GAO. (2021, July 29). *COVID-19 contracting: Opportunities to improve practices to assess prospective vendors and capture lessons learned* (GAO-21-528). https://www.gao.gov/products/gao-21-528

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DOD Has Increased Its Use of Fixed-Price Incentive Contracts, but Is It Getting Better Outcomes?

Julie A. Clark —is a senior analyst with the U.S. Government Accountability Office. She has written reports on several topics in the areas of acquisition and contracting including fixed-price incentive contracts, weapon system reliability, and acquisition reform. [clarkja@gao.gov]

Abstract

Department of Defense (DoD) guidance encourages the use of fixed-price-incentive contracts to acquire major weapon systems, where appropriate. These contracts can provide contractors with incentives to keep costs in check and stay on schedule. This presentation looks at (1) the extent to which the DoD has awarded fixed-price incentive contracts associated with Major Defense Acquisition Programs from Fiscal Years 2010 through 2019, and (2) the factors that influenced the DoD's decision to use fixed-price incentive contracts and the extent to which the DoD has assessed their use, among other objectives.

Background

The Department of Defense (DoD) spends billions of dollars annually using fixed-price-type contracts to acquire its major defense acquisition programs (MDAPs), among other things. In 2010, the DoD's Better Buying Power guidance encouraged the use of fixed-price-incentive (FPI) contracts as a way to obtain greater efficiency and productivity in defense spending.

Report Objectives, Scope, and Methodology

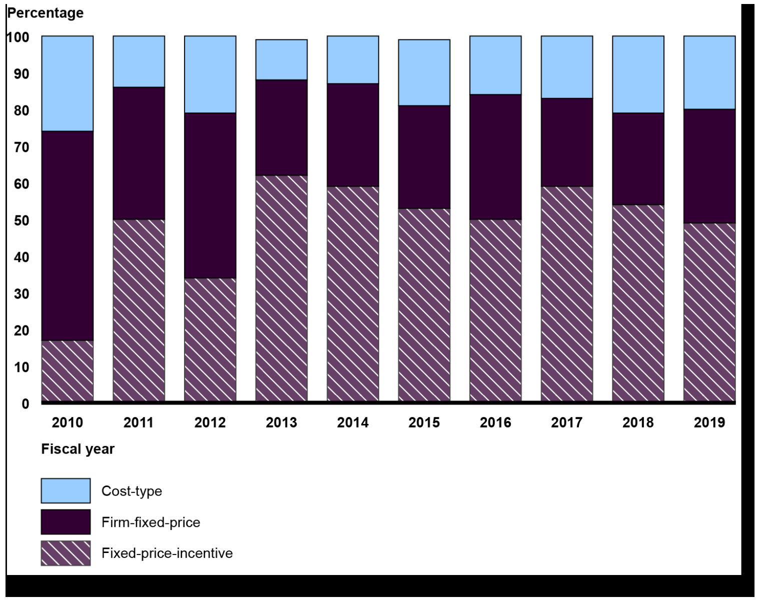
Congress included a provision in statute for the GAO to report on the DoD's use of fixed-price-type contracts, including FPI. This report examines (1) the extent to which the DoD has awarded FPI contracts associated with MDAPs from Fiscal Years 2010 through 2019, and (2) the factors that influenced the DoD's decision to use FPI contracts and the extent to which the DoD assesses their use, and (3) the extent to which the DoD has faced challenges in closing out fixed-price-type contracts.

The GAO analyzed government contracting data by contract type for Fiscal Years 2010 through 2019 on contracts for 101 MDAPs. The GAO further analyzed a non-generalizable sample of 12 contracts including six FPI and six firm-fixed-price (two of each type from each of the three military departments); conducted file reviews; reviewed policy documentation; and interviewed DoD officials.

Summary

The DoD has encouraged the use of FPI contracts where appropriate. These contracts can provide defense contractors with a profit incentive for effective cost control and performance depending on how they are structured. Over the 10-year period from Fiscal Years 2010 through 2019, obligations on FPI contracts for MDAPs grew to account for almost half of the $65 billion in obligations for Fiscal Year 2019.

Percentage of Obligations by Contract Type for Major Defense Acquisition Programs From Fiscal Years 2010 Through 2019



Source: GAO (2021).

DoD guidance, including Better Buying Power initiatives, influenced the DoD's use of FPI contracts over the last decade for the selected contracts the GAO reviewed. In addition, when selecting a contract type, contracting officers also considered factors including the availability of cost or pricing data, previous experience with the contractor, and the previously used contract type. The DoD has not assessed the extent to which use of FPI contracts has contributed to achieving desired cost and schedule performance outcomes.

See GAO-21-181 for additional details.

https://www.gao.gov/products/gao-21-181

References

GAO. (2021). *Fixed-price-incentive contracts: DoD has increased their use but should assess contributions to outcomes* (GAO-21-181). https://www.gao.gov/products/gao-21-181

PANEL 9. RESOURCING THE FUTURE FIGHT: CURRENT PPBE CHALLENGES & OPPORTUNITIES FOR REFORM

Wednesday, May 11, 2022	
12:30 p.m. – 1:45 p.m.	**Chair: Rear Admiral John Gumbleton, USN,** Deputy Assistant Secretary of the Navy for Budget (FMB)/Director, Fiscal Management Division, N82, Office of the Chief of Naval Operations **Panelist: Dr. Stephanie Young,** Director, Resource Management Program, RAND Corporation ***Resourcing Defense Innovation: The Role of Organizational Values*** Jonathan Wong, RAND Corporation ***Resourcing a Mosaic Force: Lesions from an Acquisition Wargame*** Joel B. Predd, RAND Corporation Jon Schmid, RAND Corporation Elizabeth (Ellie) Bartels, RAND Corporation Jeffrey A. Drezner, RAND Corporation Bradley Wilson, RAND Corporation Anna Jean Wirth, RAND Corporation Liam McLane, RAND Corporation ***Pathways to Defense Budget Reform*** Eric Lofgren, George Mason University

Rear Admiral John Gumbleton, USN—is a native of Falmouth, Massachusetts, and graduate of Norwich University where he earned a Bachelor of Science in Environmental Engineering. He also holds a Master of Science in Information Systems from The George Washington University (GWU), a Master of Arts in National Security and Strategic Studies from the Naval War College, and attended the GWU/MIT National Security Management Course.

Operationally, he served in numerous helicopter squadrons flying the SH-60B. His sea assignments include Helicopter Anti-Submarine Squadron Light-(HSL) 44 deploying with USS Samuel B. Roberts (FFG 58) and USS Vicksburg (CG 69). Twice serving at HSL-46, he deployed with USS Ticonderoga (CG 47) as detachment officer-in-charge and also served as squadron operations officer and as detachment officer-in-charge on board USS Taylor (FFG 50). In command, he led the Vipers of HSL-48 and the Sailors and Marines of USS Boxer (LHD 4) and Expeditionary Strike Group 3.

Gumbleton's shore assignments include the Bureau of Naval Personnel as war college and graduate education detailer; flag lieutenant to Commander, Naval Air Systems Command; legislative fellow for Senator John Warner of Virginia; congressional liaison officer, Appropriations Matters Office in the Office of the Assistant Secretary of the Navy (FM&C); military assistant to Deputy Assistant Chief of Staff Allied Command Transformation Staff Element Europe; senior fellow Strategic Studies Group 34; and director, Operations Division (FMB1), Office of the Assistant Secretary of the Navy (FM&C).

In May 2020 he assumed duties as deputy assistant Secretary of the Navy for Budget (FMB)/director, Fiscal Management Division, N82, Office of the Chief of Naval Operations. His previous flag assignments include director of Maritime Headquarters for U.S. Naval Forces Europe/U.S. Naval Forces Africa/U.S. Sixth Fleet, and most recently as commander, Expeditionary Strike Group 3.

His personal awards include the Legion of Merit (four awards), Defense Meritorious Service Medal, Meritorious Service Medal (two awards), Navy and Marine Corps Commendation Medal (five awards), and the Navy and Marine Corps Achievement Medal.

Stephanie Young—is a senior political scientist at the RAND Corporation, and program director of the Resource Management Program at RAND Project AIR FORCE. She manages a diverse portfolio of research in support of the Department of the Air Force on topics related to budgeting, acquisition, logistics, sustainment, and organizational design. Her primary research interests relate to defense acquisition, budgeting, and resource allocation, but other recent work has focused on strategic competition, security cooperation and building partner capacity, countering-weapons of mass destruction, and U.S. policy in the Middle East and South Asia. In 2012 she spent three months as an analyst embedded with the Special Operations Joint Task Force – Afghanistan, in Kabul. At RAND she also taught a Ph.D. level course on the U.S. defense budget at the Pardee RAND Graduate School, and she previously served as the associate research department director of RAND's Defense and Political Sciences Department. She was educated at the University of California, Berkeley, where she earned a Ph.D. in history and a B.A. in physics and astrophysics.

Resourcing Defense Innovation: The Role of Organizational Values

Dr. Jonathan P. Wong—is a policy researcher at the RAND Corporation. His research focuses on military force development issues such as the role of new technologies, processes, and concepts in shaping how militaries fight. Wong is a former management consultant and Marine Corps infantryman. [jonwong@rand.org]

Abstract

The U.S. Department of Defense (DoD) Planning, Programming, Budgeting, and Execution (PPBE) system aims to provide efficient and stable allocation of resources for defense needs that were first articulated in the 1960s. Today, the DoD continues to use this process even though its needs are changing. Namely, keeping pace with different adversaries and effectively capitalizing on fast-moving commercial technology developments are requiring the DoD to invest in new and different capabilities. To do so, it needs a resource allocation system with greater flexibility and agility to meet these demands. However, the DoD has only developed modest efforts to enable innovation that work within the current system. This paper will develop an evaluation framework for a resource allocation system to enable innovation and compare/contrast with the current system; explore levers the DoD currently enjoys for enabling innovation within the current system; assess several case studies of process, policy, and organizational change to bolster innovation; and develop lessons learned from past efforts, including insights related to the future promise and constraints of reform.

Background

Reforming the Department of Defense's (DoD) resource allocation process has been a subject of periodic interest to policymakers and the analytic community since its inception. The past several years has been one of those periods, as the Planning, Programming, Budgeting, and Execution (PPBE) process has been repeatedly cited as a critical impediment to the increased adoption of innovative commercial technologies with military utility, such as artificial intelligence (Spoehr & Bartels, 2022). The purpose of this paper is to examine the drivers of contemporary interest in PPBE reform, summarize the various reform proposals, and evaluate them using a framework to understand how they will affect fundamental *values* of resource allocation.

Importantly, the objective of this exploratory research is not to comment on the relative merits of any given reform proposal, but rather, to emphasize that different reform proposals reflect different sets of values and implementation of reforms will require explicit decisions about relative prioritization placed on a given set of values. Furthermore, the diverse stakeholders with critical responsibilities for aspects of PPBE will likely emphasize different values based on the nature of their responsibilities.

The New Context of PPBE

The PPBE implemented in the early 1960s was an attempt to inject more rationality into defense budget requests. The analyses required by the PPBE process compelled the DoD to link its budgets more explicitly with its strategy. Enthoven and Smith (1971) note that it also gave policymakers more ability to make choices and trade-offs between programs while considering ends and means together. Most significantly though, it enabled the Secretary of Defense to exert meaningful control over the budget process across the entire department, which was once the province of the military services.

Since the inception of PPBE in the 1960s, though, historical contexts have changed. As noted in Wong et al. (2022), four overarching trends have significantly altered the context that affects DoD resource allocation. First, **geopolitical changes** have widened the threat landscape. Growing Chinese economic and military power poses new threats to U.S. interests, while a resurgent Russia remains a potent force in addition to transnational threats. **Globalization** has altered the economic and technological landscape, creating new opportunities, as well as challenges, for the DoD. Furthermore, the United States has **considerably different resourcing priorities**; defense issues remain important, but domestic policy issues compel policymakers to prioritize attention and resources. Lastly, **advancing commercial technologies** are creating new challenges and opportunities for an acquisition system that was not designed to import and adapt technologies developed outside the traditional defense industrial base.

These trends have affected the context under which previous DoD technology development has taken place. In particular, the DoD has struggled to integrate advancing commercial technologies with military utility using existing policies and practices. This has motivated the DoD to reform its acquisition processes over the past decade to address these shortcomings. New organizations such as the Defense Innovation Unit and AFWERX have improve the way the DoD identifies promising commercial technologies and firms and created new, streamlined processes that allowed firms to work more easily with the DoD on prototypes.[19] The DoD expanded use of flexible Other Transaction authorities, enabling further flexibility in getting firms on contract in ways that are beneficial to both firms and the government (Mayer et al., 2020). The DoD launched a new set of acquisition pathways that offer more specific oversight and monitoring requirements tailored for different kinds of programs instead of a one-size-fits-all approach.[20] The upshot of these and other reforms is that the DoD can now work more easily with many commercial firms on product development and prototyping.

Those reforms have uncovered further challenges, with flexibility of resource allocation being the most prominent. The strict and deliberate process described in McGarry (2021) results in resources being allocated two years after they are first proposed. Greenwalt & Patt (2021) note that this deliberate pace prevents the adoption of the latest technologies, particularly ones originating from the commercial sector, where product development cycles are much faster. The process also stymies fast adaptation and iteration, as funds that are allocated for one purpose cannot easily be reprogrammed for another without congressional approval above a certain threshold, even when there is an opportunity to take advantage of an emerging development or an imperative to meet an unforeseen need (Wong, 2020).

Organization of This Paper

The rest of this paper examines these challenges. We will first examine recent ideas for PPBE reform, grouping them into five distinct proposals. We will then turn to business administration, public policy, and defense analysis literature to develop evaluation criteria by

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[19] In particular, these organizations have built up business development teams that help commercial firms understand DoD problems, source selection processes inspired by venture capital firms that quickly identify the most promising ideas, and concierge-like services that help firms navigate the DoD acquisition bureaucracy.

[20] Six pathways now exist for acquisition programs: major capability, middle tier, software, business systems, services, and urgent capabilities acquisition. See https://aaf.dau.edu/ for more details.

which we can compare the five groups of PPBE reform proposals. Finally, we will evaluate those ideas and offer observations about the potential consequences of each proposal.

Proposed Changes to Resource Allocation

To summarize the proposed changes to the PPBE process, we reviewed documents recommending tangible changes to DoD resource allocation to enable greater technological innovation.[21] While many recommendations were general calls for change, 14 documents contained 22 distinct proposals for change that varied in detail, scope, and importantly, organization that would be responsible for acting to effect change.[22] From those recommendations, though, appeared five distinct types of groupings:

- More efficient execution of existing PPBE process
- Broader or different units of analysis
- Integrated portfolios
- Removal of RDT&E from the FYDP
- More powerful reprogramming

Importantly, these categories of recommendations are not mutually exclusive within a reform proposal, and indeed several call for a portfolio of reforms to achieve desired ends. We will now characterize each one in turn.

More Efficient Execution of Existing PPBE Process

This set of proposed changes envisions making marginal changes to the PPBE that aim to make it live up to its original purpose, empowering policymakers with clearer access to information that allows them to pick between alternatives. More efficient execution might reducing the number of stakeholders that must indicate approval to streamline the process, modernizing budget justification material to make the production of PPBE products faster, or other ideas to reduce the administrative burden needed to execute the process, thereby making it work faster (Hale, 2021). Other recommendations are to provide more incentives to ensure strategic documents are developed on time, enabling a tighter linkage between strategy and budgets; this would ostensibly create a system that is more responsive to changes dictated by policymakers. Such recommendations suggest that at least in the target areas, the PPBE process is fundamentally sound, but opportunities exist to improve implementation (Greenwalt & Patt, 2020).

Broader or Different Units of Analysis

This set of proposed changes would create different budget categories instead of the current Major Force Program (MFP) construct. The existing MFP construct reflects the threat environment and platform centric military capabilities which shaped it at its inception. These MFP bins were developed to reflect the units of analysis at which meaningful resource trades

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[21] We note that enabling greater technological innovation may not be the only goal for PPBE reform; other goals may exist.
[22] In reviewing the literature on PPBE reform, it was evident that many calls for reform focused on characterizing problems and encouraging change, but specific recommendations were uncommon. The 14 documents noted previously were the exception.

could be explored. As reform proposals, this category would reconsider those bins in light of the current threat environment, technological landscape, and nature of military capabilities. Most proposed changes in this vein would make the categories encompass more program elements (PEs) or PEs that are more aligned with current modernization priorities that traverse the seams and slip through the cracks of current MFPs, like networked communications or other information technology programs as suggested by Snyder (2022). For example, from a budgetary perspective, increased consolidation might be likened to the detailed PEs and programs contained in the procurement budget with the broader, more flexible categories in the operations and maintenance budget.

Another example of these kinds of proposals is an instantiation of these changes proposed in Lofgren (2021) that focuses on changes that enable greater technological innovation. He envisages the consolidation of various RDT&E PEs organized by service into larger groupings by a responsible program executive officer.[23] This would create a seven-fold reduction in the number of PEs responsible for a greater dollar amount. This in turn would reduce the amount of analysis required for each set of PEs.

Finally, another proposal would be to set aside small parts of the DoD budget as a sort of contingency fund for the DoD that is not constrained by appropriation title. This "unspoken for" money could be spent on emerging priorities that become apparent after the original budget is programmed, enabling greater DoD budget flexibility (Hale, 2021). As a whole, these recommendations believe that changing the unit of analysis to better reflect contemporary needs will yield a better result.

Integrated Portfolios

These proposed changes are more radical versions of the proposed changes to the units of analyses. Instead of merely reconfiguring Major Force Programs, these recommendations suggest consolidating major portions of the defense budget around single missions, capability areas, or regions. These changes would make each consolidated portfolio responsible for multiple appropriation titles (or "colors of money" in DoD parlance) such as RDT&E, procurement, and O&M. Examples of these proposed changes exist; the Joint IED Defeat Organization (JIEDDO), the Joint Artificial Intelligence Center (JAIC), and the Strategic Capabilities Office (SCO) all exemplified some characteristics for specific mission or capability areas (Lofgren, 2021). Schmid et al. (2021) described a Joint Mission Office that consolidated acquisition authorities, appropriation titles, and a streamlined governance model to deliver capabilities faster and more efficiently for DARPA's Mosaic concept (itself a program that would fall between the seams of different MFPs). The common thread between all of these proposals is that a greater degree of agility and coherence can be achieved with a portfolio-based approach to resource allocation.

Removal of RDT&E From the FYDP

This proposal would maintain most of the PPBE status quo, but focus on bringing RDT&E resource allocation out of the PPBE process and its years-long process that is difficult to change. Instead, RDT&E budgeting would revert back to the pre-1961 practice of annual

[23] It is important to note that the PEO is the organization most likely to have the authority to make resource trades.

budgeting without longer-range projections as is done in the FYDP. This would ostensibly increase flexibility and the DoD's ability to harness commercial technologies with faster resourcing.

More Flexible Reprogramming Authority

Finally, the last group of proposals would focus on creating more flexibility after the PPBE enters execution phase by increasing the DoD's ability to move, or reprogram, funds between programs after they are programmed and budgeted (McGarry, 2021b). This would include increasing the amount of money that the DoD can reprogram without needing time-consuming Congressional intervention or devolving reprogramming authority to lower levels of an organization where it can be more responsive to newly identified needs. These recommendations would also increase the DoD's budget flexibility, but from a post-hoc, reactive point of view.

A Proposed Evaluation Framework of Options to Meet the Strategic Goal of DoD Resource Allocation

How would we compare the proposed resource allocation changes? Having consistent evaluation criteria to compare alternatives against the status quo PPBE system and to each other is critical for identifying future steps to improve DoD resource allocation, and to develop a structured approach for exploring potential trade-offs between reform proposals. To find the right evaluation criteria, we drew from several sources:

- Management and business administration
- Public policy, administration, and analysis
- Previous analyses of the PPBE system with inferred values

Each body of literature offers useful insights that can inform the development of a framework to evaluate PPBE and its alternatives, but none is a perfect match for evaluating a public sector resource allocation process. Management literature such as Richard et al. (2009) is rich with ways of measuring success for an organization and examples of metrics, but all are aligned around measuring organizational changes meant to maximize profit. Unlike the management literature, the public policy literature has excellent examples of evaluation schemes that can hold many, sometimes competing values at once. However, the public policy evaluation literature such as Hatry (2009) is focused on measuring the performance of specific policy interventions meant to enable a societal good or value. Finally, various analyses of the PPBE process described in the previous sections often recommend changes, from which we can infer values that those changes seek to emphasize over the status quo. However, this body of literature did not intend to use those values as a neutral means of evaluating alternatives.

Taken together, though, four qualities emerge that can form a set of evaluation criteria. We will use these to explore evaluation of PPBE and its alternatives:[24]

- Consistency

[24] To identify these criteria, we identified all 39 relevant individual values from all four bodies of literature and used a pile sorting method to iterative group them until the four criteria emerged. For further reading on pile sorting and theme identification, see Ryan & Bernard (2003).

- Agility
- Coherence
- Transparency

Importantly, these qualities are presented without discussion of how they will be prioritized, as such implementation considerations will vary across stakeholders and need to be tailored to address specific resource challenges.

Consistency

Consistency is the ability of the process to allocate resources predictably and consistently over time. This quality is a hallmark of the PPBE system as it was designed, and remains useful for planning in certain modern contexts as well; planning and programming for multiple years lays the foundation for a predictable flow of resources. Consistency disciplines spending by keeping resources focused on programs for as long as they are needed. Wong et al. (2022) notes that this consistency was considered crucial during the Cold War, when a long term great power competition with the Soviet Union was believed to be indeterminate. Chu and Bernstein (2003) also observed that consistency has real benefits even at the program level: the ability to shift resources prized by senior leaders (even under the status quo PPBE process) can be disruptive to program managers, who must try to run programs under a cloud of uncertainty and instability in their funding.

Agility

Agility is the ability for the process to effectively respond to new needs and priorities. This quality, which might be in tension with the consistency criterion examined previously, is the most prized one in contemporary PPBE reform debate, especially focused on the unique challenge of enabling innovation.[25] Agility would allow DoD leaders to fund late-breaking programs by either moving resources from another program or finding new resources at a faster pace than the status quo PPBE process, which requires two or more years to do so. In the realm of technology development, it would also encourage more fluidity between RDT&E, procurement, and O&M funds that would enable greater feedback and iterative development. All of these benefits would ostensibly give the DoD a greater ability to bring promising new technologies incubated in the multitude of defense innovation organizations across the proverbial "valley of death" between a successful prototype and a more enduring program of record.

Coherence

Coherence means that the outcome of the process results in budget requests with a clear connection to defense strategy, reflected in clear priorities among programs. Assuming that the resource allocation process is synchronized with the defense planning process (ideally, the latter should precede the former), the resource allocation process should clearly use defense strategy to shape the overall budget. This would require the process to decisively adjudicate conflicts between programs during the process, for instance. Whatever the means, the budget request at the end of the process should reflect defense policymakers' priorities.

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[25] Serbu (2021) is an excellent example of the contemporary PPBE reform debate.

Transparency

Finally, the entire process should be trusted and open to inspection. Congressional authorizers and appropriators and stakeholders within the process should have trust in the process. The process itself should be clear and understandable. The products and analyses underpinning it should be accessible for inspection to an appropriate extent. Most importantly, outcomes in budget requests should be traceable to their source. Budgeting is an inherently political activity. The criteria of transparency ensures that the stakeholders within the DoD accede to its primacy and trust its outcomes and that Congressional overseers understand what is being requested and why. There should be no surprises or decisions that emerge from a proverbial 'black box.'

Using Evaluation Criteria to Compare Resource Allocation Alternatives

Having identified the criteria, we can now apply them to the five PPBE reform proposals identified earlier. Here, we encounter the challenge of relating these criteria to the alternatives themselves. How can we measure consistency, agility, coherence, or transparency in a process? What metrics are appropriate? Hatry (2009) argues that metrics should be relevant to the issue, understandable to users, able to be feasibly collected, and not manipulable by the process itself.

However, the five proposed PPBE reforms are not ready to be measured in such a thorough way. They are not fully developed processes; many features that can be measured have yet to be specified. The changes themselves have not yet been made, so many performance measurement schemes meant to be deployed after an initiative is running would not apply.

Therefore, we will evaluate the proposed PPBE changes holistically in this paper. Based on the descriptions of each group of changes, we will assess whether they are likely to lead to an increase or decrease across each of the four evaluation criteria compared to the status quo PPBE process. In the following sections, increases in a criteria will be denoted by a (↑); decreases will be denoted by a (↓); and no change to a criteria will be denoted by a (↔). These are relatively crude measures; future research can build out the proposed PPBE changes into more comprehensive policy prescriptions and explore the possibilities of identifying proxy quantitative values or other, more systematic metrics to represent the criteria.

More Efficient Execution of Existing PPBE Process

Consistency	Agility	Coherence	Transparency
↔	↔	↑	↔

Compared to the status quo PPBE process, a more efficient execution of that same process is not likely to yield any changes in most evaluation criteria. Consistency and transparency will remain the same since the process remains the same. More efficient process execution could save time, but without changes to the process overall, the process cannot take less than two years to allocate resources to a program objective memorandum (POM); this effectively serves as a floor beyond which no further agility can be gained. However, coherence may increase. If PPBE is executed more efficiently, then strategic guidance will flow more naturally between process step and the link between strategy and budgets may increase.

Broader or Different Units of Analysis

Consistency	Agility	Coherence	Transparency
↓	↑	↔	↓

Compared to the status quo PPBE process, changing the unit of analysis from the existing PEs that aggregate up into MFPs to a hierarchy that reflects contemporary defense needs would certainly increase agility if the individual program elements are large enough to allow for meaningful trades to be made. However, this might increase turbulence between programs as resources are shifted around. Transparency is also likely to decrease, as different or larger units of analysis will make it harder for Congressional overseers to have the same detailed level of understanding as they do now with the status quo.

Integrated Portfolios

Consistency	Agility	Coherence	Transparency
↓	↑	↑	↓

Integrated portfolios that unify different appropriation types for specific missions, capabilities, or geographic areas have the potential to induce the most change to the status quo PPBE process out of all the proposed reforms. As is the case in broader or different units of analysis, agility will increase and consistency will decrease as managers of the integrated portfolios shift resources internally and between portfolios. Coherence is likely to increase as the portfolios are likely to be constituted around the DoD's strategic priorities. However, transparency is likely to decrease, as the integrated portfolios will not be broken out and open to inspection as is the case in the status quo.

Removal of RDT&E From the FYDP

Consistency	Agility	Coherence	Transparency
↓	↑	↔	↔

Removing RDT&E from the FYDP is likely to increase agility, as the delay between allocating and receiving RDT&E resources will shrink from two years to one year. However, this would also likely result in a decrease of consistency, as priorities may shift from year to year. Since the remainder of the defense budget will remain in the status quo, no changes to coherence or transparency are likely.

More Powerful Reprogramming

Consistency	Agility	Coherence	Transparency
↓	↑	↓	↓

Like the previous proposals, more powerful reprogramming authority will increase agility and decrease consistency as the DoD makes post hoc adjustments to resource allocations. However, coherence will likely decrease as reprogramming lacks any mechanism to enforce a linkage between strategies and budgets. Transparency will also decrease if more powerful reprogramming comes at the cost of Congress relinquishing or delegating some of its reprogramming authority to the DoD.

Conclusion

Missing from the current and encouraging discussion about PPBE reform to create increased agility is an explicit conversation about the values that the DoD and Congress seeks in resource allocation (both today and in the future) and how reforms will affect all of those values. In this paper, we consider both specific reforms and specific values (in the form of evaluation criteria) to understand the total effect of any proposed PPBE reform on the DoD.

Reform proposal	Consistency	Agility	Coherence	Transparency
More efficient execution of existing PPBE process	↔	↔	↑	↔
Broader or different units of analysis	↓	↑	↔	↓
Integrated portfolios	↓	↑	↑	↓
Removal of RDT&E from the FYDP	↓	↑	↔	↔
More powerful reprogramming	↓	↑	↓	↓

After evaluating the five PPBE reform proposals, we see that all of them are likely to increase agility while decreasing consistency. This is not surprising; the contemporary policy debate around PPBE is largely centered around the contention that PPBE is not agile enough to enable commercial technologies to be adopted at speeds the commercial sector expects. We should expect that most proposals seek to increase agility; since this evaluation criteria exists in tension with the criteria of consistency, we should also expect to see consistency decreasing in most, if not all proposals. If this is the case, we might see less value in the proposal for more efficient execution of the existing PPBE process since it is not likely to increase agility.

What does this mean for the remaining two evaluation criteria, coherence and transparency? Assuming that all PPBE stakeholders (including Congress) are seeking to maximize agility above all, then perhaps policymakers should be most interested in proposals that increase coherence and transparency, or at least those that minimize likely decreases to those evaluation criteria.

But there is no clear choice among the four options until we determine which value is more important. If coherence is more important than transparency, then integrated portfolios would be the most preferable reform choice, followed by broader units of analysis and removing RDT&E from the FYDP. If transparency is more important, removing RDT&E from the FYDP would be most preferable. Among the remaining choices, integrated portfolios would then be more preferable since it increases coherence, followed by broader or different units of analysis. More powerful reprogramming would be the least preferred reform option.

However, it is not the goal of this paper to make definitive policy recommendations about which PPBE reform proposals to pursue. The proposals reviewed and summarized in this paper require more development to understand the totality of their proposed changes and how they might affect the evaluation criteria. Moreover, other proposals likely exist. In this paper, we chose to focus on ones that attempt to enable greater technological innovation in the DoD. Other PPBE reform goals may exist; this is not an attempt to create a comprehensive list of ideas for PPBE reform.

Nor is it the goal of this paper to say with certainty what the right evaluation criteria are. The criteria are relatively crude. They require further refinement, possibly through structured elicitation of stakeholders, to truly understand which evaluation criteria are worth including and how they are prioritized. The criteria also require more detailed metrics and measures to enable systematic measurement of the reform proposals. Finally, even if all of these improvements were made, PPBE reform is an inherently political endeavor and systemic evaluation can only inform the eventual direction of reform, not determine it.

Nevertheless, the analytical exercise described in this paper offers some insight into the contours of the PPBE reform debate. In connecting reform proposals to the underlying values (in the form of evaluation criteria) that they emphasize or de-emphasize, we can bring those values into explicit view. This gives policymakers a more complete picture of the potential positive *and* negative impacts of any PPBE policy reform proposal.

References

Chu, D. S. C, & Bernstein, N. (2003). Decision-making for defense (Eds. S. E. Johnson, M. C. Libicki, & G. F. Treverton). RAND.

Enthoven, A. C., & Smith K. W. (1971). *How much is enough? Shaping the defense program, 1961–1969.* Harper & Row.

Greenwalt, W., & Patt, D. (2021). *Competing in time: Ensuring capability advantage and mission success through adaptable resource allocation.* Hudson Institute.

Hale, R. F. (2021). *Financing the fight: A history and assessment of Department of Defense budget formulation processes.* Brookings.

Hatry, H. P. (2006). *Performance measurement: Getting results.* Urban Institute Press.

Lofgren, E. M. (2021). The DoD budget process: The next frontier of acquisition reform. George Mason University Center for Government Contracting. https://business.gmu.edu/news/2021-10/no-5-dod-budget-process-next-frontier-acquisition-reform

Mayer, L. A., Arena M. V., Camm, F., Wong, J. P., Lesnick, G., Lovell, S., Fernandez, E., Carter, P. & Lee, G. T. (2020). *Prototyping using other transactions: Case studies for the acquisition community.* RAND.

McGarry, B.W. (2021). Defense primer: DoD transfer and reprogramming authorities. Congressional Research Service. https://sgp.fas.org/crs/natsec/IF11243.pdf

McGarry, B.W. (2021). Defense primer: Planning, programming, budgeting, and execution (PPBE) process. Congressional Research Service. https://sgp.fas.org/crs/natsec/IF10429.pdf

Richard, P. J., Devinney, T. M., Yip, G. M., & Johnson, G. (2009). Measuring organizational performance: Towards methodological best practice. *Journal of Management, 35*(3). https://doi.org/10.1177/0149206308330560

Ryan, G. W., & Bernard, H. R. (2003). Techniques to identify themes. *Field Methods, 15*(1), 85–109. https://doi.org/10.1177/1525822X02239569

Serbu, J. (2021, December 29). Pentagon’s ponderous budget process is next target for Congressional reform. Federal News Network. https://federalnewsnetwork.com/defense-main/2021/12/pentagons-ponderous-budget-process-is-next-target-for-congressional-reform/

Snyder, D. (2022). *Funding technology-related business initiatives in the Department of the Air Force.* RAND.

Spoehr, T., & Bartels, F. (2022, January 13). Reforming the Defense Department’s planning, programming, budgeting, and execution process. War on the Rocks. https://warontherocks.com/2022/01/now-the-hard-work-begins-five-principles-to-guide-the-planning-programming-budgeting-and-execution-commission/

Wong, J. P., Younossi, O., Kistler LaCoste, C., Anton, P. S., Vick, A. J., Weichenberg, G., & Whitmore, T. C. (2022). *Improving defense acquisition: Insights from three decades of RAND research.* RAND.

Wong, J. P. (2020, December 15). Bad idea: Overly focusing on speed in development and acquisition. Center for Strategic and International Studies. https://defense360.csis.org/bad-idea-overly-focusing-on-speed-in-development-and-acquisition/

Resourcing a Mosaic Force: Lesions from an Acquisition Wargame

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Abstract

DARPA has an ambitious vision for Mosaic Warfare, conceived by its Strategic Technology Office (STO) leadership as both a warfighting concept and a means to greatly accelerate capability development and fielding. Although the success of Mosaic depends on DARPA advancing multiple technologies, the Mosaic vision is inherently more challenging to "transition" than is a program or technology. Anticipating this challenge, DARPA sponsored RAND to examine the opportunities and challenges associated with developing and fielding a Mosaic force under existing or alternative governance models and management processes, as would be required for the vision to move from DARPA to widespread acceptance by DoD. To this end, RAND designed and executed a policy game that immersed participants in the task of fielding a Mosaic and required them to operate within the authorities, responsibilities, and constraints of the existing and an alternative governance model. This article presents select findings on the capacity of the existing acquisition resourcing system (i.e., the Planning, Programming, Budgeting, and Execution [or PPBE] process) to exploit STO's vision of Mosaic Warfare.

Preface

This research was sponsored by the DARPA's Strategic Technology Office and conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community. For more information on the RAND Acquisition and Technology Policy Center, see www.rand.org/nsrd/ndri/centers/atp or contact the director (contact information is provided on the webpage).

Introduction

DARPA has an ambitious vision for Mosaic Warfare, conceived by DARPA's Strategic Technology Office (STO) leadership as both a warfighting concept and a means to greatly accelerate capability development and fielding. Although the success of Mosaic Warfare depends on DARPA advancing multiple technologies (Clark et al., 2020), STO's Mosaic vision is inherently more challenging to "transition" than is a program or technology. Anticipating this challenge, DARPA sponsored RAND to examine the opportunities and challenges associated with developing and fielding a Mosaic force under existing or alternative governance models and management processes, as would be required for the vision to move from DARPA to widespread acceptance by the DoD.

This article focuses on a subset of the results of a larger study on the “big A” acquisition implications of Mosaic Warfare.[26] Specifically, this article focuses on the intersection of the status quo resourcing system (i.e., the Planning, Programming, Budgeting, and Execution [or PPBE] process) and Mosaic Warfare. Given the recent attention on defense resourcing reform and the importance of the PPBE-based barriers to acquiring a Mosaic force that were identified during the larger study, we believe this to be an opportune time to highlight this set of our larger findings.

Conceptualizing Mosaic Warfare

A complete survey of Mosaic as a warfighting concept is beyond the scope of this report but can be found in other sources (Clark et al., 2020; Deptula et al., 2019; Grana et al., 2021; Grayson, 2018; O'Donoughue et al., 2021). Briefly, Mosaic Warfare is conceived by STO leadership as both a warfighting concept and a means to greatly accelerate capability development and fielding. With regard to warfighting, Mosaic Warfare entails a more fractionated, heterogenous force that can be dynamically composed on tactical timelines into unique force packages to surprise and overwhelm an adversary. As such, Mosaic Warfare entails shifting away from a focus on monolithic platforms, which are slow-to-develop and slow-to-field, to focus on simpler force elements that can be developed and fielded quickly and integrated at mission execution.

At the top level, the Mosaic concept envisions a U.S. Force characterized by three properties.

> *Fractionation*. Fractionation refers to the extent to which the capabilities of a military force are concentrated on particular weapons platforms. A monolithic or non-fractionated force locates a large number of capabilities on one platform; the F-35 is perhaps the canonical example of a monolithic platform, with the capabilities of a sensor, shooter, command control node, electronic warfare, and others all integrated on a single platform. In contrast, a fractionated force spreads such functions and capabilities across an array of platforms. Mosaic Warfare envisions a more fractionated U.S. force.
>
> *Heterogeneity*. Heterogeneity refers to the extent to which the platforms in a military force possess distinct capability sets. In a homogeneous force, platforms have a high degree of capability overlap. As the DoD transitions away from legacy fourth generation fighters to the F-35, by definition the U.S. TACAIR fleet will grow more homogenous, notwithstanding differences between F-35 variants and what will be an ever-evolving series of incremental capability upgrades. In a heterogeneous force, platform capabilities will have less commonality and more diversity; for example, the

[26] The full report is available open access and can be found at the following link: https://www.rand.org/pubs/research_reports/RRA458-3.html

same electronic warfare effect might be delivered by a UAV, an aerostat, or a low-cost cruise missile. Mosaic Warfare envisions a more heterogeneous U.S. Force.

Composability. Composability refers to the extent to which force elements can be dynamically combined in different ways to deliver an operational effect. A highly non-composable force would be constrained to fixed, pre-specified kill chains embodied by a codified system architecture; the Ballistic Missile Defense system represents an archetype. A highly composable force eliminates the concept of an architecture, allowing kill chains to be created dynamically from the force elements available at the time of mission execution. Mosaic Warfare envisions a more composable force, where an AI-enabled decision aid will facilitate the force package composition function at the time of mission execution.

For purposes of this report, we will assume that a force with these properties is militarily advantageous and technically feasible. However, let us briefly comment on the operational and acquisition-related advantages of Mosaic Warfare as conceived by DARPA.

In terms of operations, Mosaic Warfare proponents expect that a fractionated, heterogeneous, and composable force will increase the adaptability, scalability, and unpredictability of the U.S. Force. The current force, it is argued, comprises force packages that are self-contained or part of fixed system-of-systems architectures and thus limited in terms of the distinct force presentation permutations available. In contrast, a Mosaic force will decompose force packages into a larger number of more varied elements, thereby increasing the number, resiliency, and ultimately the effectiveness of force packages available for employment by U.S. Commanders. Clark et al. (2020, p. 27) succinctly characterize some of the hypothesized warfighting advantages of Mosaic Warfare, stating:

> The central idea of the Mosaic Warfare concept is to create adaptability and flexibility for U.S. Forces and complexity or uncertainty for an enemy through the rapid composition and recomposition of more disaggregated U.S. Forces using human command and machine control.

DARPA also anticipates that Mosaic Warfare may accelerate the weapons system acquisition and fielding process. The development of complex multi-mission platforms is slow and expensive. Much of the cost and schedule expended in the development of these platforms stems from a requirements system that attempts to forecast general purpose requirements, which tend to prescribe costly, complex solutions embodied by monolithic solutions. By fractionating systems–and therein decreasing the average complexity of systems in the acquisition pipeline, Mosaic Warfare is anticipated by DARPA to entail individually simpler systems that are subject to less cost, schedule, and performance risk; defer integration challenges to the mission-level; and result in a flexible, modular force that can be continually upgraded over time. Deptula et al. (2019) explain that the functional effect of transitioning to a Mosaic force composition on acquisition and fielding may be to realize the benefits sought during the many recent rounds of acquisition reform, affirming,

> Incrementally migrating the current force to a system of disaggregated capabilities is an approach that could finally achieve the goals that many of DoD's previous attempts at acquisition reform have sought.

The elements of a Mosaic force also can be expected to be more autonomous, expendable, and short-lived than the technologies comprising today's force. These traits may positively reinforce the core Mosaic concepts of fractionation, heterogeneity, and composability. For example, autonomous systems may hasten the anticipated speedup in fielding by eliminating certain portions of the operator training cycle. Expendable systems can be expected to eliminate time-intensive sustainment processes such as repair, maintenance, and upgrading. Shorter weapon system lifespans may obviate the cost and schedule implications of a requirement to maintain long (e.g., 30 year) service lifetimes.

To be sure, this is an abbreviated if not incomplete description of DARPA's vision for Mosaic Warfare. However, it suits our purpose of introducing Mosaic Warfare in sufficient detail to motivate several assumptions. We refer the reader to references cited within the preceding discussion for further information on Mosaic Warfare.

In the following section, we briefly describe the acquisition policy game designed to explore the consequences of acquiring a Mosaic force within the current and an alternative governance models.

Game Design

For the purposes of the larger study on which this article draws, we were principally interested in the implications of Mosaic Warfare for requirements, resourcing, and acquisition. In that context, two hypotheses frame our research.

1. DARPA's vision of Mosaic Warfare can enable orders of magnitude reduction in time for the transition from idea to effect, allowing force development on operational if not tactical timescales.
2. Mosaic Warfare may be necessary but will not be sufficient to achieve such increased throughput—it must be complemented with new approaches to setting requirements, resourcing, and acquisition.

Based on the two hypotheses, we distill two research questions.

1. Are the DoD's existing requirements, resourcing, and acquisition structures and processes compatible with fielding DARPA's vision of Mosaic Warfare? Are those management systems compatible with the envisioned increases in time-effectiveness?
2. If the DoD's current governance systems are not adequate to handle the increased time effectiveness, what are viable alternative governance models and management systems for acquiring a Mosaic force? What are the opportunities, challenges and risks associated with them?

To answer these questions, we reviewed existing studies, spoke to experts, and designed and executed the *Acquiring a Mosaic Force Policy Game* to immerse DARPA representatives and RAND researchers in the task of fielding a Mosaic force and required them to operate with the authorities, responsibilities, and constraints provided to them under existing or alternative governance models and management constructs. In total, we executed two internal (RAND only) play-tests of the policy game while hypotheses and the game design were still in formation and one "capstone" game with combined DARPA-RAND participation once these hypotheses were firmer.

In order to better understand how the current and an alternative governance models would work in conjunction with Mosaic Warfare, we developed a three-part activity, depicted visually in Figure 1. Each activity took the form of a virtual, half-day session conducted. The activities were exercised two times internally, and once with a mixed group of RAND and DAPRA personnel. As detailed above, the activities posited that Mosaic Warfare was technically feasible, was accepted by the DoD, and that an initial suite of capabilities had been successfully fielded. From this starting point, we asked players to consider how the acquisition of both individual capabilities and the Mosaic enterprise as a whole might be managed.

	Half Day 1: Mosaic in Today's System	Half Days 2&3: Mosaic in an Alternative Model
Goal of exercise	Identify conditions under which today's requirements, resourcing & acquisition systems support a Mosaic model	Exercise an alternative to today's management systems to assess viability & identify improvements
Role of participants	Experienced professionals and analysts	Role playing DoD stakeholders

Figure 1. Structure of Three Half-Day Virtual Event

Day 1 focused on how the current acquisition system could accommodate both individual tiles (i.e., specific Mosaic enabler technologies) and a Mosaic force as a whole. This activity was designed to explore the shortfalls of the current system by working to identify "pain points." To do this, we used a format based on previous a RAND game to assessing C2 structures (Alkire et al., 2018). Drawing on the principles of Assumptions Based Planning (Dewar et al., 1993), we provided players with a set of vignettes (two of which are included in Tables 1 and 2 below) describing instances of successful Mosaic acquisition, including descriptions of requirements, resourcing, contractor selection and management, testing and evaluation, fielding, and maintenance and sustainment. Players were then asked to describe what assumptions would have to hold true in today's system for the vignette to play out as described. A facilitator then led a discussion regarding the reasonableness of those assumptions. This process allowed players to grapple with the difficulty of making Mosaic Warfare work under the current rules and processes, adding to our understanding of the barriers to acquiring a Mosaic force.

The second two activities changed the focus from examining Mosaic under the current system to exploring Mosaic acquisition under an alternative system. While these activities drew on lessons from past work on acquisition policy gaming (Bartels et al., 2020), the activities that were used during days two and three was designed specifically for exploring acquisition under a Mosaic Warfare construct. This allowed us to explore the interaction between a pipeline of Mosaic capabilities and an alternative acquisition system designed to accommodate Mosaic acquisition.

Entering days two and three, the research team presented the Joint Mission Office (JMO)-centered acquisition model (the details of the JMO as played are described in the full report [Predd et al., 2021].) Activity two focused on how enterprise-level acquisition management might occur under the JMO-centered model. Activity three focused on tile-level decisions under the same model.

In both activities, players were divided into two teams. One team was comprised of players representing the Anti-Surface Warfare (ASuW) JMO. The other team was comprised of players representing traditional institutional players: the Services, COCOMs, and the Office of the Secretary of Defense. A more detailed breakdown of roles is visualized in Figure 2. Players were assigned to roles that mirrored their past expertise. These roles are shown to be seated around the proverbial table in Figure 3. Using experienced players allowed us to depend on participants' mental models of institutional equities, authorities, and processes to bring additional realism and surface concerns about which the RAND design team may not have been aware. Thus, our players added greater fidelity to the representation of the interactions between the JMO and institutional roles.

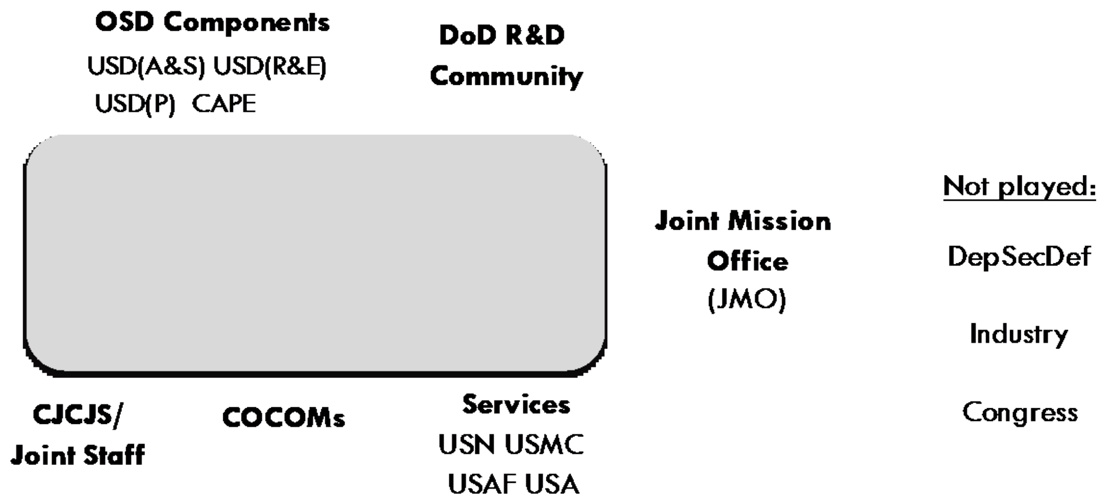

Figure 2. Players Inhabit the Roles of DoD Decision Makers

Players in RAND Play-test I and II

Former DoD officials on RAND staff, e.g.

- Retired O6, Navy rep for JCIDS
- Retired Acting Director CAPE
- Former USD(ATL) Staff member
- Former Navy Dir for Analysis, NAVAIR

Players in DARPA Game

- DARPA STO Leadership & Staff
- Retired OPNAV N81
- Former USD(ATL) Staff member
- Senior Advisor to USD(A&S)

Figure 3. Players' Backgrounds Reflect Assigned Roles

In activity two, players were provided with a portfolio of contrived Mosaic programs (i.e., Mosaic tiles) and a budget and asked to make decisions about what tiles to fully fund, which to keep warm for potential future investment, and which to terminate. For each tile, players were provided with a description of the system and data including estimates of cost, schedule, and anticipated gain in mission effectiveness. JMO players were asked to use these data to develop a strategy for acquisition, while institutional players acted as liaison officers to represent the concerns of their offices. After a first round of decisions, the RAND research team projected how the portfolio would perform the following year, with a specific eye to highlighting the tradeoffs identified in previous stages of research.

The third activity maintained the same general structure as the second: the JMO and institutional teams made sequences of decisions about the acquisition of Mosaic capabilities. However, during the third activity, decisions were made at the level of individual Mosaic tiles. In this activity, we presented players with several key decision points, which sought to elicit potential points of tension between the JMO and institutional actors. The resultant discussion provided confirming evidence to support our preliminary hypotheses, unearthed additional tensions, and offered tension mitigation strategies.

Vignettes

The intersection of the Mosaic Warfare vision and acquisition is sufficiently uncertain and abstract that planners and policymakers may benefit from concrete representations of how Mosaic acquisition would manifest. One way of providing this tangibility is through vignettes, which illustrate possible manifestations in narrative form. The vignettes describe successful "instances" of Mosaic acquisition at the tile- and enterprise-level. The tile-level vignettes are comprised of a set of events associated with the acquisition of a new ELINT sensor, an EW payload, and XLUUV-launched loitering UUV munitions. The enterprise-level vignettes consider Mosaic acquisition at the level of the DoD enterprise. They describe the changes to the force structure, industrial base, and R&D pipeline associated with shifting a portion of acquisition from monolithic platforms to dozens of new short-lived, low-cost, Mosaic tiles (e.g., attrittable platforms, data links, C2 nodes, decision aids, sensors, loitering munitions, small satellites, and counter-UAS systems). The vignettes do not reference any specific acquisition governance model or management system. Instead, they provide generic descriptions of requirements, resourcing, vendor selection, testing and evaluation, fielding, maintenance, and sustainment events for the capabilities in question. In this article, two tile-level vignettes are used to highlight tensions between the PPBE process and Mosaic-style acquisitions.

The Resourcing Function

In the larger study, we conceived of "acquisition" in a very general sense, including the end-to-end timeline that begins with an idea on an engineer's whiteboard and culminates with an operational effect delivered on the battlefield. Today, DoD exercises management control over this process through three primary management systems sometimes referred to as the "Big A" acquisition system: the requirements system, manifested by JCIDS; the resourcing system, represented by PPBE; and the DAS, represented by DoDD 5000.01 and DoDI 5000.02, and more recently by the Adaptive Acquisition Framework.[27] In this article, we are concerned with the PPBE process.[28]

The PPBE process, instituted more than 60 years ago, is the DoD's primary resource allocation managements system. PPBE occurs annually and yields the DoD's contribution of

[27] In fact, there are other relevant management systems in play, including the Global Force Management Process, which governs DoD posture and force allocation, and of course multiple operational planning processes. In the larger study we focus on those traditionally considered part of the big "A" acquisition process.

[28] We do not provide a comprehensive summary of the status quo resources system in this article. The current (as of March, 2021) DoD guidance on the PPBE Process is documented in DODD 7045.14 (effective date Aug 2017).

the President's annual budget request. It is also used each year to update the DoD's Future Years Defense Program (FYDP).

At least two features of PPBE process have implications for the acquisition of Mosaic force. First, PPBE is a calendar-driven process involving a roughly two-year gap between the resource allocation decision and the date at which these resources are available for use. Second, PPBE is inflexible with regard to re-allocating funds. The implications of these features are manifold. The section to follow elaborates several of these implications for the prospect of acquiring a Mosaic force.

The Resourcing Function and Acquiring Mosaic Capabilities

A general finding from our analysis is that the PPBE process has limited flexibility to accommodate a warfighting concept that relies on agility in terms of what capabilities are pursued and by whom. Two features of the current PPBE process were identified by players to be particularly significant impediments to acquiring a Mosaic force. These features, along with their implications for fielding a Mosaic force, are elaborated below, and summarized in Table 3.

We arrived at these findings, in part, by considering how the incumbent resourcing system might accommodate a series of hypothetical acquisition events. These vignettes were provided to participants during day one of our "Acquiring a Mosaic Force" game. The vignettes are meant to be emblematic of the types of capability acquisitions envisioned by Mosaic Warfare. They are used here to highlight the interaction of the PPBE process and Mosaic-style acquisition.

PPBE is a Calendar-Driven Process Involving a Two-Year Gap Between Resource Allocation and Resource Availability

Under the current system, funding for a program must be requested approximately two years prior to the allocation of funds. This feature of the PPBE process has at least three consequences that are at odds with fielding a Mosaic force.

First, the planning-to-resourcing gap forestalls the ability to realize novel capabilities via unanticipated technology opportunities. Table 1 describes the events associated with "Capability Thread A," a technology-push acquisition of a new ELINT sensor. Within the same fiscal year, the decision is made to integrate the ELINT sensor onto fielded aerostats, a firm is put on contract, technology integration takes place, and the capability is tested during a live fire exercise. The PPBE process requires that funding used in a given year, be planned at least two years prior. In the events described in Table 1, the technology opportunity and the resource allocation occur within the same fiscal year. During the game, participants identified this inconsistency, observing that the while the traditional PPBE process may be able to handle such acquisitions on a small scale, the incumbent resourcing model could not likely accommodate the volume of such acquisitions that would be required to field a Mosaic force.

Table 5. Vignette (Capability "Thread") A—Leap Forward Sensor Tech

Events (all occur within a single year)
• A.1. A small firm demonstrates a promising new ELINT sensor on a medium rotary-wing UAS at White Sands. • A.2. Analysis shows 20% improvement in mission (ASuW) effectiveness in 20% of scenarios analyzed with 80% probability if the sensor is integrated onto either a medium UAS or an aerostat. • A.3. Analysis shows the sensor outperforms other fielded ELINT sensors as well as those already in the enterprise-wide development pipeline. • A.4. An in-year decision is made to fund integration of the sensor onto a fielded aerostat. • A.5. The small firm is put on contract to produce enough units of the sensor to achieve the net-mission effectiveness improvement as government furnished equipment (GFE) provided to the prime aerostat sustainment contractor for integration. • A.6. The prime contractor delivers and installs an initial set of sensors onto aerostats assigned to a Naval task force ahead of a Pacific exercise, at an additional, unplanned cost representing 5% of the aerostat's program's yearly budget. • A.7. The capability is demonstrated in live fire exercises as part of a kill chain that uses aerostats to cue land-based fires against naval SAMs.

The events described in Table 2 underscore another point of friction between Mosaic Warfare and PPBE: that of quickly resourcing a capability to respond to a change in the threat environment. Table 2 describes a series of hypothetical events whereby a threat (i.e., Chinese near-real-time situational awareness of U.S. movements via a long range UAS) is identified, a means of mitigating that threat is found, and funds are allocated to develop and integrate the new technology. Put plainly, Table 2 describes an acquisition system responding rapidly to a new threat. Again, participants in our game, indicated that the PPBE process was unlikely to accommodate such acquisitions *en masse* (as would be required by a Mosaic Force).

Table 2. Vignette (Capability "Thread") B—Emergent Critical Requirement Gap

Events (all occur within a single year)
• B.1. Intel reports a previously unknown Chinese long range UAS is being tested that is capable of providing near-real-time situational awareness of U.S. movements in potential future engagements. • B.2. Analysis confirms that, unimpeded, the new UAS threat may degrade mission (ASuW) effectiveness by 20% in 30% of scenarios analyzed, representing a significant requirements gap. • B.3. Analysis shows that fielding a previously prototyped yet never fielded Air Force-developed RF effector payload to Group 3 (< 1,320 MGTOW) UASs could function as an effective countermeasure to the Chinese UAS and largely mitigate net-mission effectiveness losses. Further, there is a potential force multiplication effect provided if this RF effector is fielded in concert with the sensor in Capability Thread A. Analysis suggests that if the RF effector and ELINT sensor are both fielded there is an 70% probability that anticipated mission (ASuW) effectiveness increase of as much as 30% in 35% of future scenarios analyzed. • B.4 The Air Force contracts with multiple companies (totaling 4 years, $166,000,000) to ramp up on the mothballed payload, mature the technology, and explore its performance on seven different existing platforms, as well as consider adapting existing platforms not currently in DoD use. • B.5. Field tests are conducted at the Air Force Test Center in California that reveal unforeseen challenges in integrating the RF effector payload onto existing Group 3 UAS. • B.6. A decision is made to retire an U.S. Air Force R&D project to overcome integration challenges and expedite fielding of the system.

Third, the two-year resource allocation waiting period limits new- and non-traditional firm entry into DoD contracting. Mosaic Warfare requires a highly robust technology pipeline, and its advocates seek that this pipeline be populated in large part by technologies developed by non-traditional vendors. Non-traditional defense contractors such as startups or civilian-servicing firms often lack the resources or willingness to wait two years before receiving funding.

PPBE is Inflexible with Regard to Re-allocating Resources

Within the current resourcing system, the primary means of reallocating funds in the year of execution—reprogramming—is inflexible. For example, a PEO's below threshold reprogramming (BTR) for RDT&E is just 20% of the RDT&E cost or $10 million (whichever is lesser). For procurement, the PEO's BTR is 20% of procurement cost or $20 million (whichever is lesser). This gives PEOs very little flexibility to reallocate resources to adjust to novel threats or take advantages of emergent technology opportunities.

Above the threshold reprogramming (ATR) requires passing an arduous Congressional approval process. Besides slowing the process of funds reallocation, the need for Congressional approval requires the DoD to expend scarce political capital. When players explored the source of funding for Mosaic-type acquisitions as described in Tables 1 and 2, players commented on the impracticality of relying on reprogramming for capabilities of relatively low cost—put bluntly, the bureaucratic costs of securing congressional support outweighed the limited value of each individual Mosaic capability, and the value of the Mosaic force as a whole would get lost in the small-scale transactions required under the status quo.

Another effect of inflexible funding is technology lock-in. The technological approaches or components used within a program were selected based on estimates of technical maturity and rates of technological change made years prior to the point at which they are ready to be integrated into a given weapons system. At integration time, it is therefore possible that the chosen approach is not sufficiently mature or is no longer the best solution with respect to cost or performance. In such cases, switching to a different component may be warranted. However, the rigidity of the reprogramming function often precludes such switching, resulting in the use of a component technology that is no longer optimal for the system in question.

Table 3. PPBE Features, Consequences, and Contrast to Mosaic Warfare

Feature of Current Resourcing System	**Consequence**	**Mosaic Warfare Seeks**
PPBE is a calendar-driven process involving a two-year gap between resource allocation and resource availability	Limits ability to respond to unanticipated technology opportunities	Ability to rapidly incorporate new technology into force
	Limits responsiveness to threats	Responsiveness to a dynamic threat environment
	Limits new- and non-traditional firm entry into defense innovation marketplace	A defense innovation system comprised of a greater diversity of contributing organizations
PPBE is inflexible with regard to re-allocating resources	Limits ability to respond to unanticipated technology opportunities and threats	Ability to rapidly incorporate novel technology into force and respond to threats
	Encourages technology lock-in	Ability to rapidly switch technological approaches

Conclusion

The findings presented here are not necessarily novel; the ailments of the PPBE process have been observed by many.[29] However, the use of an acquisition policy game provides a novel source of evidence in assessing acquisition system performance. In addition, the policy game that we designed proved to be a useful way of experimenting with alternative governance models. Placing DoD representatives in the mode of decision makers operating within the Mosaic model allows for insights that would not be easily deduced from mere logic. While not reported here, a variety of lessons were learned that could improve subsequent games—thus continuing the iterative learning process of formulating refined hypotheses, adapting and executing games, and so on. We suggest that DARPA and other defense agencies continue to experiment with alternative acquisition governance systems and management systems.

DARPA's vision of Mosaic Warfare is ambitious, compelling, and seemingly responsive to many attributes of the emerging technological and security environment. Transitioning this vision to widespread DoD acceptance may well require strong proponents across the DoD to create change within institutions that today may—given their accrued equity in longstanding governance structures—in certain cases view the status quo as an end rather than a means. We advise the proponents of Mosaic Warfare to be mindful of falling into the same trap by making Mosaic an end rather than a means. Like all emerging visions for the future of American warfighting, the ultimate test for Mosaic will be its contribution to the United States' ability to deter and defeat adversary aggression.

References

Alkire, B., Lingel, S., & Hanser, L. (2018). *A wargaming method for assessing risk and resilience of military command-and-control organizations.* RAND Corporation.

Clark, B., Patt, D., & Schramm, H. (2020). *Mosaic warfare exploiting artificial intelligence and autonomous systems to implement decision-centric operations.* CSBA, Center Strategic Budgetary Assessments. https://csbaonline.org/uploads/documents/Mosaic_Warfare_Web.pdf

Deptula, D. A., Penney, H. R., with Stutzriem, L. A., & Gunzinger, M. A. (2019, September). *Restoring America's military competitiveness: Mosaic warfare.* The Mitchell Institute for Aerospace Studies. http://docs.wixstatic.com/ugd/a2dd91_29e021b297f2492ca7f379d31466ad0c.pdf

Dewar, J. A., Builder, C. H., Hix, W. M., & Levin, M. H. (1993). *Assumption-based planning: A planning tool for very uncertain times* (MR-141-A). RAND Corporation.

Grana, J., Lamb, J. & O'Donoughue, N. A. (2020). *The benefits of fractionation in competitive resource allocation* (WR-1329). RAND Corporation. https://www.rand.org/pubs/working_papers/WR1329.html

Grayson, T. (2018, July 27). *Mosaic warfare*. https://www.darpa.mil/attachments/STO-MosaicDistro-A.pdf

Lempert, R. J., Popper, S. W., & Bankes, S. C. (2013). *Shaping the next one hundred years: New methods for quantitative, long-term policy Analysis* (MR-1626). RAND Corporation.

O'Donoughue, N. A., McBirney, S. & Persons, B. (2021). *Distributed kill Chains: Drawing insights for mosaic warfare from the immune system and from the Navy.* RAND Corporation. https://www.rand.org/pubs/research_reports/RRA573-1.html

Predd, J. B., Schmid, J., Bartels, E. M., Drezner, J. A., Wilson, B., Wirth, A. J., & McLane, L. (2021). *Acquiring a mosaic force: Issues, options, and trade-offs.* RAND Corporation. https://www.rand.org/pubs/research_reports/RRA458-3.html

[29] Eric Lofgren of Acquisition Talk has compiled an excellent list of calls for budget reform from prominent sources. They can be found here: https://acquisitiontalk.com/budget-reform/

Pathways to Defense Budget Reform

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Abstract

The Planning-Programming-Budgeting-Execution (PPBE) process is the most powerful system of incentives affecting acquisition management in the Department of Defense. It is the conduit to money. A key feature of PPBE is the program of record concept that relies on a multi-year planning process. Not only does the program of record hamper technology adoption through adherence to baselines, it creates barriers to interoperability by stovepiping program decisions. Many researchers have detailed the inadequacies of PPBE and the need for embracing a portfolio management approach that aligns with best practices found in commercial and international organizations. This paper dives deeper into the history of how the legislative and executive branches managed defense budget portfolios in the 1960s and before, as well as how PPBE upended those traditional processes. First, it traces the reduction in execution flexibility over time by documenting the budget structure and thresholds for reprogramming. Second, it examines criteria for effective oversight in the PPBE and portfolio settings. The paper concludes that execution flexibility in the form of portfolio budgeting is not only consistent with economic efficiency, it is consistent with United States traditions of congressional control.

Keywords: PPBE, Budgeting, Portfolio Management, Oversight, History

Introduction

Reformers can't know where they are going if they don't know where they've been. The Department of Defense is a complex institution that underwent radical change in the 1960s with the advent of the Planning-Programming-Budgeting-Execution process (PPBE). It had a profound effect not just on bureaucratic processes, but on the ability of innovators to field game-changing weapons systems. There has been a growing recognition of the need to reform the industrial age PPBE process so that the United States can outpace peer-competitors like China and Russia in military technology. Senator Jack Reed said of PPBE, "It is likely too slow and cumbersome to meet many of the DoD's requirements to adopt new technologies in a rapid, agile manner." Representative Adam Smith said, "We've got to give the Pentagon greater flexibility in terms of moving money around so that they're not locked into a two-year or five-year cycle." Former Representative Mac Thornberry wrote how "today's rapid innovation and technological change renders our industrial age approach to funding obsolete" (Lofgren, 2022).

The recognition that PPBE requires change led to action. The FY 2022 National Defense Authorization Act created the Commission on PPBE Reform. While the commission has a broad mandate, an emerging consensus in PPBE reform is the need for portfolio management. The National Security Commission on Artificial Intelligence, for example, recommended accelerating "efforts to implement a portfolio management approach for requirements and budget" (NSCAI, 2021). Representative Seth Moulton agreed to look at a "mission-based pilot" to "restructure funding so that it's tied to missions instead of specific hardware" (Hudson, 2021). Other studies have also detailed the importance of portfolio budgeting to acquisition innovation (e.g., Lofgren, 2020; Patt & Greenwalt, 2021; Modigliani et al., 2021).

This paper will examine the historical context of portfolio management in defense acquisition. It presents the idea that there was wisdom to traditional methods of appropriations and oversight that offers a pathway to thinking about future reforms. Two important areas include: (1) a discussion of how the budget structure and reprogramming authorities have changed over time; and (2) an investigation of the criteria for effective transparency and oversight. It will show that execution flexibility has dramatically decreased since the introduction of PPBE, affecting defense officials' ability to adapt to change. It will also show how PPBE replaced value-focused oversight with universal metrics based on performance to baseline. It concludes that budget portfolios are compatible with congressional control, and that traditional methods can be updated to reflect new capabilities available in the 21st century.

Budget Structure and Execution Flexibility

The structure of the budget and the process for reallocating resources in execution are intimately tied. When budget lines are finely-tuned to specific projects multiple years in advance, changes are inevitable by the time defense officials execute the funding. There could be contract delays, emergency situations, political factors, unexpected inflation, new technologies, evolving threats, and any number of fact-of-life changes. During the 1960s and 1970s, defense officials not only lost their ability to make cost-schedule-technical tradeoffs within programs, they also lost flexibility to reallocate resources between programs. This section will outline how PPBE led to a significant reduction in defense execution flexibility.

Though it is hard to imagine for many defense officials in the 21st century, there was no Congressional authorization process prior to 1959. In this context, "authorizations" establishes activities performed by the government whereas "appropriations" finances those activities. In years past, Congress would provide lump-sum appropriations to the President who then had broad discretion in defense programming. The discretionary tradition of appropriations went all the way back to the founding fathers. The foundation was set in 1801. President Thomas Jefferson intended to request "specific sums to every specific purpose susceptible of definition." Alexander Hamilton strongly disagreed, and so did Jefferson's Secretary of Treasury. Eventually, Jefferson admitted that "too minute a specification has its evils" (Fisher, 1971).

Logical controls were added to financial management over time. The Anti-Deficiency Act of 1905 made sure departments could not obligate funds in excess of the amount appropriated. The Budget and Accounting Act of 1921 required the president to submit a complete budget request along with simplified line itemization of spending categories. Although the President was not legally bound to obligate funds to anything more specific than what Congress writes into law, there existed a custom that they would be obligated according to the line items presented in budget justification documents. Still, movement of funds occurred under various names like "adjustments," "interchangeability," or even "transfers." Only the particular context made it clear whether the action occurred between appropriations or between line items within an appropriation (Fisher, 1975). In World War II, the need to move funds for emergency situations was high. Congress provided a "transferability clause" which allowed the departments to unilaterally move funds across appropriations by up to 10% percent (*Department of Defense Reprograming of Appropriated Funds*, 1965).

In the early post-WWII years, the defense budget continued on a traditional basis. Until FY 1952, the Army and Navy proposed budgets based on appropriations that were essentially organizational in structure, and budget line items based on two classifications: by activity and by object. For example, the Army's FY 1950 request had an organic appropriation of "Ordnance Service and Supplies" totaling $730 million. That figure was broken down into 13 budget activities including $103 million for "Procurement of artillery," $48 million for "Research and development," and $1 million for "Ordnance military training." The $730 million appropriation was broken down in a second way, according to nine objects of expenditure including $293 million for "Equipment," $132 million for "Personal services," and a mere $54,900 for "Printing and binding." This budget structure provided major organizational units broad flexibility in terms of allocating resources to particular weapons projects.

While "Ordnance Services and Supplies" was one large appropriation, the Army also had several small appropriations scattered throughout, such as "Expenses of Courts-Martial," "Promotion of Rifle Practice," and "Salaries" for sixteen different offices in Army headquarters. While some accounts were small, the program objectives related to development and procurement were relatively unconstrained except by budget ceilings and high-level policies.

In order to rein the services in from duplication, competition, and overlap, the budget was reorganized for FY 1952 to adopt the Hoover Commission's principles of performance budgeting. The first step was to re-classify the appropriations from broad organizations to investment and expense accounts like Research, Development, Test & Evaluation (RDT&E), Procurement, and Operations & Maintenance (O&M). This had the effect of simplifying the appropriations structure, reducing accounts from as much as 186 to roughly 40 (*Organizing for National Security*, 1961). The budget lines underneath the reorganized appropriations continued to be presented to Congress on the traditional basis of activities and objects of expenditure. The effect was to simplify the budget structure and broaden DoD discretion.

The Hoover Commission, however, intended budgetary classifications to be based upon functions, projects, and outputs. This could allow the Secretary of Defense to assign priorities and eliminate competition amongst the services through budgetary review alone. The DoD standardized the budget activities it submitted to Congress along a program basis. For example, the Army Procurement appropriation had programs including "Vehicles (Noncombat)," "Weapons," and "Ammunition." These programs included projects and sub-activities that were not submitted to Congress. The "Weapons" program included projects like "Artillery," "Small Arms," and "Chemical Weapons" (Mosher, 1954). Even project-level budgets in the 1950s represented broad portfolios.

Defense officials could not only freely move funds within budget activities, they retained flexibility to reallocate funds. Wilfred McNeil, the first Assistant Secretary of Defense Comptroller from 1949 to 1959, told Congress that in his tenure the DoD would often shift funds between budget lines, such as "between guns and ammunition, or between guns and trucks." However, Congressional approval was sought for major deviations. McNeil provided an analogy:

> If I were in business and borrowed $10,000 from the Riggs National Bank and said I wanted to put $9,000 in inventory and $1,000 in show cases, then I would not go out and spend $5,000 for show cases and $5,000 for inventory without going in and discussing it with the loan committee. (*Department of Defense Reprograming of Appropriated funds*, 1965).

The appropriations committee report for FY 1956 recognized that "rigid adherence to the budgetary activity and the budget breakdowns might unduly jeopardize the effective accomplishment of the planned program in the most businesslike and economical manner." However, the report explained that "it has never been, nor is it the intention of the committee this time, to permit the military departments to have unrestricted freedom in reprogramming." Appropriators asked defense officials to respect "the integrity of the justification presented in support of the budget requests" (Report, 1955).

Following the report in December 1955, DoD Instruction 7250.5 was issued outlining procedures and reporting for reprogrammings, or the moving of funds between budget lines. Actions requiring Congressional prior approval included: (1) actions greater than 5% for budget activities less than $200 million; (2) actions of $10 million or more for budget activities $200 million or more; and (3) actions in which the committee has "shown a specific interest" (*Department of Defense Reprograming of Appropriated Funds*, 1965). The level of reprogramming remained high with budget activities. For example, the FY 1956 budget request for Navy "Major Procurement and Production" totaled $2.9 billion and showed 11 budget activities including $755 million for "Aircraft," $1.3 billion for "Ships and harbor craft," and $30 million for "Combat vehicles" (*Department of Defense Appropriations for 1956*, 1955). Within the budget activities, defense officials retained broad discretion to make tradeoffs between particular weapons projects such as between classes of ships or types of aircraft. However, regular congressional reporting was added to the DoDI 7250.5 in October 1959 at the request of appropriators. The reports listed DoD-approved reprogramming action greater than $1 million for RDT&E and O&M, and greater than $5 million for Procurement (*Department of Defense Reprograming of Appropriated Funds*, 1965). Early in 1960, DoD started notifying Congress immediately after a reprogramming whereas before it compiled them into reports every six months (*Department of Defense Appropriations for 1961*, 1960).

Starting in 1961, Secretary of Defense Robert McNamara began implementing the Planning-Programming-Budgeting System (PPBS) which sought to add programmatic definition to budget preparation. Charles Hitch, one of the founders of the PPBS, became McNamara's Assistant Secretary of Defense (ASD) Comptroller and described how it worked to Congress. The basis of the budget would result from analyses of program elements. For example, in the RDT&E title, the Army contained 24 program elements that included particular weapons like the Pershing missile and Mauler anti-aircraft system, as well as broader portfolios like "Aircraft propulsion systems" and "Tactical communications." The Navy had just 10 program elements in RDT&E, and the Air Force 17. There were an additional seven program elements in Space Systems and three in the Advanced Research Projects Agency (*Organizing for National Security*, 1961).

In support of the FY 1964 appropriations, Hitch presented a chart comparing the budget structure to the program structure. The RDT&E budget title included five appropriations and a total of 26 budget activities. The request to Congress was supported by 325 RDT&E sub-activities, themselves made up of 1,385 technical projects, and 15,000 tasks. The sub-activities also supported a separate program structure that consisted of program elements and major force programs. The chart presented by Hitch is reproduced in Figure 1 below. While the budget structure was presented to Congress, program funding was not shown publicly.

Senator Richard Russell asked Hitch why the DoD did not create "specific appropriations" for the sub-activities rather than "having it hidden in the appropriations." Hitch responded that Bureau of Budget deputy director Elmer Staats objected. As Hitch recounted it, Staats wrote a letter that "simply states they have no other practical way of handling this matter than the way it has been handled in the past" (*Department of Defense Appropriations for 1964*, 1963a). Program estimates had long been detailed to Congress in appropriations and other hearings, but they were never married to the budget request.

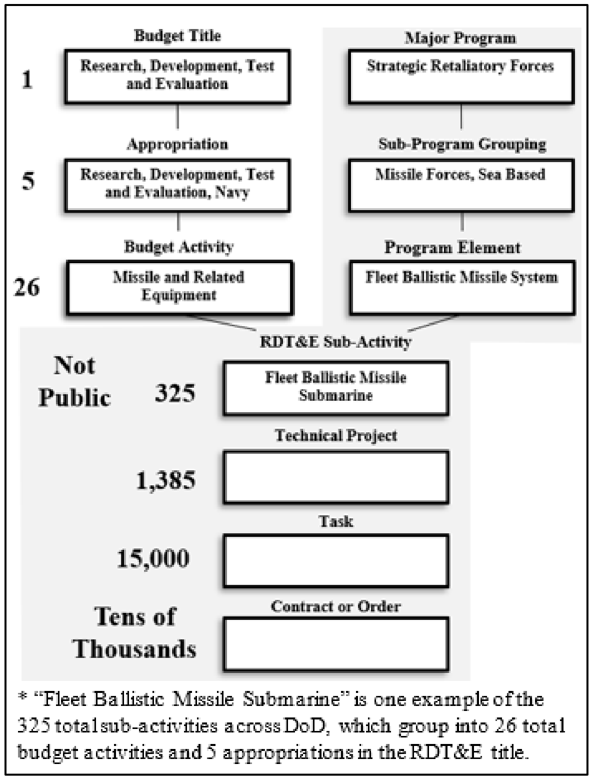

Figure 1. Budget Structure and Program Structure in FY 1963

A major incident sparking a change in reprogramming authorities was when the Navy started construction of five Fleet Ballistic Missile submarines in 1961 without approval from Congress. On March 20, 1961 Chairman of the Appropriations Committee George Mahon wrote to McNamara requesting committee prior approval to four areas of reprogramming:

1. Procurement of items omitted or deleted by Congress.
2. Programs for which specific reductions in the original request were made by Congress.
3. Programs which had not previously been presented to or considered by Congress.
4. Quantitative program increases proposed above the programs originally presented to Congress.

McNamara accepted the first two points, but not the last two. Chairman Mahon largely agreed to the more modest prior approval procedure (Fisher, 1975). McNamara had already created a program change control system, personally making 400 reprogramming decisions at the budget sub-activity level between spring of 1961 and the close of 1962 (*Department of Defense Appropriations for 1964*, 1963a). McNamara verified early in 1963 that prior approval was only required when the DoD "proposed to act contrary to the stated desires of the committee." For example, if a committee reduced a request from $100 million to $80 million on a particular project. Representative Melvin Laird, who later succeeded McNamara as Secretary of Defense, remained confused. Sub-activities like the Gemini and Dyna-Soar being discussed for reprogramming had "never been listed" in Air Force budget justifications (*Department of Defense appropriations for 1964*, 1963b).

A March 4, 1963 change reprogramming procedures brought these sub-activities or programs more fully to the attention of Congress. DoD Directive 7250.5 specified three areas of congressional prior approval: (1) items or activities omitted or deleted by the Congress; (2) items or activities for which specific reductions in amounts originally requested were made by the Congress; and (3) any increases in procurement quantity of aircraft, missiles, or naval vessels. Most reprogramming actions, however, remained the purview of the DoD. A new DoD Instruction 7250.10 added reprogramming procedures internal to the DoD that required approval from the Secretary of Defense and prompt notification to the Armed Services and Appropriations committees which could reject the action within 15 days. DoDI 7250.10 outlined three reprogramming procedures: (1) increase of $5 million or more in a budget activity for Military Personnel or O&M appropriations; (2) increase of $5 million in a procurement line item or a new procurement line greater than $2 million; and (3) increase of $2 million to any budget sub-activity line item in RDT&E, or addition of a new sub-activity estimated to be $10 million or more within a three-year period (*Department of Defense Reprograming of Appropriated Funds*, 1965).

Reprogramming actions in the 1960s were relatively high. For example, FY 1961 RDT&E reprogramming was $994 million (*Department of Defense Reprograming of Appropriated Funds*, 1965). Director, Defense Research & Engineering Harold Brown remarked that reprogramming actions were roughly 20% of the RDT&E title in FY 1961. “These actions are instituted by and large by the services,” Brown said. “They are reviewed by the Secretary of Defense Office—by me, as a matter of fact. By and large, they are passed and passed quickly” (*Federal Budgeting for Research and Development*, 1961b).

The reprogramming thresholds outlined in DoDI 7250.10, replaced in 1996 by the Financial Management Regulation (FMR), only required Congressional notification and not prior approval. For example, a reprogramming above the $2 million threshold for RDT&E that did not cross appropriation accounts required Secretary of Defense approval and Congressional notification. It wasn’t until the August 2000 update to the FMR that these reprogramming thresholds were brought under Congressional prior approval as well, further reducing execution flexibility.

Increased controls over reprogramming have not been as restrictive to execution flexibility as increasingly detailed budget line items. Until FY 1971, the DoD submitted its budget request in a format that corresponded to the traditional budget activities and objects of expenditure. Defense program elements and sub-activities were not exposed. Discussions and charts of program elements at congressional hearings had dollar amounts redacted (*Department of Defense Appropriations for 1971*, 1970). The FY 1972 budget request was the first to display program elements and projects underneath them in an appropriations hearing. By this time, the program element also became more detailed in definition; closer to what had been called a budget sub-activity in the early 1960s. In the RDT&E title, each military department had nearly 200 program elements and perhaps five times as many projects. Recognizing the burden of additional detail and control, the DoD submitted its FY 1973 budget with consolidated program elements. For example, Army program elements in RDT&E were reduced from 173 to 85 (*Department of Defense Appropriations for 1972*, 1971; *Department of Defense Appropriations for 1973*, 1972). This had the effect of widening DoD flexibility and triggered a protest from the Senate Armed Services Committee. The DoD subsequently returned to the previous format (Fisher, 1975). That format has seen some evolutions but remains largely the same 50 years later in terms of structure and quantity of budget lines. While Army proposed 173 program elements in FY 1972 RDT&E, the Army proposed 208 in FY 2022.

Long planning timelines and excess detail in budgeted programs will inevitably lead to a misallocation of resources that must be traded off in execution. Defense officials begin programming the budget—deciding on the projects and objectives of weapons acquisition—

two years before Congress releases appropriations to go execute. In reality, the constraint is much worse than that. Acquisition programs require full funding, meaning they have to be linked to a sponsored requirement, run through an analysis of alternatives, and supported by up to 49 documents including a life cycle cost estimate, life cycle sustainment plan, and test and evaluation master plan (GAO, 2015). Before officials are ready to enter the two-year process for PPBE, several years of paper documentation have elapsed. When appropriations become available, it can take another one, two, three, or five years to obligate funding (e.g., award a contract).

While O&M and Military Personnel reprogramming actions are controlled at the higher budget activity level, RDT&E and Procurement actions are controlled at the program element level, also called Budget Line Items (BLIs). The FY 2022 budget request includes 928 unclassified BLIs across the RDT&E title. Half of these BLIs are less than $30 million. The detail of program budget planning restricts tradeoffs and new opportunities not foreseen multiple years ahead of time. For comparison, the median tech startup, mostly working on software applications rather than deep tech, received $53 million in Series C funding from venture capital (Fundz, 2022).

For accounts in the FY 2022 RDT&E title, prior approval is required for any reprogramming action to a BLI that is more than $10 million or 20% of its starting value, whichever is less. Each appropriation title has its own thresholds for reprogramming, summarized in Figure 2 below. All actions above the threshold, called Above Threshold Reprogramming (ATR), must first seek up to 12 layers of approval within the Department of Defense. It can then move to the Office of Management and Budget (OMB) and four congressional committees for final approval. Congressional response takes about 45 days on average (Comptroller, 2015). The total time to approve an ATR ranges from four to six months (Section 809, 2019). Another source found that between FY 2007 and FY 2018, it took the Navy an average of 96 days to complete an ATR transaction from first record to congressional decision. The longest was 236 days (Fritsch, 2020). Roughly 30 prior approval reprogramming packages get submitted each year averaging less than $8 billion annually between FY 2000 and FY 2020 (McGarry, 2020).

Below the reprogramming thresholds, the DoD has flexibility to move funding. Comptroller DD1416 reports collected for this study reveal that between FY 2012 and FY 2020, Below Threshold Reprogramming (BTR) actions for the RDT&E title did not veer far from $1 billion annually.[30] BTRs affect more than half of all RDT&E budget lines, the average amount being roughly $2 million. Over that time, the Navy, Air Force, and DoD-Wide accounts shared roughly equally in BTRs, with the Army contributing half the amount. Yet as a percent of RDT&E funding, the Army achieved BTRs of 1.6% compared to the Air Force which BTRs about 1% on average.[31]

While total BTR dollars have been relatively stable for RDT&E between FY 2012 to FY 2020, BTRs as a percent of title funding has fallen from roughly 1.7% per year to 1%. A

[30] DD1416s show the cumulative result of reprogramming actions by BLI. Fiscal year data reported using DD1414 show figures pertaining to the appropriation and not when the action occurred. The FY 2020 RDT&E appropriation is available for obligation and reprogramming actions in both FY 2020 and FY 2021.

[31] This is likely due to Army BLIs being smaller on average, and thus more likely to hit the 20% threshold than $10 million

similar trend is apparent for Procurement, with BTRs falling from roughly 2% percent of the title per year toward 1%. The BTR data in the DD1416 report shows cumulative effects and does not reveal each individual BTR action. For example, Comptroller guidance states that "the BTR is calculated using the net of increases and decreases to a budget line." If one budget line is increased by $5 million in January and then decreased by $4 million in March, the DD1416 quarterly report would only record the net result of $1 million.

Reprogramming: Moving funds between authorized elements, but above appropriation-specific thresholds. Also, whenever procurement quantity is increased or a congressional special interest item is affected. FY 2022 thresholds:

RDT&E: $10 million or 20%* of a program element
Procurement: $10 million or 20%* of a budget line item
O&M: $10 million of a budget activity or defense agency

*whichever is less

Transfers: A reprogramming action of any size that crosses appropriations. Internal reprogrammings that do not change the intent of a budget line item may use transfer authority, but do not require congressional prior approval. The FY 2022 cap on cumulative transfers:

General Transfer Authority: $4.0 billion
Specific Transfer Authority: $2.0 billion

New Starts/Terminations: A new start is a BLI or major component thereof not previously justified in the President's Budget submission. Terminations are when an authorized program's funding is zeroed out. Below the threshold, new starts and terminations only require a letter notification to Congress. FY 2022 thresholds:

RDT&E: $10 million for entire effort
Procurement: $20 million for entire effort

Figure 2. Congressional Prior Approvals

The above analyses only scratch the surface of how defense officials achieve execution flexibility. It gets to a larger issue of congressional control. The rules around prior approval reprogrammings are not found in law but in the customs and defense regulations that have emerged over the past decades. As former chair of the House Armed Services Committee Melvin Price remarked in a 1985 hearing, "The handling of reprogrammings is really a gentleman's agreement between Congress and the Executive Branch. It is really a pretty fragile process." In remarks prepared for the hearing, Deputy Secretary of Defense William Taft IV concurred, "I also recognize that the history of, and precedence for, these procedures rests not in statutory authority, but rather in terms of continuous understanding and agreement between the appropriate congressional committees and the Department of Defense."

Legally, the executive branch is only required to spend according to what is written in law. Defense appropriations are usually limited to a few dozen accounts and special items like ship construction. BLIs are not written into law, and the prior approval process is a regulation created by the Executive. Even use of transfer authority only requires prior approval from the OMB, not Congress. However, when the Executive veers too far from established norms and breaks trust with Congress, it can result in a tightening of the purse strings.

One executive action that damaged trust was President Richard Nixon's impoundment of funds for an environmental project in 1972. It led to a congressional backlash that spilled over into defense.[32] The number of approved ATRs dropped from an average of about $2.6 billion a year in the 1960s to less than one billion in FY 1973 and FY 1974. The number of reprogramming actions also dropped from approximately 100 to just 24 in FY 1974, while each action affected fewer BLIs. While 1960s reprogrammings could bundle 30 or 40 BLIs together, the 24 actions in FY 1974 involved just 37 BLIs total (Fisher, 1975).

DoD started to rely more heavily on other sources of execution flexibility in the 1970s and 1980s including unexpended balances. Prior to 1949, obligational authority that had not been turned into expenditures were available to cover contract claims up to two years after the appropriation expired after which time funds lapsed, or were cancelled, and returned to the Treasury. In 1949, Congress allowed the DoD to accumulate lapsed funding into a Treasury account that remained available for covering claims with General Accountability Office approval. In 1956, the authority to clear the use of lapsed funding was delegated to the agencies. Separate processes were created for unobligated balances (merged surpluses) and obligated balances. In the latter case, the final contract payment may be different than the amount obligated for reasons like termination for default. These obligated balances went into the "M" account where they lost their identification with a fiscal year appropriation and were thus unlikely to encounter any Anti-Deficiency Act violations (GAO, 2004).

The merged surpluses and "M" accounts were not as large a source of execution flexibility for acquisition in the 1950s and 1960s because the RDT&E and Procurement accounts had been "no-year" money. In other words, obligational authority did not expire (Fisher, 1975). Appropriations from past years were available for future obligations. Indeed, the carryover balances were so great for Army Procurement accounts after the Korean War that Congress did not provide any new obligational authority in FY 1955 and FY 1956. The Army already had all the obligational authority it needed (*Department of Defense Appropriations for 1956*, 1955). However, total unobligated balances were large, ranging between $7 billion and $13 billion between FY 1957 and FY 1969 (GAO, 1990).

RDT&E and Procurement accounts moved from a no-year to multi-year bases after Congress discovered in 1970 that funds left over from the Polaris submarines had been a major source of DoD execution flexibility. The Appropriations report for FY 1971 stated that "The availability of these funds makes defense planners, to a limited extent, immune from tight Congressional fiscal control" (Fisher, 1975).

With the expiration of RDT&E and Procurement accounts, and the subsequent tightening of Above Threshold Reprogramming, defense officials relied more heavily on the use of lapsed funding. High inflation in the 1970s led the high inflation estimates being built into budget justifications and in turn led to large balances. By 1989, there was $25 billion in

[32] A number of other issues also emerged in the early 1970s. It was discovered in 1971 that defense officials performed BTRs between appropriation years, in effect saving funding from expiration. In 1972, there was a controversy over the Navy failing to receive prior approval of military personnel reprogramming actions.

merged surpluses and $18.7 billion in the "M" account. The GAO estimated that between 53% and 95% of "M" account usage was not used for the original purpose of the appropriation and was therefore not valid (*Abuses in the "M" Account System and Proposals for Reform*, 1990). For example, the GAO discussed how the Air Force wanted to use $1 billion of expired funds for a B-1B contract modifications. While the case was completely legal, the GAO did not find it proper (GAO, 2004). The Air Force told the GAO that it was common to reprogram funds from a valid program requirement for use elsewhere, only to make the donor program whole again by use of expired funds. The GAO called this practice "questionable." By 1995, $5.2 billion from the "M" account could not be matched to disbursements (GAO, 1990). In 1995, Congress decided to cancel the accounts and later replaced them with the Defense Modernization Account that has additional restrictions including a $1 billion ceiling and quarterly reporting requirements (GAO, 1999; 10 U.S. Code §2216). Between FY 2013 and FY 2018, theDoD saw $81 billion cancelled.

As is common in wartime, Congress grants the military additional flexibility. During the Global War on Terror, Congress increased its approval of ATRs from $853 million in FY 2020 to a peak of $21 billion in during the 2007–2008 Iraq Surge. The Overseas Contingency Operations (OCO) account provided another source of flexibility. Although ATR reprogramming actions for OCO ran through the prior approval process, the budget request was not as specified to meet unanticipated wartime needs (CRS, 2019). However, as the United States began drawing down its counter-terror operations and OCO was dropped from the FY 2021 budget, flexibility has decreased. Figure 3 below depicts the total dollar value of Above Threshold Reprogrammings as a percent of the defense budget between FY 1961 and FY 2019. It is important to remember that overall execution flexibility may have fallen more than Figure 3 suggests due to: (1) the increasing definition of budget line items leading to less flexibility within a single BLI; (2) the increasing scope of congressional prior approval to include thresholds in that had only required notification in the past; and (3) reduced opportunities to use unexpended balances to cover claims and maximize use of current budget authority. Additional reductions in flexibility include the demise of large innovation funds that had regularly been over $150 million each year in the 1950s, (Fisher, 1975) and the increased prevalence of continuing resolutions that resulted in appropriations getting passed five-months late on average between FY 2010 and FY 2022.

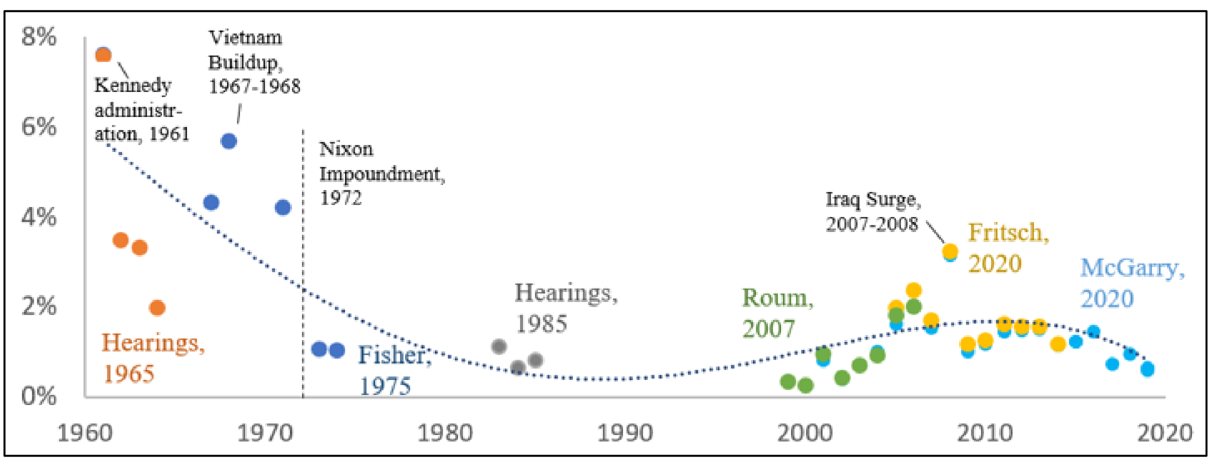

Figure 3. Above Threshold Reprogramming as a Percent of the Defense Budget

The other side of the coin of execution flexibility is budget flexibility. If Congress accepts consolidated budget lines and higher-level requirements, then the DoD has a greater capacity to make cost-schedule-technical trades without imposing many changes related to prior approval reprogramming, expired balances, or other sources of flexibility.[33] For example, consider the 18 defense Procurement accounts which are composed of 85 budget activities and roughly 900 Procurement BLIs. Between FY 2011 and FY 2019, the DoD averaged roughly $1.7 billion in positive and negative BTR actions that affect more than half of all BLIs. If BLIs were consolidated into portfolios that correspond to their budget activities (e.g., combat aircraft, ammunition, tactical and support vehicles) then many of the BTRs would offset each other. For example, the FY 2019 Army budget activity "BA 02: Communications and Electronics Equipment" shows BTR actions for 31 BLIs, 21 of which amounted to –$29.3 million and the remaining 10 amounted to +$14.7 million. Instead of requiring a total of $44 million in BTRs, a portfolio at the budget activity level could make two-thirds of those tradeoffs internal to the portfolio. Indeed, the DD1416 report indicates that three-quarters of all Procurement BTRs could be made internal to budget activity portfolios between FY 2011 and FY 2019. ATRs, on the other hand, would only be reduced by one-quarter on average, indicating that larger actions are more likely to cross portfolios and so would continue to be brought to the attention of Congress for prior approval. This move towards budget portfolios reflects the wisdom of traditional financial management practices described above.[34]

This brief overview of defense spending provides evidence that flexibility has decreased substantially since the World War II era. Budget flexibility has been reduced along two principal paths: (1) the classification and specificity of budget line items; and (2) the ability to make tradeoffs between budget line items and maximize use of budget authority. The decrease in flexibility would not matter to defense outcomes if weapon systems analyses accurately predicted program objectives and costs. Experience has proven that even the best laid plans can be upset by new technological opportunities, enemy threats, concepts of operations, and macroeconomic trends.

Yet there is something comfortable about multi-year analyses. It gives stakeholders with oversight functions a simple measure of success: performance to baseline. But in a dynamic world where technology development is modular, iterative, software-intensive, and leveraging commercial advances, execution to a fixed baseline no longer signals success. Leading technology enterprises have moved from project-based budgeting to funding persistent development teams with delegated responsibility (Rigby et al., 2019). These "new" agile processes in technology firms reflects the wisdom of traditional business practices used by defense officials prior to PPBS. However, if defense leadership, the Executive, and Congress decide to permit a dynamic system of portfolio management, a transparent process of reporting and evaluation will have to be built to establish a base of trust.

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[33] Portfolio management will likely require more authority in new starts and terminations.

[34] Because Congress appropriates to individual ships, the Navy's Shipbuilding and Conversion 1611N account does not use BTR authority and would not benefit from a portfolio budget. Current RDT&E budget activities make little sense for portfolios because they represent linear stage-gates rather than capability, mission, or organizational portfolios.

Criteria for Transparency and Oversight

Traditionally, the appropriations function and policy-making function were separate. In traditional budgeting, Congress finances a department's bureau to perform a government function but does not legally commit it to a precise level of service. If the budget also contained the policies and programs bureaus must accomplish, then there would be no point to separating appropriations from normal policy-making routines (Jones & McCaffery, 2005). Compared with debating whether an unmanned system would be available in three years at a certain cost, appropriators had historically been more comfortable with questions of overtime, travel expenses, purchase of equipment, and the leasing of property. Lump-sum appropriations allowed Congress to weigh evidence in hearings and issue across-the-board edicts such as a 10% cut without passing judgment of specific programs that could raise the ire of affected constituents (Murphy, 1969). Program choice was delegated, incremental, and repeatedly evaluated such that if harm were done, it would be incremental harm.

To reform-minded advocates of PPBS, the tradition was inadequate. Incremental program choices allowed the services to prioritize their "pet projects" at the expense of the combined forces. Charles Hitch complained that prior to PPBS in 1961, the policy had been to "divide a total defense budget ceiling among the three military departments, leaving to each department, by and large, the allocation of its ceiling among its own functions, units, and activities." Compounding the problem was the rapid increase in defense budgets and weapons complexity. Hitch concluded that "The revolution in military technology since the end of World War II, alone, would make necessary the central planning and direction of military program. The great technical complexity of modern day weapons… cannot be made properly by any subordinate echelon of the Defense establishment" (Hitch, 1965).

For Hitch, the primary impediment to rational analysis was the fact that budgets had been based on broad classifications that did not relate dollars to programs, and programs to military requirements. The fundamental precondition for creating a programmatic budget was reliable methods of systems engineering and quantifying all measures of cost and effectiveness. These "systems analysis" techniques were being developed at RAND during the late 1940s and early 1950s in order to eliminate duplicative aircraft developments by companies competing for defense production contracts. Hitch and others in the economics division at RAND like David Novick recognized that cost data were sparse and scattered throughout organizations. In order to make the right analytical decisions, it was necessary to collect better cost data. And a precondition to better cost data was a budgeting and accounting structure classified by program outputs (Hough, 1989). As Charles Hitch testified to Congress in 1961:

> It is precisely in this area that the financial management system showed its greatest weakness. It did not facilitate the relating of costs to weapon systems tasks, and missions. Its time horizon was too limited. It did not disclose the full time-phased costs of proposed programs.
>
> … Admittedly, the financial management system must serve many other purposes. Certainly it must produce a budget in a form acceptable to the Congress. It must account for funds in the same manner in which they are appropriated…
>
> But all this is not enough. The financial management system must also be made to provide the data needed by top Defense management to make the really crucial decisions on the major forces and weapon systems.

The long-range planning of weapons costs is the central aspect of PPBS. The important question in PPBS is not how much a program will cost in any one budget year, but how much it will cost to complete. This applied not only to the procurement and sustainment of systems but also to their research and development starting with operational prototyping. If defense programs were not costed across the life cycle, then analytical decisions could not meet the criteria of rationality. If one design offers twice the reliability as an alternative, that fact must be weighed against its higher investment costs. Hitch presumed that putting the DoD on a program basis would create a system for creating cost factors, activity rates, and other measures to permit accurate program predictions (*Department of Defense Appropriations for 1964*, 1963). Like others of his generation, Hitch simply presumed that the innovation and production processes had been reduced to a routine where teams of experts could turn out what is needed in predictable ways.

If analyses could be made accurately enough, the additional complexities PPBS layered on the budget process could be managed. Once a program life cycle cost estimate was formulated, there shouldn't be any need for "hectic and hurried" program reviews. The program should only require some "last minute adjustments," with the upcoming five years being reported in the Five-Year Force Structure and Financial Program. Moreover, Hitch stated that "Our five-year program and the improvement in our planning definitely should tend to reduce the amount of reprograming that would otherwise have to be done. The better you do your planning the less frequently you have to change it. I think this is a great contribution to better planning" (*Department of Defense Appropriations for 1964*, 1963). The need for reprogramming is in fact a failure of PPBS. Program changes represent execution not to plan. If programs frequently needed execution flexibility, then what was the purpose of careful cost-effectiveness analyses and the program structure in the first place?

Determining the correct solution in advance, costing it out, and budgeting for the long-range implications is certainly the most rational course of action whenever possible. For complex weapons technologies, however, systems analysis has two major faults. The first is reliance on prediction. Analysis requires certainty that an engineering specification is feasible, that it will cost a certain amount, that it hits performance metrics, that threats and operating environments don't change, that new commercial solutions won't appear, and so forth. Even if analysts were clairvoyant, the second requirement of systems analysis is optimization. The central problem here is reducing to a single number the criteria upon which alternatives are judged. What really matters? Speed, payload, range, survivability, reliability? And how about the numerous non-quantifiable factors which are often decisive in any analysis? There is no generally acceptable way to rank alternative system designs.

Neither the Bureau of the Budget nor Congress were ready in the 1960s to turn the budget structure onto a programmatic basis. Throughout the decade, the DoD continued to submit to Congress the budget classifications that resembled the previous decade. Budget Director Charles Schultz remarked in a hearing on PPBS, "When the chips are down, no President, no Cabinet officer or Budget Director—or Congress for that matter—is really willing to commit himself in advance to decisions in 1967 about the specific level of Federal programs in 1970 or 1972. Nor should he be" (Hearing, 1967). This worked out for Charles Hitch, because the President's Budget was directly compiled from the five-year program of weapons costs and objectives through a process known as the "cross-walk."

Hitch's successor at ASD Comptroller, Robert Anthony, in some ways sought to take PPBS to its logical conclusion.[35] Anthony was an accountant by trade rather than economist like Hitch. He wanted to conform the budget to the program structure and develop an accrual accounting system to match. That way, cost data could directly feed program budget estimates. By extending the programmatic structure into contract Work Breakdown Structures, more granular cost detail could be received through contractor reports. The larger effort called Project PRIME was cancelled by appropriators for FY 1969 and Anthony left the Pentagon at the start of that fiscal year. As an FY 1969 appropriations committee report explained:

> The principal element of the system is known as Project PRIME, a proposal to completely alter the character of Defense budgeting and accounting so as to bring it in consonance with the program system of the Department. The Committee is of the opinion that this proposal appears to be a case of too much too soon . . . Project PRIME would indicate a massive change which to some extent would temporarily diminish Congressional control and which appears to be proposed for at least partial initiation without regard to Congressional expression.
>
> There are a number of pitfalls that can be foreseen with respect to the proposed system, not the least of which is the inflexibility of the program structure which would necessarily follow. At present the program structure, being independent of the budgeting and accounting system, can be altered or redirected as circumstance or prudent management appears to require. Once such a program system becomes the legislative history in support of an appropriation act it can be changed only by some further legislative expression. (Carignan, 1969)

During the 1960s, congressional trepidation about PPBS and the program structure derived from fear of losing of control. If program decisions were made by teams of experts based on careful analysis, then Congress would not be in a place to argue for changes to the President's Budget. Congress would be "in the dark" about "analyses of costs and benefits of competing policies" and so "may not welcome all the implications of PPBS." Congress largely ignored the program structure throughout the 1960s. GAO Director Elmer Staats suggested GAO should move from the role as auditor to one of cost-benefit analyzer (Murphy, 1969). In 1974, Congress broadened the GAO's evaluation role and increased its budgetary responsibility, prompting it to hire scientists, actuaries, and other experts.

The entire point of PPBS is the cost-effectiveness analysis enabled by a program structure. PPBS puts an exact dollar figure on every military program, bridging the planning and budgeting functions. Advocates charged that without PPBS, military planners and civilian authorities simply blundered along with no program coordination. As Army General Maxwell Taylor testified in 1961: "We do not know what kind and how much defense we are buying with any specific budget. This kind of [traditional] budgeting makes it hard to determine what our military posture will be at any given time in the future." Former ASD

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[35] In 1965, Anthony tried to "undermine" the Office of Systems Analysis program structure (Murdock, 1971).

Comptroller Wilfred McNeil was bewildered by the statement. He said that General Taylor could read the force statement and had inventory data on “every conceivable type and size of weapon we had.” Analyses of these data and their costs had long informed budget estimates.

> I would be forced to conclude there is some lack of knowledge of what has been the general practice for years . . . Although I am sure that there are better and more formal ways to get comparisons of systems than has been true in the past, certainly the “new look” of 1953 was not decided in a budgetary vacuum, nor on the basis of a single year. Certainly the successful B-52 program of some 500 or more aircraft, planned for execution over a number of years, was not undertaken without some knowledge of the long range budgetary considerations.

McNeil reiterated multiple times to Congress that he would not budget according to the program structure. It is simply one way of evaluating the defense enterprise, and one that is highly reliant on predictions of cost-effectiveness (*Organizing for National Security*, 1961). McNeil criticized McNamara’s system for relying on 40,000 pages of paperwork. He would rather take the opinion of a lieutenant commander or an Air Force major as he climbed out of the airplane. McNeil recalled consciously starting competing programs. “Eventually, we’d cancel half of them, perhaps; but it was still the cheapest way to get along. Every day you developed something a little bit better” (McNeil, 1972).

The “budget ceiling” approach complemented the iterative development practice pervasive in the 1950s. McNeil continued his defense of the tradition: “I can think of no time that a budget ceiling has prevented the presentation and full discussion of any item that senior people in Defense thought was really necessary.” Moreover, with the program structure, McNeil wondered what good it was to know 10% went to continental defense without knowing whether “a decent job was being done.” McNeil said he kept one-third of his budget staff on the road at any given time to stay informed. In the Korean War, for example, budgeteers would visit overhaul shops on the 38th parallel and check hours on engines to judge budget markups (McNeil, 1972).

Senator Henry Jackson, Chairman of the Senate Armed Services Committee, commented how “Some good historians and objective scholars are going to have a field day with the oversimplifications that officials have put in the record since 1961 about previous Defense Department policies and methods.” He recognized that “Well before PPB, it had proved possible to assemble Defense budgetary information by functions or missions for special requirements” (Hearings, 1967).

Program decisions in pre-PPB years had consistently related issues of military planning and budgeting. Military plans and programs flowed from the President down through the Joint Chiefs of Staff and to the commands, bureaus, and technical services where responsibility of estimating costs had been delegated to line-managers in charge of execution. These plans also fed Secretary of Defense budget guidance which flowed down the civilian chain of command to the same line-managers. There was a decentralized system of checks and balances along the axes of military—civilian, staff—bureau, operational—administrative, substantive—fiscal. The relation of budgets and programs was the product of annual improvisations and personal coordination at all levels of the hierarchy (Mosher, 1954). This allowed non-quantifiable factors to be considered alongside hard data, without tying any decision-maker down until more evidence is made available. As budget scholar Allan Schick (1971) noted of traditional management, “Much program innovation is extrabudgetary, proceeding via task force, legislation, and administration action which subsequently is channeled through the budget process."

Through the revolutionary PPB System, McNamara intended to "dispense with the checks and balances of the decentralized political process" by use of "properly formulated studies of cost-effectiveness" (Murdock, 1974). The key building blocks of PPBS are not the budget elements themselves, but the larger program of record to which they are connected. Before the program of record starts, it must be baselined using long-range estimates of the cost, schedule, and key performance indicators. While this creates multiple year lag that stifles technology transition, it creates the foundations for measuring success. All that is necessary to know about program success is whether the capability was delivered on-cost and on-schedule to the approved plan. One universal metric for program evaluation can serve the needs of oversight. It relied on performance to baseline. These figures started being reported to Congress in 1968 with the Selected Acquisition Reports. With the cost growth metric, programs could be measured as if they were subsidiaries reporting profit/loss statements to their parent company.

Universal cost growth metrics, however, do not measure success if circumstances change or information is learned along the way. If the plan is riddled with errors, then execution to plan represents failure. Just how prone cost-effectiveness was to error was evidenced by the first major systems analysis performed by RAND. Analysts recommended a turbo-prop engine for the B-52 rather than a turbo-jet, while the Air Force simply ran the analysis with different assumptions and got a different answer. Another famous example was Admiral Hyman Rickover's debate with the systems analysts about whether aircraft carriers should be nuclear-powered or not. In both cases, the systems analysis performed by neutral third parties were not satisfactory. "One of the prime obstacles to adequate defense weapons," said Air Force Lt. General Ira Eaker in 1965, "has been a hurdle called cost effectiveness. This test applied by scientists and theorists has killed off many new weapons, urgently requested by military leaders" (Hough, 1989).

Not only did the analyses kill off many good ideas, they resulted in many bad ideas like the joint-service TFX aircraft, later the F-111. Senator Henry Jackson wondered how analyses of the TFX completely neglected Navy requirements. The Pentagon's top analyst Alain Enthoven said that the joint-service design was the result of "common sense judgment." Senator Jackson again pressed the point, questioning the how systems analysis could have been used to foresee the TFX difficulties. Enthoven said he was handicapped by not having as much "knowledge and experience" as the Senator. "That is the most distressing news I have heard," responded Senator Howard Baker (Hearings, 1967). Writing in Armed Forces Magazine, C. W. Borklund concluded that "we are haunted by the spectre of over-study in weapon needs; while at the same time much of the influencing analysis and basic knowledge upon which weapon development decisions are founded is superficial and shallow."

PPBS focuses on future plans at the expense of analyzing current operations. Over time, a fully articulated planning and programming system was prioritized over management control systems (Jones & McCaffery, 2005). Indeed, because planning and programming are performed by individuals not responsible for execution, it shifted power to administrators and analysts whose actions cannot be policed (Murphy, 1969). Even the term "program evaluation" in DoD has shifted from a review of development and operational outcomes to a review of forward-looking plans in the budget. Rarely are program outcomes evaluated holistically. "In taking a look at what was spent last year," Allan Schick wrote, "budgeters rarely look back to see what was accomplished." He found program evaluation to be a superior method of control to analysis which had "hobbled PPB." With evaluation, the scope and demands for data are less and can be built on the “bedrock of past experience rather than ‘iffy’ conjectures about the future” (Shick, 1971). Admiral Hyman Rickover largely agree. “This is where I think Congress falls down,” Rickover told appropriators in 1971.

> Even when you appropriate money for a particular purpose, the Administration can decide not to spend it. Therefore, the way for Congress to gain some measure of control is through your oversight function. This is what I have been advocating all these years to this committee; to exercise your oversight function. In the case of the Defense Department, it is desperately needed.

An important example of oversight performed prior to PPBS was the commission led by Harry Truman during World War II. Truman at the time was a senator on the Military Subcommittee on Appropriations. He staged 432 hearings that interviewed 1,798 witnesses between 1941 and 1948 (Hamilton, 2009). The Truman Committee did not control military plans before programs started and measure success back to that plan. Instead, the committee fact checked and observed the consequences of program decisions. Truman himself was cognizant of the need to move fast and not unduly interfere with the executive branch. Yet he was able to save perhaps seven or eight times the entire cost of the Manhattan Project by exposing faulty weapons production. The investigations had knock on effects throughout the system. Fear of investigations created a deterrent and promoted an untold amount of honest dealings (McCullough, 1992).

One of the important facts about program choice is that the technology is so complicated, moves so fast, and depends on so many factors in military operations, that a multi-year baseline of costs and capabilities cannot be locked down in advance. If universal metrics like cost growth do not signal value, then oversight must be driven by contextual metrics, user feedback, cost actuals, operational testing, and judgments of personal conduct. Modern information technology systems allow for large, real-time, and even unstructured datasets. Some high-level requirements for contextual reporting for acquisition portfolios include:

1. Real-Time Spend Reports. Organizations should report obligations and expenditures with multiple dimensions of program tagging as well as traceability to deliverables.
2. Metrics of Effectiveness. Metrics should be tailored to the program context. For example, a command and control system might track the number of connected shooters and sensors, the number and types of users, time to complete particular workflows, system uptimes, time to restore critical capabilities, user satisfaction, and so forth.
3. Descriptive Analysis. Rather than spending months at a time creating a life cycle estimate, actual cost data should be continually curated and connected with technical attributes into a single source of truth that helps inform incremental decisions.
4. Program Traceability. Project costs and technical outcomes at the lowest possible level should be mapped to their antecedents and dependencies between programs, creating a “family tree” of individual efforts.
5. Human Factors. Participant and stakeholder perspectives should be reported using the multi-disciplinary methods of project histories and linked to the strategic landscape.

Additional principals for oversight are outlined in Figure 4 below. It contrasts PPBE approach to oversight that relies on adherence to baseline with the portfolio approach that relies on contextual reporting.

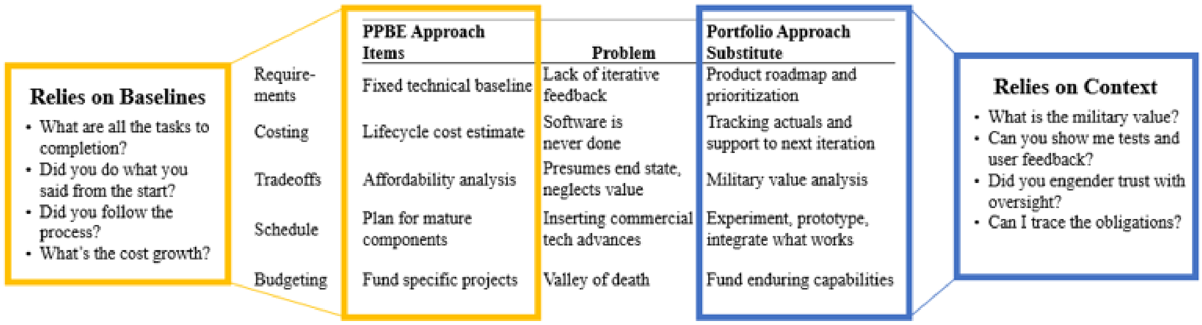

Figure 4. Comparison of Oversight Paradigms

The question of oversight has become relevant again with acquisition reform over the FY 2016 to FY 2022 era. New acquisition pathways allow programs of record to become disaggregated and proceed incrementally using rapid prototyping, rapid fielding, and iterative software development practices. However, the GAO finds that such flexibility creates "challenges for reporting, monitoring, and oversight" such as tracking "cumulative cost, schedule, and performance data for programs transitioning between acquisition pathways or conducting multiple efforts" (GAO, 2022).

Because PPBE reduces the defense enterprise into a set of analytically independent programs of record, there is no method for baselining efforts that evolve over time, merge into one another, and leverage enterprise tools. The PPBE reliance on measuring variance to baseline is an industrial era notion that worked well for repetitive manufacturing of widgets. It does not capture the value generated by creative, adaptive, and innovative behavior associated with modern technology development. As Representative Seth Moulton said in 2021:

> The truth of the matter is that the current system doesn't really give us the oversight we need. We're sort of circling the drain with this system where the DoD describes in intricate detail the ways that it isn't buying effectively, Congress signs off on that oversight, and we just keep going in circles. . . . As a member of Congress, I can keep the DoD accountable by asking that they show us how the money that they spend in a mission-based funding bucket actually meets the mission and if it's not meeting the mission then we can dive into more detail. (Hudson, 2021)

Representative Moulton touched on the need for contextual oversight within a construct of portfolio budgets. Current reports on program cost growth do little to inform stakeholders of what is going on or whether viable alternatives exist. Adding controls to new acquisition pathways will more likely destroy the intent of those pathways than add value to oversight. Complementing the pathways with portfolio budgeting and contextual metrics for oversight provides the best opportunity for improving outcomes. The GAO, Congress, and stakeholders in the Department of Defense should work towards a data collection and reporting strategy that is consistent with agile development, portfolio management, and delegated decision-making.

Conclusion

The Planning-Programming-Budgeting-Execution process represents a radical break from traditional methods of defense management. Incrementalism was replaced by analytical holism. Liberal institutions were replaced by Soviet-inspired systems. Delegated decisions were replaced by superficial cost-effectiveness analyses. This paper traced the history of execution flexibility in the Department of Defense, showing how portfolio budgets were fractured into narrow weapons programs and how reprogramming authorities have decreased over time. It also examined how traditional methods of oversight held defense officials into account for their actions using a variety of budgetary and non-budgetary methods that relied on evaluation of outcomes.

This paper has only addressed the issues in broad strokes. It is intended to provide reformers a historical lens for understanding the wisdom of traditional financial management, and a starting point for how defense acquisition can reignite the dynamism it once had. Fifty years of reforms to acquisition, contracting, requirements, and workforce can only go so far without addressing the overarching governance mechanism found in budgeting and policy making. Portfolio management is at the heart of the necessary reforms. Large technology companies no longer budget to specific projects; they budget to persistent development teams that are empowered to make cost, schedule, technical trades throughout. If the Department of Defense wants to compete against peer adversaries and do business with the most innovative commercial companies, greater execution flexibility in the form of portfolio budgets are required. A precondition to that flexibility, however, is value-driven methods of reporting and oversight.

References

Abuses in the "M" account system and proposals for reform: Hearing before the U.S. House of Representatives Legislation and National Security Subcommittee of the Committee on Government Operations, 101st Cong. (1990).

Carignan, R. E. (1969, February). *An installation study of Department of Defense resources management system*. Graduate School of Public Administration, New York University.

Comptroller. (2015, March). *U.S. Department of Defense budget execution: Processes and flexibility*. Officer of the Under Secretary of Defense (Comptroller) / CFO.

Congressional Research Service. (2019, September 6). *Overseas contingency operations funding: background and status* (R44519).

Congressional Research Service. (2020, March 3). *Defense authorizations and appropriations bills: FY 1961–FY 2020* (CRS 98-756).

Department of Defense appropriations for 1956: Hearings before the U.S. House of Representatives Subcommittee of the Committee on Appropriations, 84th Cong. (1955).

Department of Defense appropriations for 1961. Part 1: Hearings before the U.S. Senate Subcommittee of the Committee on Appropriations. (1960).

Department of Defense appropriations for 1964: Hearings before the U.S. House of Representatives Sub Subcommittee on Appropriations, 88th Cong. (1963a).

Department of Defense appropriations for 1964. Part 1: Hearings before the U.S. House of Representatives Sub-committee on Appropriations, 88th Cong. (1963b).

Department of Defense appropriations for 1971. Part 6: Research, development, test, and evaluation: Hearings before a U.S. House of Representatives subcommittee of the committee on appropriations, 91st Cong. (1970).

Department of Defense appropriations for 1972. Part 6: Research, development, test, and evaluation: Hearings before a U.S. House of Representatives subcommittee of the committee on appropriations, 92st Cong. (1971).

Department of Defense appropriations for 1973. Part 4: Research, development, test, and evaluation: Hearings before a U.S. House of Representatives subcommittee of the committee on appropriations, 91st Cong. (1972).

Department of Defense reprograming of appropriated funds: A case study: Report of the U.S. House of Representatives Subcommittee for Special Investigations of the Committee on Armed Services, 89th Cong. (1965).

Federal budgeting for research and development: Hearings before the U.S. Senate Subcommittee on Reorganization and International Organizations of the Committee on Government Operations, 85th Cong. (1961b).
Financial Management Regulation. (2015, September). *Volume 3, chapter 6: Reprogramming of DoD appropriated funds* (DoD 6000.14-R).
Fisher, L. (1971). *Presidential spending discretion and Congressional controls* [Presented to the 1971 annual meeting of the American Political Science Association].
Funds. (2022). *Series A, B, C funding: Averages, investors, valuations.* https://www.fundz.net/what-is-series-a-funding-series-b-funding-and-more
GAO, (1990, September 20). *Financial management: DoD's use of expired and lapsed appropriations*.
GAO. (1999, June). *Report to Congressional committees. "Defense modernization account: Operations and benefits.*
GAO. (2004, January). *Principles of federal appropriations law third edition volume I.* Office of the General Counsel.
GAO. (2015). *DoD should streamline its decision-making process for weapon systems to reduce inefficiencies* (GAO-15-192).
GAO. (2022). *Space acquisitions: Changing environment presents continuing challenges and opportunities for DoD*. Statement of Jon Ludwigson.
Hamilton, L. H. (2009). Relations between the President and Congress in wartime. In Thurber, J. (Ed.). *Rivals for power: Presidential-Congressional relations*. Rowman & Littlefield.
Hitch, C. J., & McKean, R. N. (1960). *The economics of defense in the nuclear age*. RAND Corp., published by Antheneum.
Hitch, C. J. (1965). *Decision-making for defense*. University of California Press.
Hough, P. (1989). *Birth of a profession: Four decades of military cost analysis*. http://www.dtic.mil/dtic/tr/fulltext/u2/a228246.pdf
House Appropriations Committee. (2020). *Department of Defense appropriations bill, 2021, full committee print*. 116th Cong.
Hudson Institute. (2021). *Transforming defense for a competitive era*.
Jones, L. R., & McCaffery, J. (2005). Reform of the planning, programming, budgeting system, and management control in the U.S. Department of Defense: Insights from budget theory. *Public Budgeting and Finance*, 1–19.
Lofgren, E. (2022). *PPBE reform*. https://acquisitiontalk.com/budget-reform.
Lofgren, E. (2020, April 27). *The last frontier of acquisition reform: The budget process* (SYM-AM-20-073). Naval Postgraduate School Symposium.
McCullough, D. (1992). *Truman*. Simon & Schuster.
McGarry, B. (2020, June 17). *DoD transfer and reprogramming authorities: Background, status, and issues for congress* (7-5700, R46421). Congressional Research Service.
McNeil, W. J. (1972, September 19). *Oral history interview with Wilfred J. McNeil by Jerry H. Hess*. Truman Library Oral History Project.
Modigliani, MacGregor, & Ward. (2021). *Five by five: Five disciplines and five strategic initiatives for the Pentagon in the digital age*. MITRE.
Murphy, T. (1969). *Congress, PPBS, and reality*. University of Missouri, Kansas.
National Security Commission on Artificial Intelligence. (2021). *Final Report*.
Novick, D. (Ed.). (1969). *Program budgeting, second edition*. RAND Corp.
Organizing for national security: The budget and the policy process: Hearings before the U.S. Senate Subcommittee on national policy machinery of the committee on government operations, 87th Cong. (1961).
Orr, Kelly. (1990). *Hornet: The Insight Story of the F/A-18*. Presidio Press: Novato, CA.
Patt, D., & Greenwalt, W. (2021). *Competing in time: Ensuring capability advantage and mission success through adaptable resource allocation.* Hudson Institute.
Report, 1955. "Defense appropriation bill for fiscal year 1956." (H. Rept. 493, 84th Cong., 1st sees.)
Roherty, J. (1970). *Decisions of Robert S. McNamara: A study of the role of the Secretary of Defense*. University of Miami Press.
Scherer, F. M. (1962). *The weapons acquisition process: Economic incentives.* Harvard University Press.
Section 809. (2019, January). *Report of the advisory panel on streamlining and codifying acquisition regulations volume 3 of 3.* Recommendation 46.
Wiladvsky, A. (1966, December). The political economy of efficiency: Cost-benefit analysis, systems analysis, and program udgeting. *Public Administration Review, XXVI*(4).

PANEL 11. ADAPTIVE ACQUISITION FRAMEWORK: HOW IT'S GOING

Wednesday, May 11, 2022	
1:55 p.m. – 3:10 p.m.	**Chair: Christopher C. O'Donnell,** Deputy Assistant Secretary of Defense, Platform and Weapon Portfolio Management ***Built for Speed: The Army's Integrated Visual Augmentation System (IVAS): A Middle Tier Acquisition Case Study*** John Kamp, George Washington University Amir Etemadi, George Washington University ***When is it Feasible (or Desirable) to use the Software Acquisition Pathway?*** David M. Tate, Institute for Defense Analyses John W. Bailey, Institute for Defense Analyses ***Defense Acquisitions: Additional Actions Needed to Implement Proposed Improvements to Congressional Reporting*** Anne McDonough, US Government Accountability Office

Christopher C. O'Donnell—currently serves at the Acting Principal Deputy Assistant Secretary of Defense for Acquisition (PDASD(A)). In this position, he advises the Assistant Secretary of Defense for Acquisition (ASD(A)) on matters relating to the Department of Defense Acquisition System while advancing innovative, data-driven approaches across the acquisition enterprise. Mr. O'Donnell performed the duties of Assistant Secretary of Defense for Acquisition from June 2021 to February 2022.

Mr. O'Donnell was appointed to the Senior Executive Service in August 2015. He has been involved in all phases of Department of Defense acquisition, sustainment, research, and engineering since joining the defense acquisition workforce in 1984. As the Deputy Assistant Secretary of Defense for Platform and Weapon Portfolio Management (PWPM), he is also responsible for managing and analyzing major platform and weapons capability portfolios across the Department. He served as the Executive Director of the Joint Rapid Acquisition Cell (JRAC) until March 2019. He was the Staff Specialist for the Joint Ground Robotics Enterprise prior to coming to the JRAC. He started in the Pentagon as a Staff Specialist in the JRAC providing rapid responses to warfighter needs and assisting in providing equipment to the Afghan National Defense and Security Forces. He has a Mechanical Engineering BS from Clarkson University.

Prior to coming to the Pentagon, he was the Head of the Acquisition and Technology Department, at the Naval Explosive Ordnance Disposal Technology Division. He led a group of scientists, engineers and technicians that develop, test, acquire and maintain equipment for the over 5,000 Joint Service Explosive Ordnance Disposal (EOD) Technicians. He has received the Office of the Secretary of Defense Medals for Exceptional and Meritorious Civilian Service, two Navy Superior Civilian Service Awards, a David Packard Excellence in Acquisition Award, a Secretary of Defense Award for Excellence and a Naval Sea Systems Command Collaboration Award. He is married to Amy, the Deputy Technical Director at the Naval Surface Warfare Center, Indian Head. Their three children are Alan, a Virginia Tech Electrical Engineer; Calaa, a University of Washington Architect; and Caitie, a Clemson Electrical Engineer.

His personal awards include the Legion of Merit (four awards), Defense Meritorious Service Medal, Meritorious Service Medal (two awards), Navy and Marine Corps Commendation Medal (five awards), and the Navy and Marine Corps Achievement Medal.

Built for Speed: The Army's Integrated Visual Augmentation System (IVAS): A Middle Tier Acquisition Case Study

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Abstract

This case study examines how the Army used Middle Tier Acquisition processes to rapidly accelerate development and fielding of the Integrated Visual Augmentation System (IVAS). After decades of precursor developments, the Army adapted emerging commercial virtual reality goggles for field conditions and use. It uses publicly-released data from 2018 to 2021 consisting of budget submissions, program-related reporting, and contemporaneous press releases to describe how the Army used Middle Tier Acquisition authorities to accelerate IVAS development, testing, and fielding.

Research limitations/implications – This research is specific to the IVAS program. The data used in this analysis was derived from public sources and results and conclusions may differ if restricted sources are used to replicate this work.

Keywords: Middle Tier Acquisition, Other Transaction Agreement, rapid prototyping, and fielding

Introduction

This case study is a product of our research during the last year on schedule risks associated with Modularity, Agility, and Middle Tier Acquisitions[36]. It presents an overview of the Army's Integrated Visual Augmentation System (IVAS) Middle Tier Acquisition project, that went from solicitation to initial fielding in less than five years. This speed was due in part to acquisition strategy decisions, and consistent execution. All information used in this case study is publicly available.

[36] This material is based upon work supported by the Acquisition Research Program under Grant No. HQ00342010010. The views expressed in written materials or publications, and/or made by speakers, moderators, and presenters, do not necessarily reflect the official policies of the Department of Defense nor does mention of trade names, commercial practices, or organizations imply endorsement by the U.S. Government.

The Integrated Visual Augmentation System (IVAS) is a project allowing soldiers to train, rehearse, and fight with a common architecture and kit. It is composed from existing commercial technologies and fielded training and operational systems and reflects decades of Army interest in training for complex missions, and is in production after a two-year rapid prototype development effort. IVAS combines a heads-up display play and a synthetic training environment capability allowing soldiers to "fight, rehearse and train on the same system"

Background

Congress enacted Middle Tier Acquisition (MTA) processes in 2016 to enable fielding and prototyping of new capabilities within two to five years of approval. Key statutory changes enabled service acquisition executives to bypass traditional requirements and acquisition processes, and establish direct-reporting program managers for these rapid acquisition programs (NDAA, 2015). Congress also modified other transaction agreement (OTA) statutes in the 2016 NDAA, revising funding approval thresholds, authorities, and applicability criteria[37], making OTAs a viable option for the IVAS program without requiring a cost share or a not-traditional performer, and allowing direct transition to production under specific conditions[38].

Program schedule speed is relative, meaning that it is fast or slow relative to plans or average programs. Programs may be slow relative to plans due to "oversell and resulting performance bias" (GAO, 1992) or overall system immaturity (Kamp, 2019). Weber and Rohracher identified systemic failure causes, such as early lock-in to sub-optimal technology, and adaptation failure (Weber & Rohracher, 2012)). Van Atta et al. identified "fast-to-field" factors including an urgency of need, senior leader sponsorship, and rapid access to available funding (Van Atta et al., 2016). Tate identified strategy decisions associated with shorter schedules such as using proven systems or developing and fielding systems with incremental performance improvements (Tate, 2016). Finally, Jaifer et al. noted that organizational competence affects planning and execution (Jaifer et al., 2020).

The Army has a long history of developing innovative technologies to gain tactical advantage. The Army developed night imaging systems at the end of World War 2, providing a sensing advantage to forces with night vision systems (Tishman & Schoen, 2021). Figure 1 shows example helmet mounted displays.

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[37] Section 815 approval authorities were modified to allow ''The senior procurement executive for the agency determines in writing that exceptional circumstances justify the use of a transaction that provides for innovative business arrangements or structures that would not be feasible or appropriate under a contract, or would provide an opportunity to expand the defense supply base in a manner that would not be practical or feasible under a contract." (NDAA, 2015).

[38] This is allowed provided competitive procedures were used in the original award and the contractor successfully completed the prototype project (NDAA, 2015)

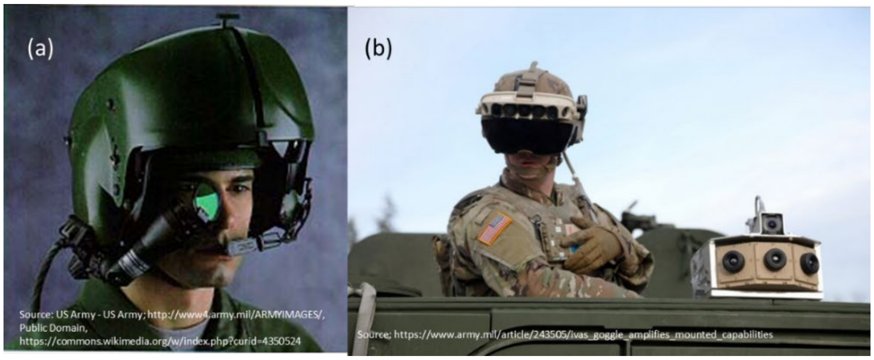

Figure 18. Helmet imaging systems.

Figure 1(a) shows a circa-1980 Cobra attack helicopter helmet mounted display. These systems included head tracking with optics allowing sensing and targeting (Li et al., 2013). The actual display in Figure 1(a) is the small monocular system covering the pilot's right eye. Figure 1(b) is a recent image of a soldier wearing a prototype Integrated Visual Augmentation System (IVAS). The IVAS in Figure 1(b) is a ruggedized version of the Microsoft Hololens[39] headset[40] and projects images onto the visor. Figure 2 shows the evolution of night vision systems to IVAS.

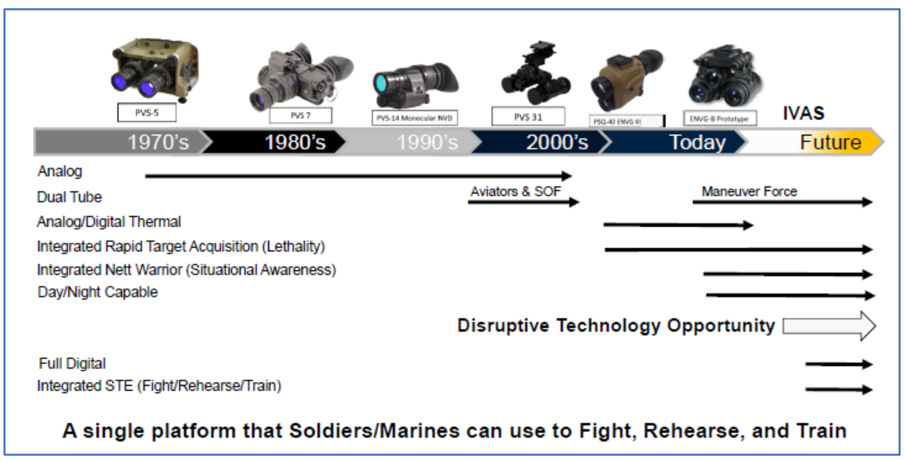

Figure 19. Envisioned IVAS capabilities (Source: 2018 Industry Day).

Early helmet-mounted display systems were designed for specific applications. The military services train to develop proficiency in individual and team skills and practice and rehearse to improve team performance and improve the likelihood of success. Simulations and game-based training are becoming more common for complex or expensive operations. Straus et al. noted that effective training elicits performance-related responses and may or may not

[39] A detailed description of the commercial product is on the Microsoft website (Microsoft, 2021)
[40] Also known as a goggle.

require high physical fidelity (Straus et al., 2019). The Army had been experimenting with virtual reality headsets for solider training (Parkin, 2015), so it was a natural extension to consider using IVAS for other applications as noted in Figure 2.

Findings

The Army IVAS acquisition strategy included a number of these choices. In particular, the program focused on rapid testing and iterations over traditional acquisition program systems engineering. On September 25, 2018, the Army Acquisition Executive approved IVAS as a Middle Tier Acquisition rapid prototyping project with four hardware and software sprints and "soldier touchpoints" between sprints (Behler, 2019). Figure 3 shows the initial IVAS program schedule (Yamakawa, 2018).

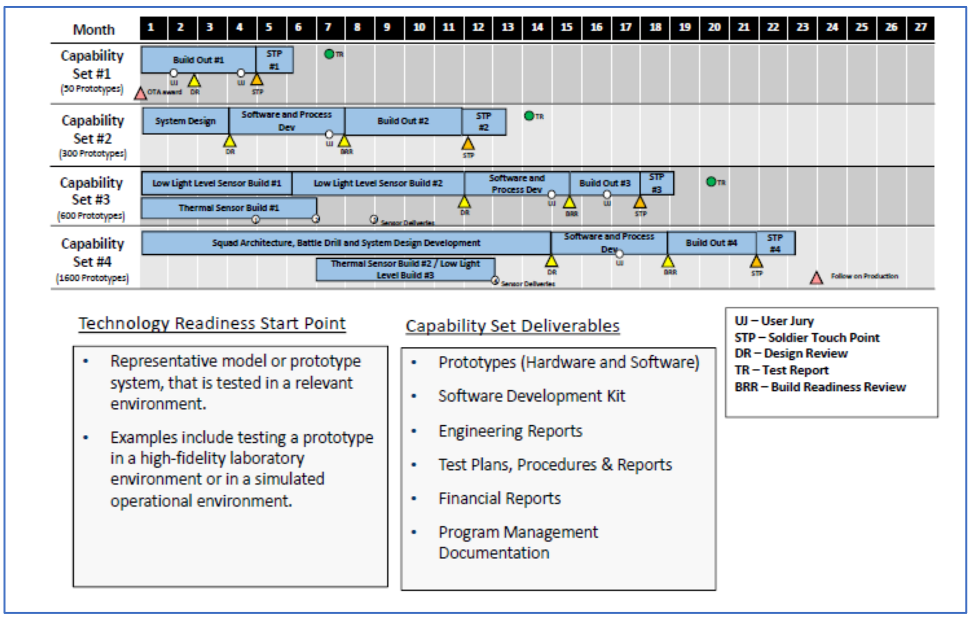

Figure 20. Initial IVAS project schedule (source: 2018 Industry Day).

The rapid schedule and cumulative capability set builds shown in Figure 3 would require performers to restrict development of enabling technologies and focus on system integration [41]. The Statement of Objectives supporting this schedule describes what is expected at each Capability Set, but is silent on explicit quantitative requirements metrics (Keller, 2018), meaning that performance would be assessed during frequent user interactions. Figure 3 also includes summary technology start point assumptions and expected deliverables. This is an efficient method to tell proposers the technology readiness and delivery expectations for a competitive proposal.

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[41] As an example, the Army Night Vision and Electronic Sensors Directorate was concurrently developing a modular night vision sensor and would provide modules to performers as government furnished equipment (Yamakawa, 2018).

The Army decided to use a competitive Other Transaction Agreement (OTA) for the IVAS project (OUSD(A&S), 2018). The solicitation disclosed the Army's intent to award an Other Transaction for Prototype, giving the Army an option for follow-on sole-source production following successful prototype demonstration (Keller, 2018) awarded to Microsoft on 20 November 2018[42]. As a rapid prototyping effort, IVAS deferred formal requirements definition, and used the soldier touchpoints to provide Microsoft feedback to guide development of a functional product (Jasper, 2021). Executing the IVAS strategy would require collaboration between multiple Army programs within various programs as shown in Figure 4.

Figure 21. PEO Soldier programs interacting with IVAS.

For IVAS, the Army announced it would award a single Firm-Fixed-Price type OTA with specific milestones (Yamakawa, 2018). Firm Fixed Price agreements and contracts transfer all cost risk to the contractor, and are typically used during mature production[43] (Grady, 2016). When cost uncertainty is higher, cost-type contracts allow the government to manage and assume risk share. Boukendour and Hughes note incentivized contracts were created to offer an alternative between fixed-price and cost-plus contracts (Boukendour & Hughes, 2014), and reward cost, schedule or technical performance with a pre-defined award or incentive schedule. The Army awarded Microsoft an Other Transaction-IDV [44] base award on November 20, 2018. The obligations are summarized in Figure 5.

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[42] Source was W91CRB1990001 base award (General Services Administration, 2021)
[43] The intent is to incentivize contractors to maximize profits by reducing costs below the fixed price.
[44] IDV is an "Indefinite Delivery Vehicle." According to fpds.gov, W91CRB1990001 initial obligation was $215,638,968.76.

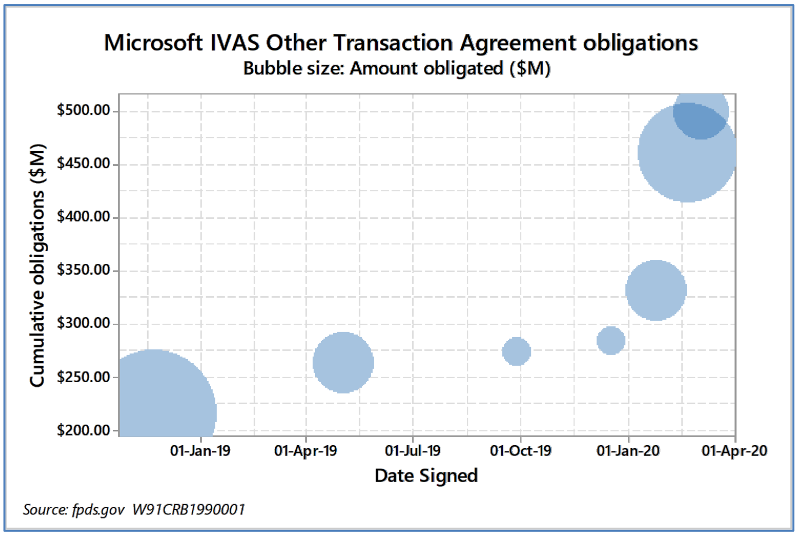

Figure 22. IVAS Other Transaction Agreement obligations by date signed.

The Army used a large initial obligation and a series of following payments to manage progress. Note the initial large obligation, consistent with award, and the subsequent payments, consistent with soldier touch points and capability set deliveries and transition to rapid fielding. Table 1 provides a summary of IVAS funding by product service codes (PSCs).

Table 6. Army funding of Microsoft by Fiscal Year ($K)

PSC Description	2018	2019	2020	2021	Total
INFORMATION TECHNOLOGY COMPONENTS	$10	$0	$0	$0	$10
INFORMATION TECHNOLOGY SOFTWARE	$9,141	$2,566	$24	$0	$11,731
IT AND TELECOM- PROGRAMMING	$0	$60,620	$112,987	$153,255	$326,862
IT AND TELECOM- SYSTEM ACQUISITION SUPPORT	$0	$2,916	$21,474	$4,792	$29,182
IT AND TELECOM- TELECOMMUNICATIONS NETWORK MANAGEMENT	$11,140	$5,131	$3,430	$4,901	$24,601
SUPPORT- MANAGEMENT: OTHER	$114,922	$90,245	$23,707	$0	$228,874
SUPPORT- PROFESSIONAL: ENGINEERING/TECHNICAL	$399	$7,828	$27,559	$15,417	$51,204
Total	$135,612	$169,307	$189,180	$178,366	$672,465

Table 1 shows that most of IVAS program funding supported programming, management, and network functions. This is consistent with an Agile program strategy, where the performer must adjust as users learn what they really want and what really matters[45]. Figure 6 shows obligation data plotted by award date and product service code.

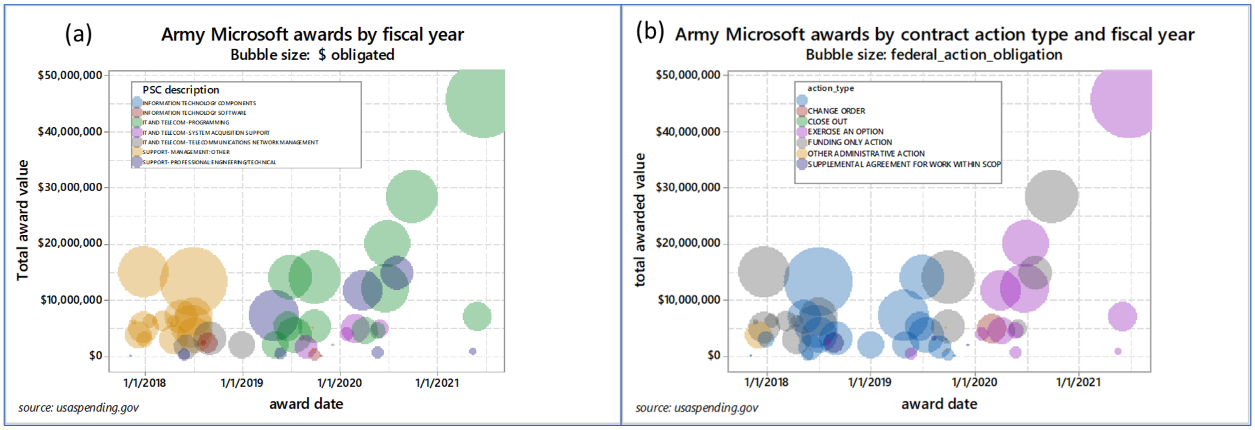

Figure 23. Microsoft IVAS obligations by fiscal year.

Note that Figure 6(a) shows individual award values, and shows the relatively large number of smaller awards. Figure 6(b) provides an alternate view of the same information, but grouped by action type. In this view, the data shows relatively few change orders and several exercised options, implying the contracting strategy anticipated and supported program execution. The obligations shift by product service code over time, showing how spending patterns shifted from early emphasis on management to later spending on programming, consistent with an Agile development effort.

Note that program spending and Microsoft programming effort increased during 2020, when Covid-19 was affecting corporations around the world. According to DOT&E, the Army delayed soldier touchpoint 3 from July to October 2020 (Behler, 2021). Microsoft and the Army were able to maintain the program pace and continue system development and testing after the pandemic delay. Soldier touchpoint 4 was executed in March 2021.

The above figures do not include procurement funding. The IVAS Rapid Fielding Decision was approved December 14, 2020 by the Army Acquisition Executive and on January 19, 2021 by the Under Secretary of Defense, Acquisition and Sustainment. The IVAS follow-on production OTA was awarded March 25, 2021 (ASAFM, 2021). The Army is planning to procure over 44,000 IVAS at a per-system unit cost of over $20,000 in the next two years, with the first lot delivery in October 2021 (ASAFM, 2021).

Discussion

The technology had matured in the commercial market to where proxies for government objectives existed in the market. The Army was able to spend most of its effort ruggedizing the system and developing user-focused applications. Technology vectors affecting IVAS include

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[45] PEO Soldier stated: “When a soldier says ‘this sucks,’ it may not be technical, but it has great meaning” (Freedburg, 2019).

the development of low-cost high quality thermal and infrared imaging systems and their increasing use in vehicle safety and surveillance (Mounier, 2011). Smart phones saw increasing market demand for messaging, imaging and video systems, and internet access (Meeker, 2018), driving down component costs and raising performance.

Microsoft business strategy aligned with Army objectives. In 2014, Microsoft purchased key intellectual property from the Osterhout Design Group for virtual reality headsets (Lunden, 2014), and announced that its Azure cloud computing platform would embrace open standards (Roberts, 2014). By 2018, Microsoft had sold about 50,000 headsets with an estimate unit price of about $3,500 (Hills-Duty, 2018), so when the Army was starting to develop IVAS, Microsoft and the market had matured key technology elements.

Concurrent with IVAS program development, the Army reorganized, creating an advocate for future readiness, called Army Futures Command, which provided a champion, advocacy with external stakeholders, and in particular a process to rapidly interact with users, specifically the Soldier Lethality Cross Functional Team[46].

IVAS development featured iterative testing with frequent user and key stakeholder involvement. The Program Executive Officer[47] stated: "Our number one factor that we evaluate …is… do soldiers love it?" (Freedburg, 2019). The Army focused development on addressing the first user issues and making IVAS something they would want to use, and using MTA authorities to eliminate programmatic obstacles (Freedburg, 2019). The Army did not have a formal operational test strategy, but brought in the operational testing activities with each soldier touchpoint. The Director, Operational Test and Evaluation was able to observe the first soldier touchpoint occurred less than four months after award and report their findings to Congress (Behler, 2019).

The contracting strategy mattered. The Army could have used a traditional request for proposal or Broad Agency Announcement, followed by a full and open competition. Typical contracting timelines for such efforts are over a year from solicitation to award. Other Transaction Agreements do not use Federal Acquisition Regulation requirements. They do define objectives, deliverables, payments, and risk share. They can be structured in many ways, but are like a fixed price payable milestone contract. The Army was able to obtain permissions and approvals to use an OTA shortly after program start, and structure the program to use both OTA flexibility to develop prototypes, but also use the new authorities to transition to production.

The Army established novel control methods, such as mandating a government-owned architecture, using government furnished equipment to segment technical risk, and aligning payments with measurable progress events such as soldier touchpoints and capability set deliveries. Use of soldier touchpoints had the additional advantage of stimulating contractor innovation, and the frequent interactions resulted in rapid incremental changes meeting user needs.

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[46] Cross functional team descriptions are on the Army Futures Command website (Department of the Army, 2021).
[47] The Program Executive Officer Soldier in 2019 was BGEN (Freedburg, 2019).

The Army was able to largely remain on schedule, despite the Covid delay. The result was that most objections were not provided in time to slow program progress. In 2020 Congress enacted a funds limitation on IVAS (P.L. 116-283, 2021). This did not slow the Army. They awarded Microsoft a production contract on 31 March 2021 worth nearly $22 billion including all options (PM IVAS, 2021).

The IVAS program is still in execution, but continues to move at a rapid pace. It is an ambitious and is built for speed. The Army acquisition professionals who imagined, created, executed, and sustained this effort contributed not only to the rapid acquisition body of knowledge, but provided an exciting and innovative example of what can be done to deliver a long-desired capability to soldiers. Hooah![48]

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References

ASAFM. (2021). Department of Defense Fiscal Year (FY) 2022 Budget Estimates Army Justification Book Volume 2 of 3 Other Procurement, Army Communications and Electronics Equipment, Budget Activity 2. Department of the Army. https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2022/Base%20Budget/Procurement/OPA_BA_2_FY2022_PB_Other_Procurement_BA2_Communications_and_Electronics.pdf

Behler, R. F. (2019). Director, Operational Test and Evaluation FY 2019 Annual Report. Director, Operational Test and Evaluation. https://www.dote.osd.mil/Publications/Annual-Reports/2019-Annual-Report/

Behler, R. F. (2021). Director, Operational Test and Evaluation FY2020 Annual Report (p. 310). Director, Operational Test and Evaluation. https://www.dote.osd.mil/annualreport/

Boukendour, S., & Hughes, W. (2014). Collaborative incentive contracts: Stimulating competitive behaviour without competition. Construction Management and Economics, 32(3), 279–289. https://doi.org/10.1080/01446193.2013.875215

Department of the Army. (2021, September). Army Futures Command—Cross Functional Teams. Army Futures Command. https://armyfuturescommand.com/cft/

Freedburg, S. J. (2019, December 13). Soldiers, Coders Surprise Army Brass By Changing IVAS Goggles. Breaking Defense. https://breakingdefense.com/2019/12/soldiers-coders-surprise-army-brass-changing-ivas-goggles/

General Services Administration. (2021, September 30). Federal Procurement Data System—Next Generation. Fpds.Gov. https://fpds.gov

Grady, C. (2016, April 1). Guidance on Using Incentive and Other Type Contracts [Guidance letter]. https://www.acq.osd.mil/dpap/policy/policyvault/USA001270-16-DPAP.pdf

[48] Army battle cry (Sicard, 2017).

Hills-Duty, R. (2018, May 1). Microsoft HoloLens Sales Figures Revealed. VR Focus. https://www.vrfocus.com/2018/05/microsoft-hololens-sales-figures-revealed/
Jasper, M. (2021, April 28). Army Officials Tout Flexible, Fast Acquisition Authorities as Keys to AR Headset Program [NextGov]. https://www.nextgov.com/emerging-tech/2021/04/army-officials-tout-flexible-fast-acquisition-authorities-keys-ar-headset-program/173675/
Kamp, J. (2019). Integrating Immature Systems and Program Schedule Growth. The George Washington University.
Keller, D. (2018). Draft Statement of Objectives (SOO) for Prototype Project Award (PPA) Heads Up Display (HUD) 3.0 Program. Department of the Army.
Li, H., Zhang, X., Shi, G., Qu, H., Wu, Y., & Zhang, J. (2013). Review and analysis of avionic helmet-mounted displays. Optical Engineering, 52(11), 110901–110901. https://doi.org/10.1117/1.OE.52.11.110901
Lunden, I. (2014, March 27). Microsoft Paid Up To $150M To Buy Wearable Computing IP From The Osterhout Design Group. Tech Crunch. Microsoft Paid Up To $150M To Buy Wearable Computing IP From The Osterhout Design Group
Meeker, M. (2018). Internet Trends 2018 (p. 294). Kleiner Perkins. https://www.kleinerperkins.com/perspectives/internet-trends-report-2018/
Microsoft. (2021, August 1). Microsoft Hololens. Microsoft Hololens. https://www.microsoft.com/en-us/hololens
Mounier, E. (2011). Technical and market trends for microbolometers for thermography and night vision. 8012(1), 80121U-80121U – 6. https://doi.org/10.1117/12.877050
OUSD(A&S). (2018). Other Transactions Guide Version 1.0. Office of the Undersecretary of Defense (Ascquisition and Sustainment). https://www.dau.edu/guidebooks/Shared%20Documents/Other%20Transactions%20(OT)%20Guide.pdf
Parkin, S. (2015, December 31). How VR is training the perfect soldier. Wareable. https://www.wareable.com/vr/how-vr-is-training-the-perfect-soldier-1757
PM IVAS. (2021, March 31). IVAS Production Contract Award. Program Executive Officer SOldier. https://www.peosoldier.army.mil/News/Article-Display/Article/2556870/ivas-production-contract-award/
Roberts, J. (2014). Gigaom: Microsoft bucks its own history, embraces “openness” in push for Azure adoption. Newstex Trade & Industry Blogs. https://gigaom.com/2014/06/18/microsoft-bucks-its-own-history-embraces-openness-in-push-for-azure-adoption/
Sicard, S. (2017, October 5). Army Battle Cry. Task and Purpose. https://taskandpurpose.com/history/mysterious-origins-hooah-armys-beloved-battle-cry/
Straus, S. G., Lewis, M. W., Connor, K., Eden, R., Boyer, M. E., Marler, T., Carson, C. M., Grimm, G. E., & Smigowski, H. (2019). Collective Simulation-Based Training in the U.S. Army: User Interface Fidelity, Costs, and Training Effectiveness. RAND Corporation. https://doi.org/10.7249/RR2250
Tishman, J., & Schoen, D. (2021, January 22). We Don’t Own the Night Anymore. Modern War Institute at West Point. https://mwi.usma.edu/we-dont-own-the-night-anymore/
National Defense Authorization Act for Fiscal Year 2016, Pub. L. No. 114–92 (2015), S.1356. https://www.congress.gov/114/plaws/publ92/PLAW-114publ92.pdf
National Defense Authorization Act for Fiscal Year 2021, Pub. L. No. 116–283, 1480 (2021). https://www.congress.gov/bill/116th-congress/house-bill/6395/text/enr
Weber, K. M., & Rohracher, H. (2012). Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive “failures” framework. Research Policy, 41(6), 1037–1047. https://doi.org/10.1016/j.respol.2011.10.015
Yamakawa, L. J. (2018, August 10). Heads Up Display (HUD) 3.0—Industry Day Brief. Sam.Gov. https://sam.gov/opp/318f17b4157e78b24ca718a4b5ab4478/view

When is it Feasible (or Desirable) to use the Software Acquisition Pathway?

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Abstract

DoD Instruction 5000.87 establishes a Software Acquisition Pathway (SWP) "for the efficient and effective acquisition, development, integration, and timely delivery of secure software" (Office of the Under Secretary of Defense for Acquisition and Sustainment, 2020, p. 1). Under SWP, programs are required to deliver a Minimum Viable Capability Release (MVCR) deployed to an operational environment within 1 year of initial funding. This MVCR must be secure and suitable for operational deployment and must enhance warfighting capability. This paper discusses the challenge of determining for a software development effort whether the minimum capabilities that meet these criteria and enable ongoing agile development can plausibly be developed, tested, and operationally deployed in less than a year. We use a standard software cost and schedule model to derive bounds on the size of software that can be developed and ready to field in 12 months.

The study concludes that many DoD software acquisitions will require too much development effort for the MVCR to comply with the SWP deadline if SWP is used from program initiation. We propose some criteria the Under Secretary of Defense for Acquisition and Sustainment might use to determine whether the SWP is appropriate for a particular new or existing program or software development project. We also consider development strategies that might improve the chances of success in using the SWP, including how non-SWP programs and projects should be architected if the intent is to later transition to SWP.

Executive Summary

Department of Defense Instruction (DoDI) 5000.87 establishes a new Software Acquisition Pathway (SWP) to facilitate streamlined acquisition of software-centric applications. The instruction specifies that programs using the SWP must "demonstrate the viability and effectiveness of capabilities for operational use not later than 1 year after the date on which funds are first obligated to develop the new software capability" (Office of the Under Secretary of Defense for Acquisition and Sustainment [OUSD(A&S)], 2020b, sec. 1.2(e)). The thesis of this brief study is that this requirement may be significantly more restrictive than the drafters intended, due to basic constraints on how much operationally adequate software can be designed, developed, tested, and fielded in a single year. In particular, the need for fielded software to be safe, secure, and easily upgraded imposes significant up-front requirements on the architecture, design, verification, and validation of a minimum viable capability release (MVCR) for the system.

Using calibrated models of past defense software development efforts, we estimate that a military software project MVCR is unlikely to exceed ~28,000 equivalent source lines of code (ESLOC) if accomplished in less than 1 year, producing at most ~250,000 physical source lines of code (SLOC).[49] For programs using the SWP, this first-year product would need to include implementation of key non-mission software features, such as communications architectures and modular design. It would also need to accomplish verification of the effectiveness and suitability of the MVCR, such as cybersecurity, system safety, and interoperability. These are best-case estimates, using optimistic assumptions regarding developer capabilities, application complexity, off-the-shelf tools, code reuse, automated code generation, and the deployment environment. The achievable capability may be significantly less for more complex applications, such as embedded software, software with extensive interoperability requirements, very high required reliability, software incorporating machine learning, or software for use in extreme safety environments (e.g., space or undersea). Embedded software is particularly noteworthy on this list, in that 5000.87 provides an explicit separate path for embedded software that acknowledges the need to coordinate development of the software and its hosting platform.

Conversely, existing software programs that have already passed their MVCR and are now implementing the iterative phase of an agile or DevSecOps process have a much better chance of meeting the strictures of 5000.87 after transitioning to SWP, both in terms of initial delivery and ongoing capability drops. Post-MVCR transition might also help programs resist pressure to take shortcuts with regard to architecture, modularity, and other non-functional features important to future agility.

Background

As part of the new Adaptable Acquisition Framework (AAF), DoDI 5000.87 establishes a new acquisition pathway for software with the explicit intent of decreasing development lead times and increasing upgrade frequencies for software-intensive defense systems. The SWP defines two distinct paths: one for applications programs operating on commercial hardware, and a second for development of software embedded in defense systems employing military-unique hardware. The instruction also provides for existing acquisition programs to transition all or part of their acquisition strategy to the SWP. In either case, one criterion for entry into the SWP is that the program must demonstrate viability and effectiveness for operational use within 1 year of the program's first software expenditures. This time constraint clearly places limits on the capabilities that can be implemented using this pathway.

To bound the upper limit of the amount of software that can be developed and delivered in 1 year, we define two segments of software development that could be

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[49] Equivalent SLOC are defined in terms of how many new lines of code could be produced with the same effort. Code reuse, adaptation, and auto-generation all increase the ratio of SLOC to ESLOC in a development effort.

executed in parallel, and we describe the required attributes and qualities that the delivered software must have, regardless of mission domain. The first segment is the mission-specific functions that constitute the outward behavior and capabilities of the application, and the second segment is the core infrastructure software that enables the mission features to execute on the host computing platform. We refer to these segments as the mission software and the infrastructure software, and assume that the interface between these segments can be well-defined so that their developments can be concurrent. Both of these segments must also satisfy what are often called “non-functional” requirements that the software (and its host system) have certain attributes, such as safety, security, reliability, ethics, maintainability, and so forth. These non-functional requirements are not satisfied by a specific body of code but rather must be achieved and supported by all mission and infrastructure software. Although these requirements add to the size of the software being developed (and the effort to develop it), they cannot be satisfied by adding to or modifying that code after it is written. These are attributes that the developing code must manifest from its inception.

Under DoDI 5000.87, that first operationally effective and viable increment of capability is referred to as the “minimum viable capability release,” or MVCR. The instruction defines this as “the initial set of features suitable to be fielded to an operational environment that provides value to the warfighter or end user in a rapid timeline.” Any program whose initial feature set of mission software and all necessary infrastructure software cannot plausibly be completed within a year while achieving the mandatory non-functional requirements should not attempt to use the SWP. Furthermore, any program that would have to trade away future agility in order to meet the 1-year deadline[50] should not attempt to use the SWP, since the lack of future agility would defeat the purpose of the pathway.

The Under Secretary of Defense for Acquisition and Sustainment (USD[A&S]) has authority to direct acquisition programs to use other acquisition pathways if the SWP is not appropriate. This research investigates some criteria USD(A&S) might use to determine whether the SWP is appropriate for a particular new or existing program or software development project. It also considers acquisition strategies that might improve the chances of success in using the SWP, including how non-SWP programs and projects should be architected if the intent is to later transition to SWP after an MVCR has been fielded, or at the earliest, during the year prior to fielding an MVCR.

What Constitutes a Minimum Viable Product?

Programs executing the SWP are explicitly not subject to the reporting and review requirements of major defense acquisition programs (MDAPs), regardless of expected life-cycle cost. This has the potential to enable SWP programs to begin significantly sooner than if those programs were required to execute the full sequence of major capability acquisition governance processes, from Mission Needs Statement through Analysis of Alternatives to

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[50] An example of this kind of trade would be to opt for a proprietary, monolithic system architecture rather than an open, modular architecture. Relaxing the requirement for openness and modularity may permit faster initial release, but would also make subsequent upgrades more difficult and more expensive.

Milestone A/B authority. If the goal is to field new capabilities as quickly as possible, spending less time getting underway is clearly desirable.

While DoDI 5000.87 requires that the MVCR be "viable," it does not specify where authority lies to determine the minimum acceptable infrastructure and operational capabilities (and non-functional requirements) that define the MVCR. The instruction says, "The PM and the sponsor will … define a minimum viable capability release" (OUSD[A&S], 2020b, sec. 3.3(b)(5)) without constraining who may or should participate in that MVCR definition process. According to agile precepts, the specification of the minimum viable capability should be determined collaboratively by the user community, senior acquisition executives, the commands that will employ the system, the program manager, and importantly, the developers. In practice, this level of collaboration may be hard to achieve.

The instruction further defines the *sponsor* to be "the individual that holds the authority and advocates for needed end user capabilities and associated resource commitments" (OUSD[A&S], 2020b, sec. G.2). The sponsor is also the individual who approves the Capability Needs Statement (CNS) developed by the operational community. The DoD Components are directed to create streamlined requirements processes to develop, coordinate, and approve CNSs, including an expedited joint validation process if the Joint Staff deems it necessary to protect joint equities.

Instruction 5000.87 explicitly states that assurance of system safety, security, effectiveness, and suitability are still very much required and should be integrated and automated to the maximum extent possible. This provides further evidence that the MVCR will generally have mandatory attributes that cannot be deferred or waived; it must be safe, secure, suitable, and effective in accordance with the mission capability priorities established in the CNS. Those priorities might include operational features like interoperability as well as structural features like modularity or conformance to an architectural standard.

It is worth noting that, while DevSecOps and agile development offer many benefits to the overall efficiency and productivity of development projects, some of those acceleration benefits apply only to the portion of the project that implements non-mandatory features. In particular, a major efficiency benefit of the agile philosophy is to have the freedom to defer or eliminate the development of features that turn out to be low priority. By definition, the MVCR does not contain any low-priority or "optional" features—if it did, it would not be the *minimum* viable capability release. On the other hand, it might include some features that are important in the long run but not yet useful at the time of initial deployment. Implementation of a modular open system architecture (MOSA), for example, has no immediate benefits for MVCR operations. The benefits of MOSA come later, making it easier and faster to add and upgrade capabilities during the subsequent agile phase of the system life cycle. As a result, the effort to develop the MVCR may include necessary work that does not correspond to any explicit functions in MVCR operations. Similarly, the cybersecurity architecture for the full system may be more complex than required for just MVCR operations, but must still be engineered to support the eventual full range of system operations. For these reasons, the infrastructure software for the MVCR including all its non-functional requirements may constitute a disproportionate fraction, even the majority, of the total code effort.

DoDI 5000.87 describes a workflow in which government developmental and operational testing are integrated from inception and throughout the life cycle to support software assurance, cybersecurity, and mission capability (OUSD[A&S], 2020b, sec. 3.2f(2)). This reinforces the point that the system architecture and design implementing the

MVCR must not only be sufficient in terms of infrastructure and mission capabilities to support the MVCR; they must also implement full safety and security requirements to enable it to be fielded in the operational environment, and must be compatible with agile development thereafter.

MVCR Is Not a Prototype

As noted above, the MVCR must implement all the necessary security features, user permissions, encryption, firewalls, etc. to operate safely in the network so as not to introduce flaws or security back doors into the operational environment. This differentiates the MVCR from a *prototype* application. Important non-functional system attributes are seldom implemented in prototypes. The principal exception is in cases where the application technologies are immature and the purpose of the prototype is to verify that a candidate design approach can meet requirements. Any program that is still verifying the feasibility of technical approaches is a poor candidate to be ready to field in less than a year.

It is tempting to say that the MVCR could be implemented as a prototype of the eventual full-up system in order to save time and effort in getting the first release to the users, but this could be dangerous. It is simply not feasible to change the architecture of an application that implements only a prototype solution. Also, applications that do not implement mission-capable cybersecurity would not be granted authority to operate (ATO). The authors have first-hand experience with the acquisition of a very large defense application that had to be rewritten from scratch late in the development process because the program opted to try to save time by enhancing a prototype that had not been architected to provide cybersecurity. The developers found it impossible to achieve security assurance after the fact. The necessary design, architecture, and development processes to ensure the presence of the fundamental qualities must be incorporated from the beginning.

It would be theoretically possible to develop a disposable MVCR just to meet the 1-year deadline and then replace it with the real code at a later date. However, this seems inconsistent with the objectives of the pathway. Any disposable MVCR would still need full cybersecurity and a complete operational test and evaluation, and fielding it could introduce version control and interoperability issues between the MVCR and the eventual fully compliant application that would replace it. Further, even if a disposable MVCR was thought to be cost-effective in order to maintain conformance to the SWP, it would be antithetical to the DevSecOps philosophy of early testing and integration of the actual application as it will be delivered.

MVCR Is Not MVP

DoDI 5000.87 also defines a minimum viable product (MVP) in the context of SWP acquisition. The MVP is defined as an early version of the software that allows users to evaluate and provide feedback on basic capabilities and design features, helping to shape scope, requirements, and design. In practice, an MVP could be a mock-up or storyboard that enables the developers and users, as well as other stakeholders, to agree on how the final application should look and behave. Agile developments use such prototypes to make both the application’s requirements and the proposed solutions visible and understandable to all parties.

Language in 5000.87 suggests that the MVP delivery could not only be a waypoint along the path to producing an MVCR, it might even be identical to the MVCR if it is operationally deployable. This suggestion is also dangerous in many respects. The MVP is meant only to illustrate design and function so that developers can show users different options and ideas.[51] The goal of getting the MVP in front of users and commanders as quickly as possible actually mitigates *against* trying to make it suitable for eventual operational use. Building it correctly, with all of the mandatory structural attributes and security, would take too long, defeating the purpose of eliciting early feedback. The MVP can (and indeed *should*) be devoid of most internal functions and lack many required features but still be useful for generating important requirements feedback. Requiring the MVP to have a secure and modular architecture would miss the point of the MVP. At the same time, basing the MVCR on an MVP that was neither secure nor modular would be an extremely inefficient, and potentially disastrous, way to code. As valuable as the MVP is, there is little chance (and no need) for that product to factor into the deployable application. It should be considered little more than an interactive requirements demonstrator, not production code. Remember also that the MVP and MVCR necessarily compete for resources during early development. Putting too much effort into the MVP could shortchange the development of the MVCR. The two can (and should) be simultaneously developed, but the MVP should be as simple as possible to achieve its purpose—information collection regarding stakeholder acceptance and priorities.

Operational Testing and ATO

Before any changes or additions are made in the operational environment, software must be granted ATO and must pass rigorous operational test and evaluation (OT&E). Consistent with a DevSecOps development process, the required analysis to achieve ATO can be performed continuously and iteratively during development, an approach referred to as continuous ATO (c-ATO). Successful c-ATO can eliminate the dedicated ATO process that confronts programs that treat ATO as a test to be passed, rather than as a state to be maintained.

OT&E has customarily been treated as an end-of-development hurdle to be overcome by an independent team after developers consider a product ready to field, introducing another sequential activity that must be completed before live deployment can occur. IDA experts in conducting OT have concurred that, like c-ATO, continuous OT&E can be integrated into and performed concurrently with development. Although this integration would not entirely eliminate a final evaluation before deployment, it is intended to make that final check routine and efficient. Our discussions with OT&E experts led us to conclude that less than 2 months of OT&E can be sufficient if continuous verifications have been conducted during development. The ability to run developmental and operational testing concurrently during development greatly reduces the late discovery of defects, incompatibilities, and other surprises.

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51 The definition of MVP used in the commercial world is somewhat different from that in DoDI 5000.87. The commercial usage is more akin to the definition of MVCR in the instruction. This may be a source of confusion regarding the potential for an MVP to also be an MVCR.

How Much Capability Can You Deliver in a Year?

Some Optimistic Assumptions

To assess how much capability could plausibly be developed in 1 year, we will start by making some optimistic assumptions. In particular, we assume that:

- The requirements (both functional and non-functional) for the MVCR are well-defined and fixed.
- A single version of the software is to be fielded.
- The development process takes advantage of all reasonable measures to allow as much concurrency of effort (i.e., parallel development) as possible.
- The development team employs best-practice agile and DevSecOps methods, including continuous testing and early user feedback.
- The development team uses as much automation as possible.

A recent source on software development with agile teams estimates that these conditions could improve development speed by 15% to 20% relative to traditional development methods (Elk et al., 2020, p. 76).

The MVCR is required only to be mission-capable and to provide operational value to users and stakeholders. As noted above, the most efficient way to achieve this would be to divide the project into two parallel developments that run concurrently but independently: 1) mission software that can deliver a modest but useful subset of capabilities, and 2) core application infrastructure providing all the necessary operating system connections, messaging, user privileges, encryption, external interfaces, and essentially anything that is not strictly mission-specific from the user's viewpoint. We need to make some assumptions regarding the relative effort between implementing core infrastructure versus implementing functional mission capabilities, and the implications of non-functional requirements for both infrastructure and mission development effort.

We assume that such a partition of effort is feasible, so that the time to produce a deployable MVCR is determined by the longer of 1) the time to implement the mandatory infrastructure, and 2) the time to implement the mission capabilities. We also assume that development of the core software can adapt and reuse existing, commercial, and open-source code to a much larger extent than the mission software. Finally, we assume that the MVCR must instantiate the full set of non-functional attributes, such as cybersecurity or modularity. The next section explores the maximum amount of code the MVCR could conceivably deliver in a 1-year development effort.

Modeling with COCOMO

To understand how much software could be developed and deployed in 1 year, we turned to the current COCOMO software cost model, now formally named COCOMO-II.[52]

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[52] We will adopt the common practice of simply using COCOMO to refer to the more recent COCOMO-II version of the model, an update based on 20 additional years of software project data.

This version incorporates updates to the cost-estimating relationships published in the original 1981 text by Barry Boehm (Boehm, 1981).

The COCOMO cost equations accept software size estimates and yield estimates of the required number of staff months of effort required to produce that much software. A second COCOMO equation estimates the schedule over which that amount of effort can be accomplished. Schedule does not vary linearly with size, since a larger team can be applied to a larger project, so COCOMO first yields an estimate of total effort and then uses that to provide an estimate of the schedule. Since our constraint is the schedule, not the effort or cost, we used the model to reverse-engineer the largest code size that could be developed and delivered within 1 year under our optimistic assumptions from the previous section.

COCOMO accepts five scaling factors and 17 effort adjustment factors to accommodate the differences among software development projects that were observed to have an effect on software development productivity. All 22 factors have nominal (default) values reflecting typical software projects. Each can be tuned to reflect atypical aspects of a given project or development environment. The COCOMO models have been calibrated against historical outcomes to predict the influence of these factors on project outcomes (Boehm et al., 2000).

Of the 22 factors that can affect productivity and schedule, we left all but four at their default values. The non-default values we applied were as follows:

1. *Required software reliability* was set to "high," one level above nominal, to reflect the demands of operational defense mission software.
2. *Use of software tools* was set to its maximum value, reflecting our optimistic assumption about use of automation by the development team.
3. *Required development schedule* was set to "maximum compression of schedule" to maximize the delivered content within the fixed 1-year period.
4. *Process maturity* was set to its maximum value, CMM Level 5, assuming a highly capable development team and organization.

We did not alter the "volatility of requirements" setting because the default is "no volatility," which was one of our optimistic assumptions.

The effects of these parameter settings vary. High reliability adds 10% to the effort and about 3% to the schedule.[53] Setting the tool use factor to Very High reduces effort by 22% and also reduces schedule by about 8%. Tool use is particularly important for the development of the core software since reuse, code generation, and off-the-shelf software are all likely to be extremely useful for that portion of the development.

Setting the Required Development Schedule driver to Very Low results in a 25% reduction in schedule but a 43% increase in effort, trading a 30% drop in productivity for

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[53] In COCOMO, schedule estimation involves spreading the estimated effort over a feasible schedule. Since the relationship between effort and schedule is not linear, it means that the effect on schedule from a given effort adjustment factor varies depending on the size of the project.

faster execution. The COCOMO development research determined that no further schedule compression is possible beyond this since the calibration data did not contain any programs that successfully completed in less than 75% of a nominal schedule.

In addition to setting these four adjustment factors, we eliminated the earliest development phase estimated by COCOMO, called the inception phase.[54] This choice reflects our assumption that the requirements for the MVCR are well-defined and have been finalized before commencement of the SWP. COCOMO also provides a final operational verification effort and schedule, which the model calls the transition phase that occurs after development is complete. For developments that complete in close to 1 year, the transition phase in COCOMO is between 1 and 2 months. This phase begins at IOC and ends with product release, making it analogous to our estimates of ATO and final OT&E.

Measuring Size

ESLOC

COCOMO uses "equivalent source lines of code" (ESLOC) to measure the size of software development efforts. ESLOC is a derived value that considers how many new lines of code must be written, how many preexisting lines of code are reused unmodified, how many preexisting lines of code will be modified and adapted for use by the project, and how many lines will be generated by software tools. For a project that requires all new code, ESLOC is the same as the number of SLOC. When code is reused, adapted, or generated by tools, the ESLOC count will be less than the physical SLOC count. It is a theoretical measure of the number of new lines that could have been written with the same effort as that required to adapt and integrate the reused or generated code. This allows the cost and schedule modeling to work with a single, normalized measure of program size.

For our estimate of the largest MVCR that could be achieved in 1 year, we assumed that all required mission software would be newly developed. However, we assumed that the infrastructure software to support this new mission software would either be highly reused and adapted from preexisting software, or would be generated by software tools with much less human effort than required to develop those lines of code from scratch. In other words, the ESLOC measure of the infrastructure software is expected to be much less than its delivered software size.

Function Points

Function points (FPs) are an alternative measure of code size based on functionality provided rather than volume of code required. COCOMO allows unadjusted function points (UFPs) to be estimated as a size input to the effort estimation and the corresponding schedule projection. This involves prior conversion of UFPs to SLOC and running the model as before. Conversion tables are provided in the COCOMO documentation to determine the SLOC that would be comparable to one UFP in various computer languages. These

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54 Through collaboration with Rational, Inc. in 1999, USC parsed the COCOMO-II effort into four phases: Inception, Elaboration, Construction, and Transition. The middle two estimate the main software design and development activity, and the final phase is analogous to the operational deployment, discussed in Part B.

conversions range from 300 lines of assembly language per function point to as few as 10 or fewer lines per function point for fourth- and fifth-generation languages. Third-generation languages, such as C and Ada (and older languages such as Fortran), range from 70 to 120 source lines per function point. Object-oriented languages like C++ and Ada95 can implement a function point in about 50 lines.

Although it may be possible to use a single language for all of the mission software development, this is unlikely to be true for the system and support software due to the various tools and operating system software that we expect will have to be integrated to complete the implementation. Thus, any conversion to UFP will be crude for the non-mission portion of the MVCR development.

COCOMO Calculations

Modeling Results

COCOMO modeling with the settings described above indicates that 28,000 ESLOC could be developed and made ready for deployment in 12 months, including either the COCOMO estimate for transition or our independently derived estimate of between 1 and 2 months for OT&E. This estimate assumes that the mission software and the non-mission infrastructure software can be developed independently and concurrently. Continuous verification of the compatibility between the two parallel tracks would be necessary to prevent any incorrect assumptions about their interfaces from delaying their eventual integration. DevSecOps processes would help to achieve the integration of verification with developmental testing cycles.

We assume that the MVCR mission software will be almost entirely new code, with little reuse from prior applications. Thus, the maximum delivered size of the mission code in the MVCR would remain close to 28,000 SLOC.

For the non-mission infrastructure software, we assume significant opportunities for reuse. The literature suggests various overhead factors to reuse existing software, based on how much study is required to understand the software, whether it has to be modified, and whether it has to be tested and verified or can be assumed to function as specified. For our bounding exercise, we optimistically assume that the infrastructure software is well-understood and well-supported by tools and existing software. Based on discussions with software development experts at our company who are familiar with the development of infrastructure software through the use of tools and reuse, we assume that the composite of all the reuse effort factors for the infrastructure software could be as low as 5% to 15% of the cost of new code development.[55]

Thus, for the infrastructure segment, our modeling estimates that as many as 250,000 physical lines of software could be produced with 28,000 ESLOC of effort. To arrive

[55] A 15% cost relative to new code development was also observed by one of the authors in *A Component Factory for Software Source Code Re-engineering*, University of Maryland, 1992. Bailey measured the rate of near-verbatim mission software reuse at the Software Engineering Laboratory at the University of Maryland and NASA Goddard. Our expectation is that the general case of reusing operating system and support software should be even more efficient.

at this total code size, we used optimistic estimates for the efficiency of reuse due to the high tool use adjustment factor and the wide availability of construction tools for this more general-purpose software.[56] If the infrastructure software were unprecedented (e.g., if it had to be hosted on novel hardware), the availability of tools and reusable code would be much more limited. As a result, the same amount of effort would not be able to deliver nearly as much code. A case study we used for other insights into relative sizes and efforts for mission and infrastructure software is described in the next section titled “Case Study Data.”

COCOMO Modeling Details

According to COCOMO, after applying the effort adjustment factors of high reliability, high tool use, and shortest schedule, and adopting the highest process maturity, 28,000 ESLOC would take 10.8 months to develop. The transition phase (corresponding to OT&E) is estimated to take an additional 1.4 months, which we optimistically reduce to 1.2 months due to continuous verification during development. Since we assume mission software is nearly all new code, this bounds the mission software that can be delivered as part of the MVCR.

Potentially more infrastructure software (in terms of SLOC) can be included in the MVCR, due to available tools, reuse, and adaptation of existing software. If we assume that 28,000 ESLOC of infrastructure software would require only 10% of the resulting SLOC to be newly developed, and the remainder would require 50% of the integration effort of new code, it would be possible to deliver about 150,000 SLOC of software. If the integration effort were only 10% that of new code, COCOMO modeling suggests that over a half million SLOC could be delivered. As a compromise, we estimate that the upper limit for delivered infrastructure software from a highly automated 28,000 ESLOC effort is probably somewhere in the range of 200,000 to 300,000 SLOC under these highly optimistic assumptions. Figure 1 shows the maximum ESLOC as a function of available time.

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[56] Examples from one of our colleagues include COTS RTOS run-time operating system tools, such as those from VxWorks or QNX, and for appropriate applications, cloud-native functions associated with platform as a service (PaaS) and software as a service (SaaS). Development with open-source software (OSS), adoption of middleware, virtualization, or containers were also offered as common approaches.

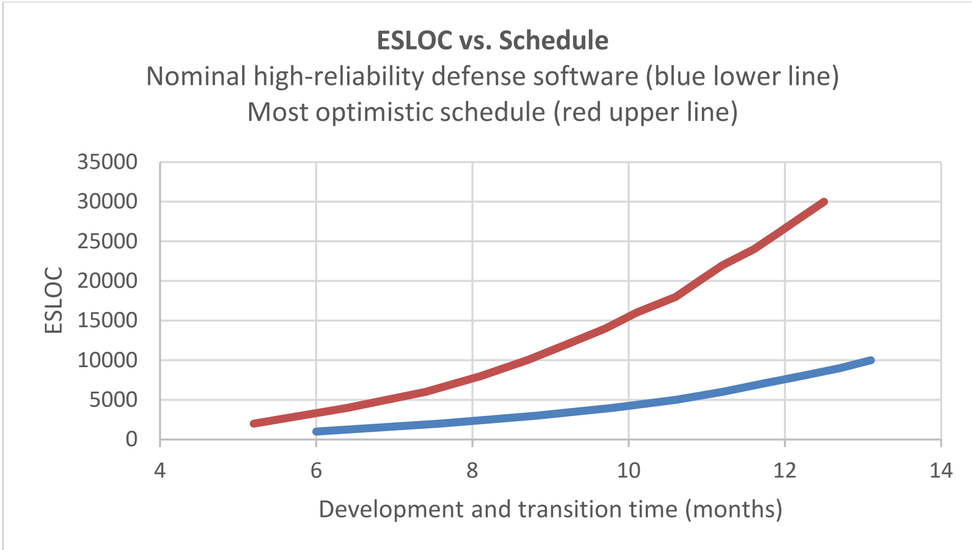

Figure 24. Development schedule vs. software size for typical defense software

Case Study Data

Now that we have estimates of the maximum ESLOC that can be delivered and deployed in 1 year, the remaining questions are 1) how much mission function can be delivered with a maximum of 28,000 new lines of software, and 2) would 250,000 lines of system and support software, including the requisite cybersecurity, be enough to host the MVCR mission software in the operational environment?

Capers Jones summarized 265 new and enhancement military software projects prior to 2000 (Jones, 2000). Application sizes were expressed in function points to eliminate the effect of language in the comparison. To compare this to our COCOMO modeling, we converted to ESLOC by assuming implementation in a third-generation language such as Ada, C, or Fortran.

The new projects in Jones average 2,800 function points, implying they probably average between 200,000 and 300,000 SLOC. Further, a graphic in Jones shows some much smaller completed projects, on the order of 100 function points. Although many of these could be enhancement projects, we note that software enhancements can also qualify for SWP. A 100 UFP development using C would amount to about 12,000 source lines. In fact, at 120 lines per UFP, up to a 233 UFP project in C could be developed within the 28,000 ESLOC limit for a 1-year MVCR deployment. This implies that some of the projects in that data set could have been entirely completed in a 1-year development effort, according to our modeling. However, most of the projects clearly would have required several years, even under our optimistic assumptions. Jones does not address the relative effort needed for infrastructure versus minimally viable mission software for those systems; it is probable that some of those larger projects could have demonstrated viable and useful operational capability in just 1 year. The authors are unaware of any statistics on the typical size of the MVCR for military applications relative to the mature application after iterative improvements.

As a case study, we examined data on a military software project that involved the development of multiple radio waveform applications that would run on a core of hardware-specific infrastructure software. Each waveform corresponded to a legacy radio family that the new system would be able to communicate with. The infrastructure software would implement signal processing, cryptography, and other common radio functions, while the waveform software would enable the radio to communicate with various legacy radio systems. Although the program office estimated a need for more than 4 million lines of waveform software in total, the individual waveforms were estimated to each need anywhere from 2,500 to 200,000 SLOC. Our modeling confirmed, therefore, that a small but operationally useful number of those waveforms could have been developed within the 1-year MVCR deployment constraint. (This was consistent with the outcome of earlier prototyping efforts in a similar application.) Unfortunately, because of the more limited opportunities for low-cost reuse and available tools than in our optimistic scenario, the infrastructure software was estimated to require more than 1 million ESLOC to deliver 2.1 million SLOC, a net gain from reuse and tool-generated code of only 50% of the cost of new code. This suggests that this program would not have been a viable SWP candidate from its inception. A more realistic plan would have been to implement the infrastructure functions under a different pathway—perhaps Middle Tier Acquisition (OUSD[A&S], 2020a)—and then to transition the balance of the development to the SWP after or within 1 year of the successful completion of the infrastructure portion of the MVCR plus an operationally useful subset of waveforms.

Some projects implementing DevSecOps have reported higher software development productivity than was observed in the projects used to calibrate COCOMO. There is some evidence that agile and DevSecOps approaches can improve even our optimistic MVCR productivity rates through the benefits of early and continuous testing and user feedback. These improvements, if real, would not be captured in COCOMO-II, which attempted to be forward-looking with some of its adjustment factors but was last calibrated in 2001. Similarly, the examples from Jones are also more than 20 years old. Novel tools and code generators to help build operating systems and infrastructure software continue to appear in the marketplace. Although these advances generally show up first in commercial software development, applicable ones eventually appear in defense acquisitions. It is conceivable that our best-case estimates of productivity should be bumped up by an additional 10% to 20% to account for this. However, even with that additional headroom, many defense software projects—and particularly those associated with major capabilities—still appear unlikely to be executable to MVCR in 1 year of development. A significant impediment to the delivery of operationally deployable software is the stringent non-functional requirements associated with deployed operational systems, and the extensive infrastructure effort needed to support operational viability and long-term maintainability of the applications.

Transitioning Into SWP

DoDI 5000.87 provides for programs that are currently being executed under some other acquisition pathway to transition to the SWP when they can plausibly meet the specified timelines. Our analysis provides a template for how program managers could assess whether they are within 1 year of achieving the needed software maturity. First, separate the remaining development into two segments: the architectural and infrastructure requirements and the minimum mission capability requirements. Second, estimate the remaining development time (including OT&E) to complete the MVCR set of requirements for each of the two segments, including verification of all non-functional requirements that are mandatory for actual operations. When the larger of those two estimates is less than 1 year, the program may be ready for transition to SWP.

Since the infrastructure requirements of the application will often require more development effort than the minimal set of mission capabilities, it is important that programs not be tempted to skimp on non-functional attributes such as cybersecurity, reliability, or modular design in an attempt to accelerate delivery of the MVCR. Missing non-functional attributes at MVCR are very unlikely to be satisfied later, short of a complete rewrite of the application. Where the complexity of infrastructure requirements or the non-functional demands of future capability (or both) are high, transitioning to SWP after implementation of the infrastructure functions may be the more effective process in the long run.

Our research suggests that programs that cannot expect to deliver a fieldable capability that provides operational value by the end of the first year of development should be conducted under a different acquisition strategy, such as Middle Tier Acquisition, at least until an MVCR can be completed in 1 additional year. At that time, transitioning to SWP would be feasible as long as continuous ATO and embedded OT&E verification of required non-functional attributes had been practiced, and care had been taken in architecting the solution such that annual upgrades could be delivered after every subsequent year of development. The time prior to transition to SWP could also be used to develop automated test environments to support rapid capability upgrades post-transition.

Summary

This exploratory study examines the implications of the DoD policy that acquisition programs using the software acquisition pathway (SWP) must have produced viable and effective code suitable for operational deployment within 1 year of initial funding. We estimate the maximum amount of completed code that could be produced under ideal conditions within that time span, and use those results to bound the feasible attributes of the minimum viable capability release (MVCR). To do this, we distinguish three drivers of MVCR effort: implementation of core infrastructure code that mission capabilities will rely on; implementation of an operationally useful set of mission capabilities; and assuring the mandatory non-functional attributes that the application must possess prior to operational use and maintain throughout its life. We note that the infrastructure code effort typically generates the more binding constraint, especially when assurance of the non-functional requirements is considered.

Using the COCOMO-II software cost estimation model, we estimate that 28,000 equivalent source lines of code (ESLOC) is the most optimistic limit on the size of either the non-mission infrastructure software or the mission package that could be fielded in 1 year. Comparison against historical DoD software development efforts suggests that many past systems exceed 28,000 ESLOC of mandatory infrastructure software, and would thus not have been good candidates for SWP execution under the new pathway. Even though we find that useful mission software subsets can often be completed in under a year, many DoD software applications are likely too complex to complete and field enough of the required infrastructure software to supply that mission subset with the required core system services, external interfaces, data management, and other non-mission-specific functions while maintaining required levels of safety, information assurance, and other non-functional requirements. This is even more true for applications planning to support future agility by using modular open-systems architecture (MOSA), or for embedded applications on new or existing defense-specific platforms.

Since the SWP also allows projects that are already underway to transition to the SWP development model, that pathway is available to any number of DoD software projects as long as they are also able to adopt an annual, agile release cycle for deployment upgrades. This may be a heavy lift for legacy applications that were not planned from the start to be agile. Programs intending to transition to SWP at some point should therefore devote early attention to architectures and design choices that will allow them to achieve and maintain continuous authority to operate and regression testing of effectiveness and suitability. This attention should also include explicit verification and tracking of non-functional requirements from very early in the program life cycle.

All of the estimates developed in this study were based on excessively optimistic estimates of the effectiveness of the development team, the ease of software reuse, and the benefits of agile and DevSecOps methodologies when implementing a fixed set of requirements. In the authors' opinions, it is more likely that two concurrent segments of 10,000 to 15,000 ESLOC is the effective upper limit on a 1-year development of a nontrivial new-start application to be used in combat or intelligence environments. It is not clear that the drafters of DoDI 5000.87 intended the 1-year restriction to be this binding, but as currently promulgated, it would prevent many of the Department's highest-profile software efforts from starting on the SWP.

References

Bailey, J. W. (1992). *A component factory for software source code re-engineering* [Dissertation, University of Maryland].

Boehm, B. W. (1981). *Software engineering economics*. Prentice Hall.

Boehm, B. W., Abst, C., Brown, A. W., Chulani, S., Horowitz, E., Madachy, R., et al. (2000). *Software cost estimation with COCOMO-II*. Prentice Hall.

Elk, S., Berez, S., & Rigby, D. K. (2020). *Doing agile right*. Harvard Business Review Press.

Jones, C. (2000). *Software assessments, benchmarks, and best practices*. Addison-Wesley Longman Publishing Co.

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2020a, January 23). *Operation of the adaptive acquisition framework* (DoDI 5000.02). DoD.

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2020b, October 2). *Operation of the software acquisition pathway* (DoDI 5000.87). https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500087p.PDF

Defense Acquisitions: Additional Actions Needed to Implement Proposed Improvements to Congressional Reporting

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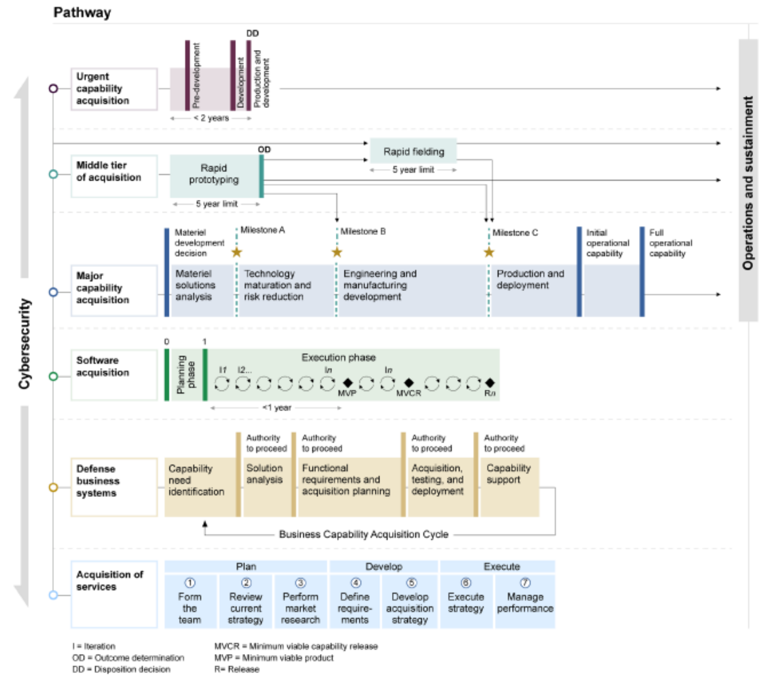
Abstract

GAO is in the midst of conducting its 20th annual assessment of DOD's major weapon acquisition programs. DOD's approach to acquisition has shifted during those 20 years, most recently with the introduction of the Adaptive Acquisition Framework (AAF) in January 2020, intended to, among other things, deliver solutions to the end user in a timely manner. However, many of the challenges GAO has observed with weapon programs' cost, schedule, and performance remain consistent. This presentation will draw primarily from GAO's 2021 and 2022 reports, which are the first annual reports to focus on changes associated with the AAF, including DOD's efforts to accelerate the acquisition process and progress in delivering capabilities more quickly. The presentation will offer observations on DOD's initial progress in implementing the AAF for weapon programs, including potential program oversight implications; the overall characteristics of DOD's major weapon system acquisitions, including changes in the pathways used to acquire weapon systems; and how these programs have performed with regard to selected cost, schedule, and knowledge attainment metrics.

Background

Adaptive Acquisition Framework

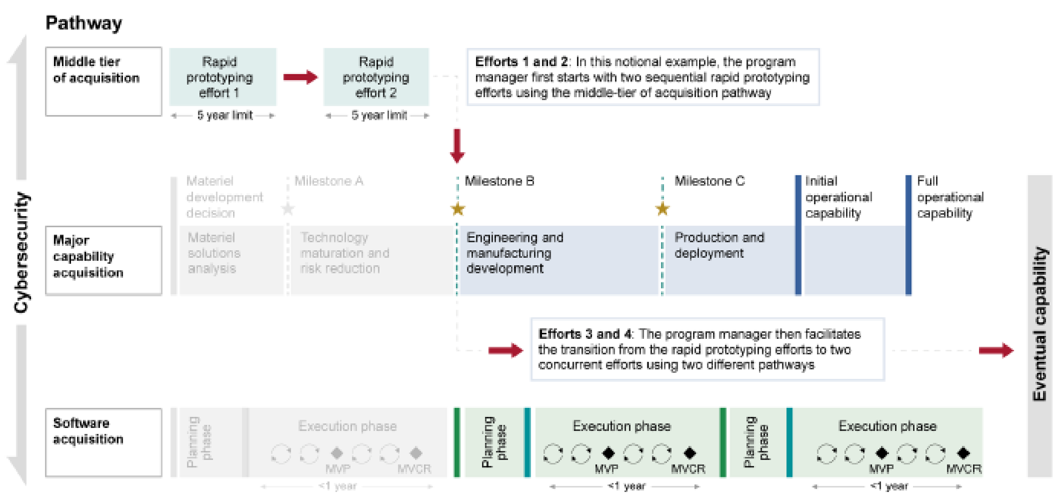
In January 2020, DOD reissued Department of Defense Instruction (DODI) 5000.02, Operation of the Adaptive Acquisition Framework. In the updated guidance, DOD established the AAF, which includes six acquisition pathways. Each pathway has different requirements for milestones, cost and schedule goals, and reporting. Figure 1 shows the six AAF pathways.



Source: GAO analysis of Department of Defense data. | GAO-22-104687

Figure 1. The Adaptive Acquisition Framework Uses Six Different Pathways

In a June 2021 report, we noted that the AAF introduces new considerations for program oversight.8 In addition to allowing program managers to use one or more of six acquisition pathways, program managers can tailor, combine, and transition between pathways based on program goals and risk associated with the weapon system being acquired. Figure 2 shows an example of how a program could use multiple efforts within a single pathway and multiple pathways to achieve operational capability.



MVCR = Minimum viable capability release
MVP = Minimum viable product

Source: GAO analysis of Department of Defense data. | GAO-22-104687

Figure 2. Notional Example of How Programs Can Use Multiple Efforts and Pathways in the Adaptive Acquisition Framework

In the June 2021 report, we reported that DOD had trouble tracking cumulative cost, schedule, and performance data for programs transitioning between acquisition pathways or conducting multiple efforts using the same pathway and had yet to develop an overarching data collection and reporting strategy. We recommended that DOD, among other things, report overall cost and schedule information for capabilities developed using multiple pathways. DOD concurred with our recommendation but has yet to address it.

In an additional report from June 2021, we noted the lack of data strategies for the software and business systems acquisition pathways and reported that DOD lacked a defined approach for automated data collection.10 We recommended that, among other things, DOD automate data collection efforts for the software acquisition pathway to allow stakeholders to monitor and assess acquisition performance. DOD agreed with the recommendation and reported that it is developing plans for automation of data collection for AAF pathways.

Roles and Responsibilities for DOD Acquisition Oversight

Acquisition oversight responsibilities for weapon programs are shared between the Office of the Secretary of Defense (OSD) and the military departments, with specific roles and responsibilities varying to some extent based on pathway and program size. Over the last several years, the decision authority for many MDAPs has largely shifted from OSD to the military departments.11 Oversight roles for programs other than weapon programs vary depending on the pathway.

The Under Secretary of Defense for Acquisition and Sustainment is the Defense Acquisition Executive and has specific responsibilities for certain AAF pathways. For example, the Under Secretary:

- serves as the milestone decision authority for certain MDAPs,13
- approves the use of the middle tier of acquisition (MTA) pathway for programs that exceed the cost thresholds for designation as an MDAP,
- advises the decision authority on their MTA programs and maintains responsibility for prototyping activities within the MTA pathway, and
- serves as the decision authority for special interest programs in the software acquisition pathway on a by-exception basis.

The Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S)) is also responsible for establishing policies on and supervising all matters relating to:

- system design, development, and production;
- procurement of goods and services; and
- sustainment (including logistics, maintenance, and materiel readiness).

Several other entities also play a role in oversight, acquisition, and budgeting for DOD acquisition programs, efforts, and pathways. For example:

- The Director of the Office of Cost Assessment and Program Evaluation (CAPE) is responsible for conducting or approving independent cost analysis and issuing the policies for collection of cost data. At the direction of the Secretary of Defense, Deputy Secretary, or the CAPE Director, CAPE staff also conduct numerous special studies and offer

advice in other areas, such as information technology and defense economics; and
- The Director, Operational Test and Evaluation, reports on operational and live fire tests and evaluations carried out on MDAPs, among other duties.

Selected Acquisition Reports

Before SARs were introduced, there were no summary recurring reports on DOD's major acquisitions that reported cost, schedule, and performance data for comparison with prior and subsequent estimates. In 1967, DOD began internally producing SARs to apprise the Assistant Secretary of Defense (Comptroller) of the progress of selected acquisitions. DOD's goal for these reports was to focus department leadership on programmatic performance and changes to acquisition plans. In 1969, DOD began providing these reports to Congress to help enable congressional oversight by providing summary level cost, schedule, and performance data on MDAPs, and more recently, other program types. The SAR became the key recurring summary report for Congress to obtain consistent, reliable data on MDAPs.

The content and the scope of SAR reporting evolved over time to meet the oversight needs of DOD leadership and Congress. Recently, in 2019, Congress broadened the reporting requirement beyond programs designated as MDAPs; specifically, the NDAA for Fiscal Year 2020 amended the SAR requirement to include programs estimated to require eventual total costs greater than the threshold for designation as an MDAP.[14] In response, DOD submitted to Congress MTA program reports similar to MDAP reports. Also in 2019, Congress terminated the requirement for DOD to submit SARs after the final submission of reporting covering fiscal year 2021.[15] However, the NDAA for Fiscal Year 2022 subsequently extended the requirement for 2 years, through fiscal year 2023.[16] Figure 3 shows selected changes to SARs since the report was mandated by statute in 1975.

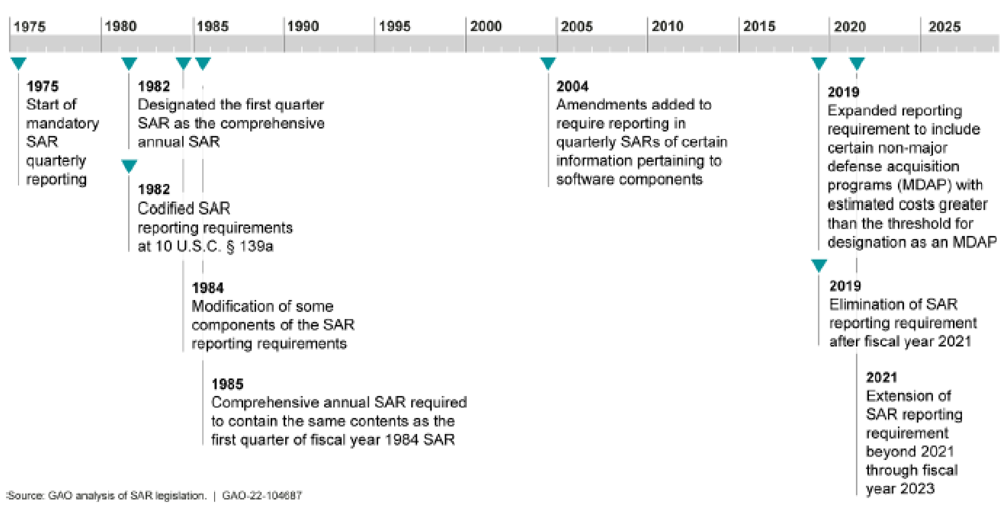


Figure 3. Examples of Changes to Selected Acquisition Report (SAR) Statutory Requirements for the Department of Defense (DOD)

SARs generally include data on total program cost, schedule, and performance, as well as other information such as program unit cost and life-cycle cost analysis of the program and its subprograms that reflect the President's Budget submission. Figure 4 depicts types of information SARs typically include.

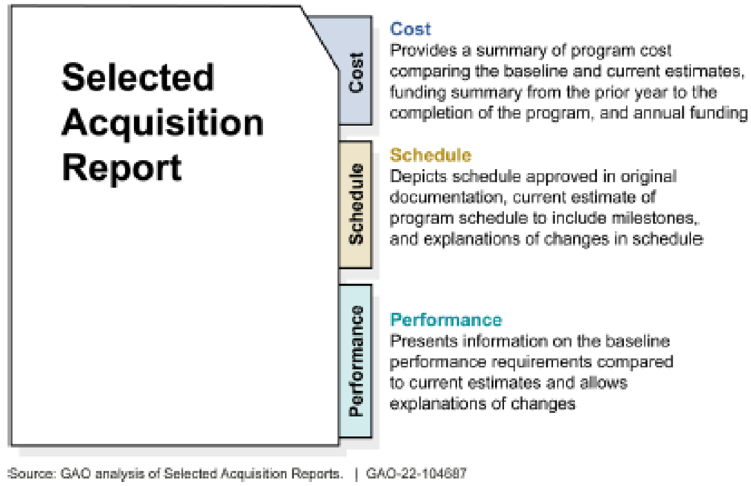


Figure 4. Examples of Data Points Presented in the Selected Acquisition Report

Responsibility for developing and submitting SARs to Congress is shared between the military departments and OUSD(A&S). Military departments are responsible for entering and approving data on their acquisition programs in acquisition data collection systems. After each military department certifies its acquisition data, data are submitted to OUSD(A&S). OUSD(A&S) then verifies the submitted data, compiles them, and transmits them to Congress.

Acquisition Data Collection and Analysis Systems

DOD uses multiple systems at the OSD and military department level to store, analyze, and report acquisition data of the type reported to Congress in SARs.

- In September 2021, DOD began using its Defense Acquisition Visibility Environment (DAVE) system as a collection point for selected acquisition program data. DOD intends for DAVE to eventually serve as a centralized hub that provides convenient access to acquisition data from several disparate data repositories. DAVE is envisioned to be the collection point for core data for all AAF pathways when fully functional. As of November 2021, DOD officials told us that DAVE has limited functionality and that the department's efforts to develop the system's full capability are ongoing.
- Advana (derived from the term Advanced Analytics), the common enterprise data repository for DOD, is a centralized data and analytics platform that provides DOD users with common business data, decision support analytics, and data tools. Advana was developed and is maintained by DOD's Comptroller.
- The Air Force and Army use the Project Resource Management Tool to manage acquisition data, while the Navy uses its Research, Development and Acquisition Information System to maintain, report, and disseminate acquisition data. According to OUSD(A&S) and military department officials, the department plans to determine how each of the individual military department acquisition systems will interface with OSD-level systems, such as DAVE or Advana, in the future.

DOD Proposed a Web-based Reporting Process

DOD's proposed alternative approach to acquisition reporting focused on transitioning to web-based reporting on acquisition programs starting with the fiscal year 2022 reporting cycle, which began in October 2021. As envisioned by DOD, the proposed process would provide Congress and others with access to real-time cost, schedule, and performance data on DOD acquisition programs. The proposal includes the following key elements:

- DOD plans to use Advana to allow Congress to extract cost, schedule, and performance data on all reporting programs, portfolios, and pathways within the AAF. This data extraction is an alternative to producing a separate, stand-alone report for each program, as has been done historically. The proposal notes that the use of Advana for congressional acquisition reporting is part of a long-standing partnership plan between OUSD(A&S) and the DOD Comptroller for data automation and extraction. The department has already used this approach to support financial audits and senior leadership meetings.
- DOD plans for each AAF pathway to have its own data strategy and reporting metrics. The proposal notes that DOD is reviewing the feasibility of including expanded program risk data and that it plans to continue to report unit cost data for MDAPs in the same way that it had previously reported the information in SARs.
- DOD plans to transition from a process that required manual data input by the military departments, to an automated process that extracts data from existing acquisition data collection systems from the military departments and populates the information into either DAVE or Advana.

Table 1 provides additional detail about statutory requirements for DOD's proposal on an alternative reporting approach and DOD's response.

Table 1. Statutory Requirements and DOD's Proposal for an Alternative Acquisition Reporting Approach

Statutory requirements for proposal on alternative acquisition reporting	Summary of DOD's October 2020 proposal
Align acquisition reporting to Congress with recent acquisition policy changes[a]	• The Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S)) developed a plan that will provide overarching guidance on data reporting for all six acquisition pathways identified in the Adaptive Acquisition Framework (AAF). Each pathway will have its own data strategy and reporting metrics. • To improve the transparency of acquisition data, DOD will automate data transfer from existing acquisition data systems to a web-based platform that will allow Congress to extract cost, schedule, and performance data on all reporting programs, portfolios, and pathways.
Address reporting requirements related to Selected Acquisition Reports (SAR)	• OUSD(A&S) and the DOD Comptroller have a long-term plan for data automation and extraction through the Comptroller-managed Advanced Analytics (Advana) system, which DOD uses for data analytics. • OUSD(A&S) generally intends to report information on cost, schedule, and performance through Advana, similar to what was previously reported in SARs. • OUSD(A&S) is studying whether a classified risk assessment reporting portal in Advana would be beneficial to respond to congressional interest in receiving additional information on program risk.
Address reporting requirements related to unit cost[b]	• Unit cost reporting is collected through an existing internal reporting process and, according to the proposal, could easily be automated and reported to Congress through Advana. • DOD recommended no change to the statutory requirements for unit cost reporting.
Address reporting requirements for acquisition programs that use alternative acquisition pathways or tailored acquisition approaches	• DOD plans to provide automated acquisition data through Advana for all AAF pathways beginning with the fiscal year 2022 reporting cycle. • DOD expects Advana, when mature, will provide Congress on-demand, real-time information on thousands of acquisition programs across the AAF pathways. The proposal does not provide a date for when DOD anticipates that Advana will be mature.

Source: GAO analysis of Section 830(b) of the National Defense Authorization Act for Fiscal Year 2020 and Department of Defense (DOD) documentation. | GAO-22-104687

OUSD(A&S) officials cited a number of potential benefits expected to result from their proposed approach.

- Improved data transparency. The proposal states that automated data transfer through Advana is designed to improve data transparency and facilitate DOD-wide analysis and management of business operations. This effort to improve transparency of congressional acquisition reporting aligns with the department's overall priority to improve data transparency throughout the department. DOD expects that this greater data transparency will enable it to assess the progress of its recent acquisition policy changes, promote monitoring of the defense acquisition system, and inform program and portfolio decisions.19
- Delivery of timelier information. The proposal states that an automated data extraction process would provide Congress with more current information and would facilitate DOD's ability to adapt to changing reporting requirements. According to OUSD(A&S) and military department acquisition officials, the process of gathering data and preparing SARs has historically been cumbersome, sometimes taking months to complete. As a result, they stated that the approval process coupled with the manual data entry process resulted in out of date information being presented to Congress.
- Reduced DOD resources required to vet and release information. Once the military departments input their acquisition data, OUSD(A&S) officials manually check the data submitted by the programs to verify accuracy and completeness. According to OUSD(A&S) officials, this process of manual data entry and verification requires resources from an already small group of personnel. When using Advana, OUSD(A&S) officials anticipate less manual data entry and checking of data.

DOD's Preparation to Implement Its Proposal Has Been Limited

Although the proposal states that DOD planned to begin using its proposed approach in the fiscal year 2022 reporting cycle, DOD's preparation to implement the proposed approach has been limited to date. Many open questions remain about how the approach would be implemented, including questions on fundamental issues such as which programs the department will report on and how it will provide Congress access to data. We found that DOD's initial planning for its proposed approach did not fully address the leading practices that our past work has shown support successful agency reforms, including practices associated with implementation planning. The NDAA for Fiscal Year 2022, enacted in December 2021, requires DOD to develop plans and demonstrations related to the reporting system that will replace SAR requirements. As DOD moves forward with addressing these new requirements, fully implementing leading practices would improve the department's preparation to effectively transform congressional acquisition reporting in a timely manner.

DOD Has Yet to Determine Fundamental Aspects of Implementation

DOD has made progress improving its management of the acquisition information that could be reported to Congress, but its preparation to implement its proposed reporting approach has been limited. Although the proposal states that DOD planned to begin implementing its proposed approach for the fiscal year 2022 reporting cycle, which began in October 2021, many questions remain about how and when DOD's proposed web-based reporting process will be implemented. Figure 5 shows key questions and decisions for implementing the proposal that DOD has yet to address.

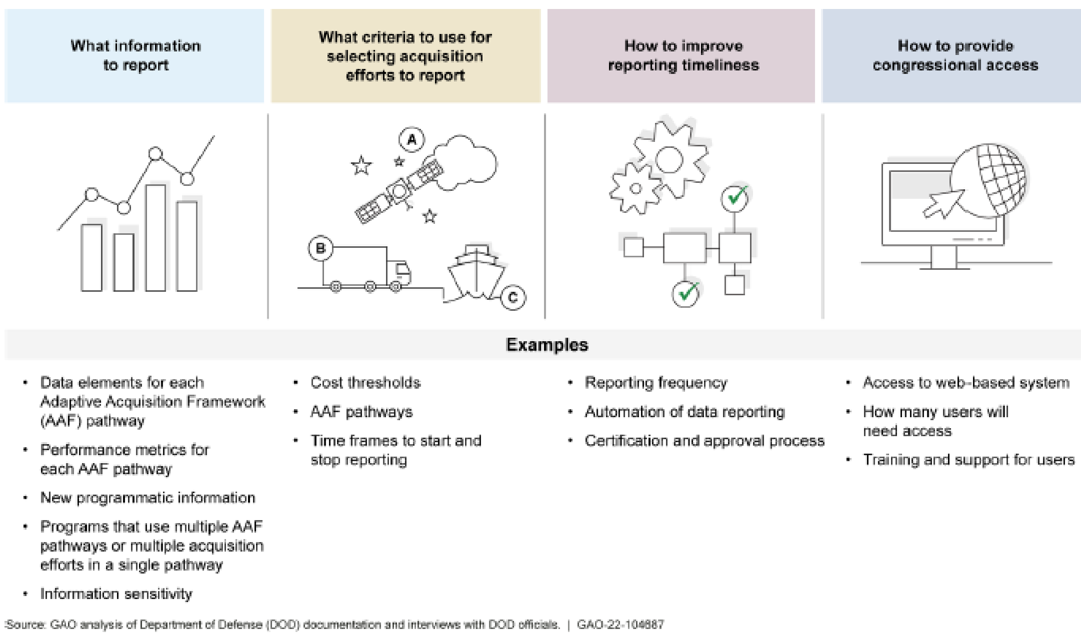


Figure 5. DOD Has Yet to Address Open Questions Related to Its Proposed Reporting Approach

DOD has yet to finalize what information to provide to Congress in future reporting. The introduction of the AAF and its six accompanying pathways introduced new considerations for program oversight, including what data elements DOD should collect for acquisition efforts using each pathway and what performance metrics would allow it to best measure the performance of those efforts. These considerations are particularly significant for acquisition efforts in pathways—such as the MTA or software pathways—for which data elements and performance metrics collected and reported for MDAPs are not necessarily applicable. As part of the department's work to fully implement the AAF, OUSD(A&S) has been engaged in broader ongoing work to implement foundational data governance initiatives, including some ongoing prior to the AAF. DOD intends these data governance initiatives to improve its acquisition data management and to establish internal data needs and performance metrics for AAF pathways.

OUSD(A&S)'s data governance initiatives are directly related to DOD's ability to transform congressional acquisition reporting. OUSD(A&S) officials described these initiatives as a significant, multiyear undertaking (see appendix III for additional details about DOD's initiatives). They stated that they have already spent several years working to move the department forward in this area and years of work remain to fully implement effective data governance for acquisition data. In the meantime, we found that DOD has made progress in identifying data elements collected for the AAF pathways and improvements in the collection process for acquisition data. For example:

- Data standards for AAF pathways. Between October 2020 and August 2021, DOD established data standards for five of the six AAF pathways and is currently in the process of implementing them.20 Data standards are intended to provide common data definitions to align military department and OSD acquisition data systems. OUSD(A&S) officials expect the data standards to enable consistent, department- wide collection and analysis of data. In 2021, for example, at the direction of the Deputy Secretary of Defense, DOD began using its acquisition data to conduct analysis of acquisition portfolios.
- Acquisition Visibility Data Framework. In October 2020, OUSD(A&S) established the Acquisition Visibility Data Framework to be the common data framework for all AAF pathways in the future. The framework categorizes and defines acquisition data elements as well as trusted data sources, among other things. OUSD(A&S) plans for this framework to be the mechanism for documenting and providing department-wide data standards for the AAF pathways as they mature.

Despite this progress, OUSD(A&S) has yet to finalize performance metrics and decide what new information it will report to Congress for all pathways. Officials we spoke with in DOD told us that including certain additional information could improve the utility of reporting. For example, CAPE officials stated it would be useful to add data on sustainment; officials from DOD's Office of the Director, Operational Test and Evaluation stated it would be useful to add additional metrics not traditionally reported on testing and schedule. In August 2021, OUSD(A&S) officials told us that an initiative to identify additional available information to potentially include in acquisition reporting was postponed and would not be completed until after the Senate confirms a new Under Secretary of Defense for Acquisition and Sustainment. Table 2 provides additional detail about open questions related to what information DOD intends to report to Congress.

Figure 2. DOD Has Yet to Decide What Information to Include in Acquisition Reports to Congress

Issue	Explanation and examples
Data elements for each Adaptive Acquisition Framework (AAF) pathway	• The Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S)), in coordination with the military departments, identified data elements to be collected for five of the six AAF pathways and is determining the data elements to be reported to Congress under its new acquisition reporting approach. OUSD(A&S) has yet to finalize data elements that will be collected for the acquisition of services pathway.
Performance metrics for each AAF pathway	• OUSD(A&S) officials stated they expect to report largely the same metrics as they have previously for major defense acquisition programs (MDAP). For example, they would continue to report on programs' progress in meeting specific schedule milestones for MDAPs. However, these performance metrics may not be applicable to all AAF pathways. For example, programs using DOD's software pathway track different metrics than those used for programs using other pathways. • OUSD(A&S) officials stated that DOD needs more time to fully implement the new AAF pathways before they know which performance metrics are most useful both internally for oversight and for reporting to Congress. • In March 2021, a Federally Funded Research and Development Center began a 15-month study to assist OUSD(A&S) with developing performance metrics for each AAF pathway and across pathways.
New programmatic information to report	• OUSD(A&S) officials said they had yet to finalize new information to be included in reporting. The National Defense Authorization Act for Fiscal Year 2022 requires the Director of Cost Assessment and Program Evaluation to include information on software development and cybersecurity risks, among other data elements, in the plan they must submit to Congress. • DOD also acknowledged in its October 2020 proposal for an alternative acquisition reporting methodology that there is a desire for the department to report additional information on risk that was not included in Selected Acquisition Reports (SAR). DOD noted, however, that risk assessments are sometimes classified. SARs are required by statute to be unclassified.[a]
Reporting for programs that use multiple AAF pathways or multiple acquisition efforts in a single pathway	• Under the AAF, capabilities may be developed and fielded using a single pathway or multiple pathways. In addition to using multiple pathways, a program manager can also undertake multiple distinct efforts using the same pathway—such as two or more software efforts using the software acquisition pathway. • OUSD(A&S) officials stated that they have yet to determine how information will be combined across pathways or for multiple acquisition efforts within the same pathway to provide insight into the overall cost and schedule for achieving a capability. • In June 2021, we recommended that DOD address this issue. DOD concurred with our recommendation but has yet to determine how to address it.[b]
Information sensitivity	• OUSD(A&S) and military department officials stated that reporting to Congress in the proposed web-based format raises concerns about the sensitivity of acquisition program data that have yet to be resolved. • For example, the officials stated that they have yet to determine the extent to which sharing data through Advana—potentially allowing users to aggregate performance data on multiple programs—creates information sensitivity concerns beyond those that would exist in creating a separate report for each program.

Source: GAO analysis of Department of Defense (DOD) documentation, the National Defense Authorization Act for Fiscal Year 2022, and interviews with DOD officials. | GAO-22-104687

Determining What Criteria to Use for Selecting Acquisition Efforts to Report

DOD has yet to determine which acquisition efforts it will include in congressional acquisition reporting. The proposal states that DOD plans to provide data to Congress through Advana for all pathways beginning in the fiscal year 2022 reporting cycle and that, when mature, Advana would provide information on thousands of programs. However, OUSD(A&S) and military department officials subsequently told us that they were not certain which AAF pathways or acquisition efforts would be included in reporting. The proposal does not address specific criteria that would define which acquisition efforts should be included in congressional acquisition reporting.

In the short term, OUSD(A&S) officials said they expect to continue to use the same criteria they previously used for SARs—which requires DOD to report on MDAPs and other acquisition programs over the MDAP cost thresholds—to identify acquisitions to include in reporting.21 These criteria also specify when during the acquisition process an MDAP is required to be included in congressional acquisition reporting.22 However, the same criteria may not be applicable for acquisition efforts using pathways other than the major capability acquisition pathway or for those acquisitions using a combination of AAF pathways. For example, for programs using the software pathway, cost estimating methodology and criteria related to acquisition phases are not the same as they are for MDAPs. Table 3 provides additional detail on open questions related to which acquisition efforts to include in reporting.

Table 3. DOD Has Yet to Determine What Criteria to Use for Selecting Acquisition Efforts to Report

Issue	Explanation and examples
Cost thresholds	• DOD's October 2020 proposal to Congress for an alternative acquisition reporting methodology did not specify a cost threshold for reporting. • Not all Adaptive Acquisition Framework (AAF) pathways use the same approach to cost estimating, so it may be challenging to apply the same cost threshold across each pathway. For example, the statutory reporting threshold for Selected Acquisition Reports (SAR) is based on eventual total expenditure. However, in most cases middle tier of acquisition (MTA) prototype estimates do not reflect any future investment that DOD will need, if it decides to further develop and field the capabilities being prototyped.
AAF pathways	• DOD has previously only provided SARs or similar reporting to Congress on major defense acquisition programs (MDAP) and programs using the MTA pathway. • Office of the Under Secretary of Defense for Acquisition and Sustainment officials told us they are primarily focused on reporting on these two pathways at this point and are not certain which, if any, additional pathways they will report on in the future.
Time frames to start and stop reporting	• SAR requirements for MDAPs generally apply from the time funds are appropriated for the program and the Secretary of Defense decides to proceed to system development and program demonstration, until a program delivers 90 percent of its items or made 90 percent of planned expenditures.[a] • However, because each pathway in the AAF has different acquisition phases, it is unlikely that a single set of criteria for determining when programs should report would work. For example, our past work has shown that key schedule events for programs using the MTA pathway can vary widely from program to program.

Source: GAO analysis of Department of Defense (DOD) documentation, 10 U.S.C. § 4351, GAO-20-439, and interviews with DOD officials. | GAO-22-104687

Determining How to Improve Reporting Timeliness

While one of the intended benefits of DOD's proposed approach is the ability to provide more timely information, the department has yet to determine the specific process improvements needed to achieve this benefit. DOD officials expressed dissatisfaction with the timeliness of SAR reporting, which is affected by several factors including the (1) frequency of reporting, (2) automation of data collection, and (3) approval process. For example, OUSD(A&S) officials told us that the certification of SAR data by the military departments, a part of the approval process, tended to cause the longest delays in reporting. For the fiscal year 2020 reporting period—the last time that annual SARs were submitted to Congress—program offices were required to submit data by February 2020. The SARs were scheduled to be provided to Congress in March 2020, but they were not released until May 26, 2020. However, OUSD(A&S) officials stated that they anticipate that the certification process would remain the same and that it would only change if associated statutory requirements also changed.23 Table 4 includes additional information on open questions related to the timeliness of congressional acquisition reporting.

Table 4: DOD Has Yet to Determine How to Improve Reporting Timeliness

Issue	Explanation and examples
Reporting frequency	• Although DOD's October 2020 proposal for an alternative acquisition reporting methodology states that data eventually would be provided in real time, officials from the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S)) told us that information will not be updated in Advanced Analytics (Advana) continuously. Rather, they expect to provide Congress the latest official information available, which differs by metric. • OUSD(A&S) officials told us that information on funding, for example, will be tied to the President's Budget, which is updated annually.
Automation of data reporting	• DOD plans for Advana to be used for automated reporting and analysis of acquisition data. The proposal states that automation would provide Congress with more current information. The source data in Advana is planned to come from the Defense Acquisition Visibility Environment (DAVE), military department-specific acquisition data systems, and other legacy systems. While OUSD(A&S) intends for DAVE to be a central source of acquisition data, officials stated that they are in the early stages of aligning several disparate data systems. • DOD officials stated that much work remains to implement data automation improvements. For example, programs using the software pathway manually submit data to OUSD(A&S) because DAVE does not yet capture the pathway's required data elements.
Certification and approval process	• The approval process for Selected Acquisition Reports includes certification by senior military department officials as well as reviews at lower levels in each military department. • While OUSD(A&S) officials stated that the certification process was one of the most time-consuming elements of the reporting process, they were not able to describe any planned changes that would result in providing Congress timelier information.

Source: GAO analysis of Department of Defense (DOD) documentation and interviews with DOD officials. | GAO-22-104687

Determining How to Provide Congressional Access

DOD has yet to determine how to provide Congress access to acquisition data in Advana. To implement its proposed approach, DOD would need to provide access to acquisition data in Advana for users outside of DOD, including congressional staff. However, OUSD(A&S) and DOD Comptroller officials told us in November 2021 they have yet to put in place a plan to grant access to Advana to users outside of DOD. Officials said there are cost implications regarding the number of users since they must be provided an approved computer and access to the DOD network. Table 5 provides additional information on open questions related to access.

Table 5: DOD Has Yet to Determine How to Provide Congressional Access

Issue	Explanation and examples
Access to web-based system	• DOD cannot currently provide access to Advanced Analytics (Advana) for individuals outside of the DOD network due to information security concerns. • The Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S)) and DOD Comptroller officials stated that they discussed different options for providing access. They are considering providing DOD-furnished computers and credentials to those who need access to the system to allow them to get on the department's network. However, as of November 2021, a solution to provide access has yet to be determined.
How many users will need access	• OUSD(A&S) and DOD Comptroller officials said that they did not know how many users outside DOD would require access to Advana, which may affect their proposed solution for providing access.
Training and support for users	• OUSD(A&S) and DOD Comptroller officials stated they have technical support and office hours in place for Advana to help answer questions from the DOD user community, which could also support congressional users. However, they added that, at this point, they do not know the level of expertise of potential users or how much support they would require.

Source: GAO analysis of Department of Defense (DOD) documentation and interviews with DOD officials. | GAO-22-104687

DOD Has Not Fully Implemented Leading Agency Reform Practices in Preparing for Reporting Transformation

DOD's planning to date has been limited in part because it has yet to fully implement two leading practices associated with successful reforms. Specifically, our prior work has shown that following leading reform practices such as those related to

(1) leadership focus and attention and (2)managing and monitoring the implementation of reforms, improves the likelihood of successful reforms.24 In planning for the implementation of its proposed approach, DOD addressed some but not all elements of these practices.

Leadership focus and attention. DOD is following some aspects of this practice, but has yet to follow other aspects that could help address related challenges OUSD(A&S) officials identified. DOD's planning documentation broadly establishes ongoing leadership for the new reporting approach by OUSD(A&S) in partnership with the DOD Comptroller. Senior DOD leadership also defined and articulated a compelling reason for DOD's reform of how it collects and uses all data, including for acquisitions, in the department. However, DOD has yet to take other actions that would facilitate addressing certain aspects of this practice.

- Although leadership is broadly assigned, DOD's planning documentation does not address the specific responsibilities of offices with leadership roles, or of the military departments or other organizations that will need to provide the information necessary to enable effective congressional acquisition reporting. OUSD(A&S) officials told us that significant coordination is needed between their office, other OSD organizations, and the military departments to support efficient implementation of the proposal. For example, OUSD(A&S) officials stated that the DOD Comptroller—not OUSD(A&S)—determines the order of development priorities for Advana. Officials noted that the DOD Comptroller is currently focused on developing non-acquisition related capabilities in Advana to support departmental decision-making and leadership. Further, the military departments are responsible for providing data for congressional acquisition reporting, and their willingness to transparently share data about their acquisition programs is critical to DOD's proposed approach. We previously reported that they and OSD have had disagreements about the level of data that the military departments should be required to provide on some acquisitions, which, if not resolved, could hinder DOD's ability to implement the proposal.
- DOD officials told us they have yet to determine the resources necessary to implement the proposal, such as the funding that will be required or the number of government and contractor staff needed to help execute the approach. Our previous work has emphasized the importance of establishing a dedicated implementation team that has the capacity—including staffing and resources—to manage the reform process. Without determining needed resources, DOD is not well positioned to form an effective implementation team to ensure progress. OUSD(A&S) officials stated they have no dedicated funding for acquisition reporting initiatives, and that the OSD-level offices working on this effort are short-staffed and relied upon contractor support to make initial changes to Advana to support acquisition reporting. An OUSD(A&S) official noted that his office had a directed cut to staffing levels, so finding resources to get work done on Advana was a challenge. Military department officials also expressed concerns about resources. For example, Army acquisition officials said the Army may not have the resources to report on more programs than it currently does, as smaller programs are not typically staffed to support congressional acquisition reporting. Further, they said that staff would need training on a new methodology for congressional acquisition reporting,

which could be significant if reporting requirements were extended to additional programs.

Managing and monitoring implementation. DOD has focused on continued delivery of services during reform implementation, but has yet to address other aspects of planning related to managing and monitoring implementation. Specifically, DOD officials indicated the department has an interim approach to ensure the continued delivery of SAR information while it is trying to implement a new form of acquisition reporting. OUSD(A&S) officials said they are preparing to use Advana to produce SARs for MDAPs. They noted that the acquisition reports produced with Advana will only include information currently required by statute and that some data previously included in SARs, but not statutorily required, will be removed. As of November 2021, officials said the department was on track to be ready to provide portable document format (PDF) reports for upcoming SAR submissions reflecting fiscal year 2021 as required.26 OUSD(A&S) officials also told us they plan to continue to provide Congress with reports for programs using the MTA pathway that are similar to what they submitted to Congress for these programs in 2020. However, DOD officials have yet to develop an implementation plan with key milestones and deliverables to track implementation progress for the proposal. During our review, they told us that they had a notional, high- level schedule and did not see the value in developing additional detailed planning. DOD officials also have yet to develop a plan to measure congressional satisfaction with changes resulting from implementing the proposed plan.

OUSD(A&S) officials also described a number of other factors that limited implementation planning to date. For example, they explained that developing the capabilities needed to implement the proposal is only one of a large number of priorities awaiting decisions once senior OUSD(A&S) leadership is in place following the 2021 change in presidential administration.27 They stated that, as a result, they were not able to provide a more definitive time frame to complete the work. An OUSD(A&S) official also noted that given the substantial changes to the acquisition process related to the AAF, the office needs more time to determine how it would fully implement the proposal. Further, OUSD(A&S) officials added that for some of the implementation details, they were not certain how congressional staff and other stakeholders would prefer for them to be addressed and were waiting for further legislative direction.

Congress recently provided DOD with additional direction on acquisition reporting. The NDAA for Fiscal Year 2022, enacted in December 2021, requires DOD to develop plans and demonstrations concerning certain aspects of the reporting system that will replace the SAR requirements. Specifically, it requires:

- DOD to provide to the congressional defense committees a demonstration of the capability improvements needed to achieve full operational capability for its proposed reporting system on a recurring basis starting not later than March 1, 2022.
- The Director of CAPE to prepare a plan for identifying and gathering the data required for effective decision-making not later than March 1, 2022; and
- The Under Secretary of Defense for Acquisition and Sustainment to submit to the congressional defense committees, not later than July 1, 2022, a plan for the new reporting system that includes information related to some of

the practices our past work has found can help government agencies improve the likelihood of effective reforms, such as the implementation schedule and milestones for DOD's proposed reporting system, among other things.

Following leading practices associated with effective reforms while addressing these new requirements will help DOD lay out steps, such as how it will answer outstanding questions, to make the transition to its proposed congressional acquisition reporting approach more achievable.

Conclusion

DOD outlined an ambitious yet high-level approach to modernize its congressional acquisition reporting to align with significant reforms in recent years, including the introduction of the AAF. The proposal will likely require sustained leadership commitment and take DOD many years and potentially significant resources to implement. Yet, DOD's planning to date leaves fundamental questions unanswered about how the proposed approach will work in practice, in part, because DOD has not fully followed leading reform practices in the areas of leadership focus and attention and managing and monitoring reforms.

Given that execution is well underway for programs using the AAF, aligning acquisition reporting with this new framework in a timely manner is essential to ensure that Congress has relevant information to assess whether DOD's acquisition programs meet warfighter needs and invest taxpayer dollars wisely. The new requirement in the NDAA for Fiscal Year 2022 that DOD take certain steps towards developing a reporting system that will replace SAR requirements underscores the importance of DOD conducting effective planning for this effort. By taking actions associated with leading reform practices—such as ensuring that the agency has the staffing and resources it needs for implementation and developing an implementation plan with key milestones and deliverables—DOD can help ensure that Congress and other key stakeholders have a better understanding of how the open questions that remain will be addressed and assurance that this critical effort will be executed successfully in a timely fashion.

Recommendations for Executive Action

We are making the following two recommendations to the Department of Defense:

- The Secretary of Defense should ensure the Under Secretary of Defense for Acquisition and Sustainment fully implements leading reform practices in the area of leadership focus and attention while developing the reporting system that will replace the Selected Acquisition Report requirements, such as by creating a dedicated implementation team that has the capacity, including staffing and resources, to manage the reform process. (Recommendation 1)
- The Secretary of Defense should ensure the Under Secretary of Defense for Acquisition and Sustainment fully implements leading reform practices in the area of managing and monitoring reforms while developing the reporting system that will replace the Selected Acquisition Report requirements, such as by developing an implementation plan with key milestones and deliverables. (Recommendation 2)

PANEL 13. CAN SPACE ACQUISITION CHART NEW, AGILE PROCESSES?

Wednesday, May 11, 2022	
1:55 p.m. – 3:10 p.m.	**Chair: James H. Newman,** Chair, Space Systems Academic Group, Naval Postgraduate School ***Developing United States Space Force Acquisition Occupational Competencies*** Chad Millette, USSF Space Systems Command ***Introducing Agile/DevSecOps into the Space Acquisition Environment*** Michael Orosz, University of Southern California Brian Duffy, University of Southern California Craig Charlton, University of Southern California Lieutenant Colonel Spear, U.S. Air Force ***Can the Next Generation Overhead Persistent Infrared Program Overcome an Aggressive Schedule Using the Middle Tier of Acquisition?*** Claire Buck, US Government Accountability Office ***How is the DoD Addressing Challenges with Its Mobile User Objective System Program?*** Erin Cohen, US Government Accountability Office

James H. Newman—Chair of the Naval Postgraduate School Space Systems Academic Group, Dr. James H. Newman is a veteran of four space shuttle missions, including a critical mission to repair the Hubble Space Telescope.

Newman graduated from La Jolla High School, San Diego, California, in 1974; he received a Bachelor of Arts degree, cum laude, in Physics from Dartmouth College in 1978, a Master of Arts degree and a Doctorate in Physics from Rice University in 1982 and 1984, respectively.

In March 2006, Newman was detailed to the Naval Postgraduate School in Monterey, California, as a NASA Visiting Professor in the NPS Space Systems Academic Group. Newman left NASA in July 2008 to accept a position as Professor, Space Systems at NPS to continue his involvement in teaching and research, with an emphasis on using very small satellites in hands-on education and for focused research projects of national interest.

Developing United States Space Force Acquisition Occupational Competencies

Chad Millette—is the Space Systems Command (SSC) Chief Learning Officer. His responsibilities include implementing an acquisition-related learning and development program. Millette is a retired USAF Lieutenant Colonel. His acquisition career culminated with an assignment as a Materiel Leader overseeing the ISR Sensors and FMS Division. Millette's last military assignment was as the Acting Associate Dean of the AFIT School of Systems and Logistics (AFIT/LS). He returned to AFIT/LS as a civilian Course Director. Millette has a master's degree in systems management from AFIT and software engineering administration from Central Michigan University. [chad.millette.1@spaceforce.mil]

Abstract

As part of its competency-based talent management strategy, which is outlined in *The Guardian Ideal* (U.S. Space Force [USSF], 2021), the U.S. Space Force (USSF) is identifying foundational and occupational competencies. Foundational competencies are those with which all Guardians will demonstrate some level of proficiency. Occupational competencies (one set for each of the four Space Force occupations—intelligence, operations, cyber, and acquisitions) will be used to code each position within the USSF and to guide Guardian professional development. This paper outlines the challenges associated with identifying a set of acquisition occupational competencies for the USSF by documenting the planning, execution, and results of the Acquisition Occupational Competency Study held in January 2022. It is hoped that by capturing the USSF experience, other acquisition competency-related efforts can be informed.

The U.S. Space Force (USSF) was established in late 2019 dedicated to the defense of space because space capabilities are essential to the security and prosperity of the United States (U.S. Space Force [USSF], n.d.). One of the reasons the USSF was established as a separate service was to improve space systems and services acquisition. The establishment of a new uniformed military service—the first since the Air Force became a service in 1947—provides opportunities to establish new practices for the management of its people. A key personnel initiative of the new USSF is competency-based talent management. In order to perform this type of talent management, the USSF is identifying foundational and occupational competencies. During the winter of 2021–2022, the USSF began the process of documenting USSF acquisition occupational competencies. Analysis of the process and results of this effort should inform further efforts across all services to codify and implement acquisition competencies.

The initial Space Capstone Publication, *Spacepower Doctrine for Space Services*, identifies engineering/acquisitions as one of seven Spacepower Disciplines. Guardians who specialize in this discipline do so as part of the acquisitions career field. The acquisitions career field is one of four active duty Guardian officer career fields (the others are space operations, cyber operations, and intelligence). In the USSF, the acquisition career field consists of acquisition program managers (formerly Air Force Specialty Code, AFSC, 63) and developmental engineers (formerly the 62 AFSC).

The USSF is embarking on a radically different military talent management methodology. Taking the best practices from other services' recruiting, development, retaining, and development processes as well as having a unique opportunity to incorporate innovative practices from industry and academia, the USSF published *The Guardian Ideal* in 2021. One of the key tenets of this innovative strategy is the concept of performing competency-based talent management. *The Guardian Ideal* describes this concept further:

> Guardians will have more choices about their future as we migrate from highly structured career paths to a regulated market approach and talent

> management based on a competency framework. In the near future, Guardians will be able to see the competencies needed for every position in the Space Force and their current competency levels to inform decisions about development and next steps. (USSF, 2021)

In order to effect a competency-based talent management approach, the USSF must have a set of well-defined competencies. “Some competencies are foundational to all Guardians, while others are specific to mission sets, occupations, or positions” (USSF, 2021). As such, the USSF first moved out on the identification and codification of a set of foundational competencies. This effort was spearheaded by the USSF Chief Human Capital Office (USSF/S1), working with the Air Force Air Education and Training Command (AETC). They formed a diverse team of high-performing airmen and Guardians to participate in studies and focus groups. In order to identify those competencies that are foundational to all Guardians, the focus group addressed questions such as: “What makes a Guardian likely to be successful across a USSF career?” and, “As the USSF changes, what competencies will prepare Guardians to be most successful in the future?” (Barron, 2021). This effort resulted in a draft set of Guardian foundational competencies that are being coordinated by USSF senior leadership.

With the foundational competencies identified and submitted for coordination, attention turned to the definition of the occupational competencies. These were to be identified by career field, resulting in space operations, cyber operations, intelligence, and acquisition occupational competencies. *The Guardian Ideal* (USSF, 2021) calls for the Space Force occupational competencies to be complete by June 2022. With the competencies baselined, each position within the USSF would then be coded with the requisite proficiency level thresholds (this is scheduled to be complete by September 2022). In September 2021, USSF/S1 partnered with the AETC to begin the effort of identifying the USSF acquisition occupational competencies. The first order of business was to identify the team of subject matter experts (SMEs) that would be involved in the study that would result in a draft set of acquisition occupational competencies.

Study Planning

The Acquisition Occupational Competency Study was scheduled for early January 2022. The study was facilitated by the AETC Occupational Competency Branch Chief. Additional AETC competency staff also participates as needed. The team was composed of USSF acquisition SMEs. These SMEs were pulled from organizations across the Department of the Air Force (DAF). USSF acquisition career management is the purview of the office of the assistant secretary of the Air Force for Acquisition, Technology, and Logistics (SAF/AQ). The military deputy in that office and the Space Acquisition Workforce Integrator were key initial team members. A preponderance of the USSF acquisition workforce is assigned to the Space Systems Command (SSC); as that is the field command responsible for developing, delivering and sustaining innovative capabilities to protect our interests in space (insideSSC Hub, n.d.). The SSC Chief Learning Officer and members of the SSC Talent Management organization—particularly from the SSC Career Field Teams—were also identified as team members. Finally, as these identified team members were primarily senior in grade and experience, study participants identified a need for including junior USSF acquisition personnel in order to get a fresh perspective on the career field. Alumni from the SSC Galaxy development program (a competitively-selected SSC junior force 6-month rapid professional development program) were identified to participate in the study as well. These junior officers provided a necessary diversity of thought to the team.

The study effort needed to be scoped to the appropriate competencies to be identified. The DoD acquisitions workforce consists of six functional areas: Program Management (PM), Engineering and Technical Management (ETM), Contracting (PK), Logistics (LG), Business (both Financial Management [FM] and Cost Estimating [CE]), and Test and Evaluation (T&E). Would the study be identifying competencies for all six functional areas, as an "Acquisition Occupational Competency Study" might imply? The answer was no—the study would identify the 63 PM and 62 ETM occupational competencies only. This is because the first iterations of USSF occupational competency identification were to focus on active duty Guardian competencies. When the USSF was stood up, only the PM and ETM career fields were established within the force as career fields. Remaining acquisition functional support would be provided by airmen and DAF civilians (there are no USSF civilians; all civilians supporting the USSF are DAF civilians).

This limiting of the scope of the study caused some consternation, particularly within the SSC. In an effort to be inclusive of the totality of the workforce, when many in SSC leadership use the term "Guardian" they are referring to not only the 62 and 63 active duty officers, but also the DAF civilians and airmen assigned to and supporting SSC program offices. As the activities and responsibilities of active duty and civilian PMs and ETM personnel overlap significantly, the study was deemed to be identifying the occupational competencies for all USSF PM and ETM personnel, military or civilian. However, a review of the civilian positions within the SSC indicated that this would still not include 51% of the SSC workforce. When pressed on this, study leadership decided to progress with the limited scope as a first iteration of identifying acquisition occupational competencies with a plan to evaluate the necessity and process for capturing occupational competencies associated with other USSF acquisition functional areas.

With the scope of the study established, efforts turned to preparation for the study itself. The study was schedule for January 10–13, 2022 in the SSC Innovation Lab at Los Angeles Air Force Base. Read-ahead materials were distributed to team members. These included documents capturing existing acquisition-related competency models and a briefing highlighting the process and methodology for the study. The methodology involved a Future Scanning discussion, activities to identify a draft set of competencies, identifying the behaviors for each level of proficiency within each competency, and finally a mapping of the "soft skills" to each competency.

Study Execution

An initial challenge with the study itself was the lack of availability of key team members. As the study kicked off, the SSC Program Manager Career Field Team Lead was on paternity leave and the Engineering Career Field Team Lead was in transition to a new position within a program office and neither were able to participate in the study. No suitable substitutes were available, either. On the positive side, the team was augmented with an acquisition officer from the USSF Space Operations Command (SpOC). The Lieutenant Colonel brought a perspective of an acquisition professional not assigned to a program office. In addition, an SME who had participated as an acquisition representative on the foundational competency development effort also participated—even though he was stationed in Germany and had a significant time difference to deal with. Finally, a mid-level Guardian program manager who had previously taken it upon himself to dive into the service's PM development processes was also invited to participate, as he brought both a mid-level professional's perspective and a passion for the topic. The AETC facilitator and team decided the team was suitable enough to develop a draft set of competencies and continued with the study effort.

The study itself began with a baselining of terminology. Some of this material had been sent out as "think-aheads" to the study participants, but the AETC Occupational Competency Branch Chief presented them for discussion to ensure that the study team was on the same page with regards to the fundamental terms that would be used throughout the week. Specifically, the team used the definition of the term "competency" from *The Guardian Ideal*: "A competency is the combination of knowledge, skills, abilities, experiences, and characteristics that manifest in the behaviors needed in designated roles" (USSF, 2021). The team was also presented with definitions and examples of knowledge, skills, abilities, experiences, and characteristics, as they would all be wrapped up in the identification of the acquisition occupational competencies.

A key definition was for "behaviors," as it is distinct from the competency that results in the behavior as well as the tasks that are associated with the behaviors. Further, the team would be identifying behaviors later in the study as they are associated with each level of proficiency within a competency. For purposes of the study, a behavior is "an activity performed to achieve objectives of the job. Involves observable (physical) components and unobservable (mental) components. Behaviors consist of the performance of one or more tasks. Knowledge, skills, and abilities are not behaviors, although they may be applied to work behaviors" (Villanueava, 2022). To further the team's understanding of the concepts, an excellent graphic was shown of an iceberg. The word "Behaviors" was on the iceberg and the words "Experiences," "Knowledge, "Skills," and "Abilities" were depicted on the portion of the iceberg below the water line (Villanueava, 2022).

With a common understanding of the terminology, the team began the work of identifying the competencies themselves. Led by the facilitator, the team performed a Future Scan discussion where we discussed the challenges our acquisition workforce is likely to encounter in the future and the desired characteristics of that future workforce. This led to the team's day 1 homework: from a list of identified competencies, identify the top 20 for consideration for USSF acquisition occupational competencies. A discussion item for clarification came up regarding whether the output of the study would be a single set of acquisition occupational competencies that could include PM and ETM subsets or distinct sets of PM (63) occupational competencies and ETM (62) occupational competencies. The team landed on the study's task being to identify 63 acquisition occupational competencies and 62 acquisition occupational competencies.

As the homework was assigned, and along with the clarification that two sets of competencies were to be created, another team composition-related shortfall was identified. Specifically, the team was short on 62 ETM experience. Recall the SSC ETM Career Field Team Lead was unable to participate. That left a small team of 62s to perform the homework and subsequent ETM occupational competency work. To compensate, the team decided that the SAF/AQ career field manager (an experienced colonel) and the SSC chief learning officer (retired lieutenant colonel and senior civilian) would rely on their experience, not as actual 62 officers but in working with them and having them assigned to work for them, to also identify their top 20 62 competencies.

The team sought clarification with regards from where to pull the top 20 candidate competencies. Specifically, could the team start with a blank sheet of paper or was there a master list of competencies from which to select? The AETC facilitator suggested and the group agreed to start with the competencies that were sent to the group as read-aheads. These included a generic competency set, the Office of Personnel Management's 2013 Multipurpose Occupational Systems Analysis Inventory—Close-Ended (MOSAIC) list. With regards to the 63 PM competencies, the master set included the 2021 Office of Secretary Defense (OSD) PM competency list, a comparison of those to the Project Management Institute's Knowledge Areas, and a 2002 Federal Acquisition Institute Technical Competency Validation Report. For the 62 ETM competencies, the master set included the OSD Engineering Career Field Competency Model, Version 2.0 and a 2014 Naval Postgraduate School paper, *Development of a Systems Engineering Competency Career Development Model: An Analytical Approach Using Bloom's Taxonomy*.

The participants submitted their top 20 competencies to the AETC facilitator such that he could consolidate the input into a product the entire team could review the morning of day 2. The facilitator was able to highlight the competencies that were identified by the most study team members. This allowed the team to group like competencies, e.g., individual competencies like “acquisition strategic planning” and “technical planning” were wrapped up in the broader draft competency of “program planning.” This exercise resulted in a draft set of 63 PM competencies. The exercise was then performed for the 62 ETM competencies. In both cases, these draft lists set up the remainder of the study effort.

It was becoming increasingly clear to the team that the intent to develop a full competency list for both 63 PM and 62 ETM Guardians within the four days allotted for the study was perhaps aggressive. In fact, the AETC facilitator had suggested as much at the outset, i.e., he hadn’t tried to do two AFSC competency definition efforts in the same week before. The next step in the process started to bear this out. The team was broken into two teams; one for 63 PM competencies and the other for 62 ETM competencies. The teams were charged with defining each competency and identifying a proficiency delineation framework and representative behaviors associated with each level of proficiency. The proficiency levels in this model are basic, intermediate, advanced, and expert. The proficiency framework provided a scaffolding to assist in identifying the behaviors at each level. For example, a proficiency framework might be that people are only able to demonstrate certain behaviors based on their position within the organization. Completing this activity for the 63 PMs closed out the study.

Study Results

Given the aggressive agenda—two career field competency lists in a one-week study—the results of the study are not surprising. The team was not able to create the intended results of the study, i.e., complete draft lists of 63 PM and 62 ETM competency lists with proficiency level behaviors drafted and soft skills competencies mapped. At the completion of the study, the team had a draft list of 63 PM competencies with representative behaviors for each proficiency level. As for the 62 ETM competencies, at the end of the study, the team had a draft list of competencies. [NOTE: As of this paper’s writing, the draft competency lists have not been fully coordinated with senior leadership and therefore are not releasable.] The team was not able to complete and review as a group the representative behaviors associated with each proficiency level. As such, the teams left with an expectation of follow-on work to complete the lists.

The study team met the expectations of the original study plan by completing the deferred work after the study itself. The 63 PM team performed the soft skills mapping exercise to select the top 3 soft skills (derived from the draft USSF Foundational Competency List) that most applied to each of the 63 PM competencies. The 62 ETM team—this time augmented by additional experienced and available engineering career field SMEs—finished their competency work remotely. In a virtual follow-on session, they finished defining the competencies, identifying representative behaviors for each proficiency level, and mapping the soft skills that most fit each competency.

The next step in the formal baselining of the competency lists is for them to be validated. A survey was created to validate the occupational competency model the study team came up with. There are two surveys: a senior leader survey for lieutenant colonels and colonels and a general survey for the rest of the rest of the workforce within each career field (i.e., separate surveys for 63 PM Lt Cols and Cols, other 63 PMs, 62 ETM Lt Cols and Cols, and other 62 ETM personnel). As this paper is being written, survey participation has not been high enough to allow for validation of the competency lists and the AETC staff is working to improve the response rate.

Analysis

Although likely not by the date called for in *The Guardian Ideal* (USSF, 2021), the USSF will soon baseline a set of acquisition (both 63 PM and 62 ETM) occupational competencies and begin to use them as part of an innovative competency-based talent management methodology. It was a benefit that AETC had an existing process and methodology for identifying occupational competencies. However, instead of providing broad guardrails for the study team to operate within, the process was highly prescriptive. This resulted in some question as to whether appropriate consideration was given to existing competency models in these career fields. Further, the direction within the study itself to identify the candidate competencies from existing (predominantly OSD) competency lists had the inevitable consequence that the resulting USSF Acquisition Occupational Competency lists were a subset of previously identified OSD competencies. A question remains … is that appropriate for the USSF? Finally, given the initial issues with the number and experience levels of SME participation in the study, the validation by the workforce becomes all the more important. However, as of this paper's writing, this validation process is not progressing as survey participation is low. This could also contribute to challenges with broader workforce acceptance of the competency models.

How could the task of identifying acquisition occupational competencies have gone differently to address the challenges previously identified in study planning, execution, and results? These challenges largely regarded identifying the scope of the study. Specifically, for whom was the team developing competencies; just military Guardians? Which acquisition career fields would be covered with the resulting competencies? Within the study itself, what would be the approach for identifying candidate competencies: start with a blank sheet of paper or with an existing framework? Although the study team reached consensus on the resulting competency lists, i.e., they could support the list to external stakeholders and would not undermine the validation of the results, what follows are alternative methods for deriving Guardian acquisition occupational competencies.

Going into the study planning activities, there was a question whether the task was to identify "acquisition" occupational competencies for the USSF or 63 PM and 62 ETM competencies. This question involves two concerns: are the competencies to be developed military-only or for both military and civilian personnel, and what about competencies associated with the other acquisition functional areas (FM, PK, LG, T&E)? The study team was directed to focus on the military AFSCs with the belief that the competencies created would also apply to the corresponding civilians supporting the USSF in the PM and ETM functional areas. Implementation of the fully competency-based talent management framework for DAF civilians comes with many challenges as, whereas the USSF completely owns the military recruiting, evaluation, promotion, and development processes, DAF civilians fall under OSD civilian manpower policies and procedures. However, to the extent possible, it makes sense to have the same competencies for all acquisition PMs and engineers, regardless of whether they are military or civilian.

With regard to the question of which acquisition functional areas should be covered by the resulting competency list, more discussion before or during the study might have resulted in a different construct for the draft competency lists. A proposal was floated before and briefly during the study to identify a broad set of USSF acquisition occupational competencies; that is, not a list for each acquisition functional area. The idea would be for there to be a handful of competencies that applied to all acquisition Guardians with the option/provision that functional area-specific sub-competencies could also be developed. The present study would have sought to identify the 63 PM and 62 ETM sub-competencies. As the 63 PM and 62 ETM competency lists the study team came up with have several overlapping competencies, this seems to support the idea that there are competencies that apply across the board within USSF acquisitions. Further, this methodology would have had the effect of allowing for identifying BUS-FM, BUS-CE, PK, LG, and T&E sub-competencies to cover the remainder of the Guardian and DAF civilians supporting USSF acquisitions in subsequent iterations.

Finally, there is the question of starting with a “clean sheet of paper” versus an existing framework. With the establishment of a new military service comes the opportunity to be truly innovative in all business practices. USSF leadership has encouraged this type of behavior so that USSF policies and procedures are not shackled or beholden to Air Force or even OSD practices, if there’s a better way to do things. During the study, both the 63 PM and 62 ETM teams selected their candidate competencies from OSD competencies. As mentioned previously, this has the effect of essentially directing that the resulting competency lists are subsets of existing competency lists. What if the study participants had been instructed through a facilitated process to draft from scratch the most important competencies within their functional areas? The team could reference existing competency frameworks—and not just the OSD ones—but would be encouraged to tailor those to fit those collections of knowledge, skills, abilities, experiences, and characteristics that they felt would lead to desired USSF acquisition behaviors.

There is no guarantee that the competency lists resulting from the modified processes described here would be better than the list the study team came up with. What is the objective measure of competency “goodness,” anyway? Further, who is to say that following a different methodology, the study team would not have come up with the same—or for all intents and purposes, the same—list of competencies? As the draft Guardian 63 PM and 62 ETM competency models progress through the validation process, the workforce will have a say in whether the study team got it right.

References

Barron, L. (2021, June). USSF foundational competency model [PowerPoint presentation]. insideSSC Hub. (n.d.). Mission. https://usaf.dps.mil/sites/SSC/SitePages/aboutssc.aspx

U.S. Space Force. (2021). The Guardian ideal.

U.S. Space Force. (2020). Space capstone publication: Spacepower doctrine for space forces.

U.S. Space Force. (n.d.). History. https://www.spaceforce.mil/About-Us/About-Space-Force/History/

Villanueava, V. (2022, January). Occupational competency study think-aheads [PowerPoint presentation].

Introducing Agile/DevSecOps into the Space Acquisition Environment

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Abstract

The University of Southern California (USC) and its Information Sciences Institute (USC-ISI) is undertaking research into improving the space-based systems acquisition process through the adoption of agile and DevSecOps methodologies. The USC-ISI team is currently undertaking research and systems engineering analysis to explore the mission engineering methods, analysis, metrics and training needed to transition from a traditional DoDI 5000.02 waterfall development environment to an agile/DevSecOps space systems acquisition environment. Over the past several years, the project team has been embedded at the U.S. Space Force's Space Systems Command, Production Corps (SSC/PC), developing performance measuring tools, collecting performance metrics and providing subject matter expertise on three projects – a traditional waterfall project, a hybrid parallel waterfall and agile development project and an on-going long-term highly agile development effort that is subject to traditional waterfall acquisition reporting requirements. This paper summarizes initial research results and lessons learned along with a discussion on next steps.

Introduction

As mandated by Congress via the 2018 National Defense Authorization Act (NDAA) the Defense Acquisition System (DAS) is to transition many if not all (where feasible) of its programs to agile and DevSecOps processes. This mandate reflects the need for the

Department of Defense (DoD) to rapidly develop warfighter capability to better meet the global challenges currently confronting the United States in today's environment. Competitors, using both increased manpower and technology, are producing systems at a much faster pace than traditional DoDI 5000.02 (DoD, 2020) waterfall processes can sustain. Under funding from the Systems Engineering Research Center (SERC), the University of Southern California's Information Sciences Institute (USC-ISI) is currently undertaking research and systems engineering analysis to explore the mission engineering methods, analysis, metrics and training needed to transition from a traditional DoDI 5000.02 waterfall development environment to an agile/DevSecOps space systems acquisition environment. Over the past several years, the project team has been embedded at the U.S. Space Force's Space Systems Command, Production Corps (SSC/PC), developing performance measuring tools, collecting performance metrics and providing subject matter expertise on three projects – a traditional waterfall project (Project A – the baseline), a hybrid parallel waterfall and agile development project (Project B), and an on-going long-term agile development effort that is subject to traditional waterfall acquisition reporting requirements (Project C).

After adjusting for differences in periods of performance and software lines of code, the hybrid waterfall and agile project (Project B) produced approximately 85.4% fewer open problem reports (PRs) than the traditional waterfall project (Project A). Both projects exhibited the same level of software and systems complexity.

An analysis of the performance of the waterfall portion as compared to the agile portion of the hybrid project (Project B) revealed that the agile effort produced approximately 95.7% fewer open problem reports as compared to the waterfall portion of the effort. Both efforts exhibited similar code complexity and software lines of code; however, the agile effort took 10 months less time to complete, and its workforce was considerably less experienced than the waterfall team.

Currently, the project team is embedded in Project C and is collecting performance metrics, developing and deploying additional performance measurement tools, providing subject matter expertise and developing a workforce agile/DevSecOps training program. An initial analysis of the collected data, a summary of lessons learned, and the impact of the training program is underway and is summarized in this paper.

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Multiple Projects

As described in later sections, this paper is a summary of a long-term on-going research effort that crosses three space-based DoD acquisition efforts. As noted in Row et al. (2020), there has been considerable effort and reporting on the successes and challenges of adopting agile and DevSecOps approaches into traditional DoDI 5000.02 waterfall projects. Although these efforts have produced valuable and productive results, they are often focused on only one project. Perhaps an interesting feature of the research reported here is that the USC-ISI research team has been immersed and observing (serially) three DoD space-based acquisition efforts, each focused on the same mission space, of similar complexity and size, and ranging from a fully waterfall-implemented effort to projects with ever increasing levels of agile/DevSecOps implementation. This research approach is allowing the USC-ISI team to observe the benefits and challenges of implementing agile/DevSecOps through an incremental long-term process.

Methods

Project Immersion

To uncover the steps and processes required to transition an acquisition program from a traditional waterfall environment to agile and DevSecOps, the research team fully immersed into each of the space-based projects (i.e., A, B and C) and became part of the multiple project teams (i.e., members of various integrated product teams [IPTs]). This immersion included participating in daily scrums, grooming/refinement activities and various ceremonies – including sprint and program increment (PI) reviews and demonstrations. In addition, the research team participated in various PI planning events and working group activities focused on DevSecOps processes and request for comment (RFC) explorations.

The Projects

To compare the benefits of establishing and operating an agile and DevSecOps environment, it was necessary to initially identify and study two different projects which exhibited similar levels of software complexity. The first project (Project A) which serves as the baseline for the research effort is comprised of approximately 170K software lines of code (SLOC), required 39 months to complete and was undertaken in a traditional DoDI 5000.02 waterfall environment. Project B consists of approximately 120K SLOC, required 25 months to complete and was undertaken as a hybrid project – approximately half of the project was undertaken using waterfall, and the remaining half was undertaken using agile and DevSecOps processes. Project C, which is on-going, consists predominately of an agile and DevSecOps process but exists within a traditional waterfall administration/reporting environment. All three programs were judged to exhibit the same level of software complexity. Note the waterfall methods in Projects A and B follow a DoDI 5000.02 pre–January 23, 2020, approach. The agile methods followed in Projects B and C are using a tailored “Major Capability Acquisition” approach that incorporates agile because both projects’ acquisition strategies were developed before the latest DoDI version was written.

Data Collection:

As noted in Orosz et al. (2021), for projects A and B, problem reports (PRs) were collected daily throughout the project. Cost data was unavailable at the time of this paper but will be included in future analysis. For the on-going Project C, story and feature completion status are tracked via extractions from the contractor’s Jira® (Atlassian) issue tracking system. Status tracking includes identifying which stories and features completed as scheduled (i.e., within the assigned sprint or program increment [PI]), did not complete and spilled over into the next sprint or PI, were pushed to the next PI or future PI, and which were added to the PI backlog during PI execution. Once software development begins, PRs will also be tracked via data extraction from the contractor’s implementation of IBM® Rational® Dynamic Object-Oriented Requirements System (DOORS®) or DOORS Next Generation (DNG) system (IBM). In addition, cost tracking will also be collected.

Results

Projects A (Waterfall) and B (Hybrid)

As reported in Orosz et al. (2021), to compare results between project A (baseline waterfall effort) and project B (hybrid waterfall/agile effort), the following steps were taken in processing and analyzing the collected performance data:

1. Problem reports (PRs) were collected during the integration and testing phase of each project. For the agile portion of Project B, this included collecting PRs produced during the integration and testing phase of each sprint.
2. The number of PRs in an Open (unresolved) state were captured at the end of each week of software development for each project.
3. The PR counts were plotted in online graphs (Figures 1 and 2) to compare the development history of the two software development projects.
4. The timeline of the waterfall project (Project A) was shifted so that the Formal Qualification Testing (FQT) period overlaid that of the Hybrid project (Project B).
5. The PR counts of the waterfall project (Project A) were proportionally reduced using the relative SLOC counts of the waterfall and hybrid projects.

The decision to proportionally reduce the PR count of Project A (item 5) due to SLOC count differences with Project B was motivated by the observation that the code complexity of both projects was judged to be equivalent; therefore, proportionally reducing the PR count based on the ratio of SLOC between the two projects would provide a more equivalent basis for comparing the productivity of the two development projects.

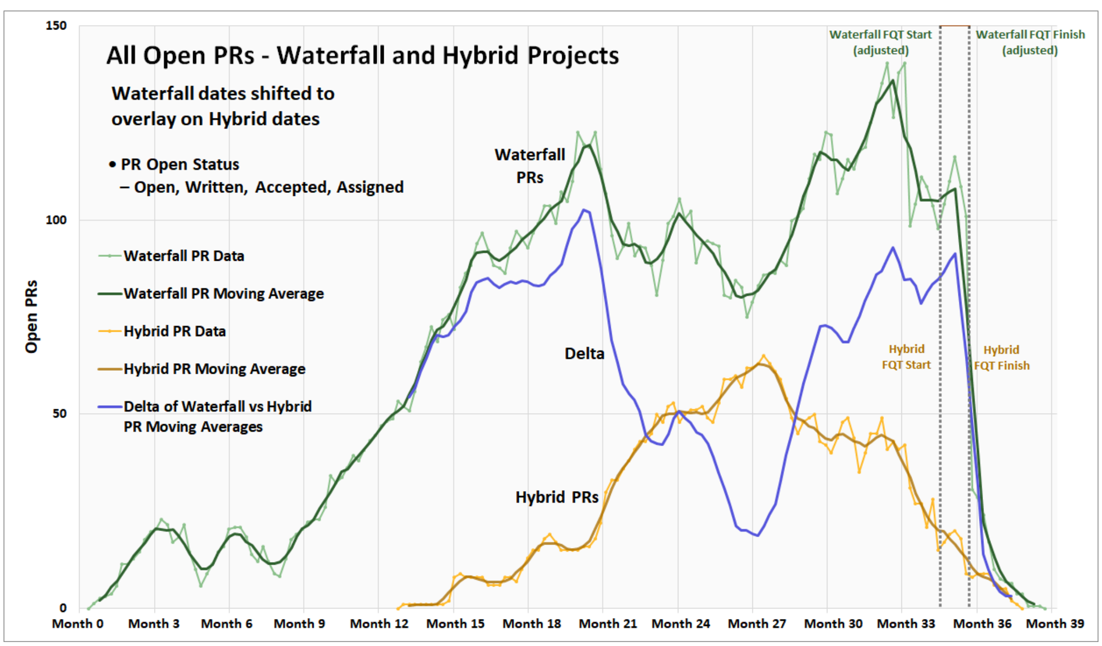

Figure 1. Comparison of PR Counts Between Project A (Waterfall) and Project B (Hybrid) (Orosz et al., 2021)

The project timeline for both projects were shifted so that the period of FQT for both projects coincide. The PR count for Project A is proportionally reduced to reflect the difference in SLOC between the two projects. Code complexity was judged to be the same for both projects. The green upper line is the PR trace for Project A. The yellow lower line is the PR track for Project B. The blue line is the difference in PR count between both projects.

In Figure 1, the two "PR peaks" for Project A reflect a situation where there were so many PRs identified during Component Integration and Testing (CIT) that the team was overwhelmed and had to stop CIT activities, address high priority PR events, and stretch the project timeline out to allow time to address the PRs before completing CIT (the second peak) and then going on to Formal Qualification Testing (FQT).

As also cited in Orosz et al. (2021), for Project B, the waterfall and agile teams worked in parallel, with periodic “merges” that underwent integration and testing. This helped reduce the “PR bow wave” because integration problems were discovered early during these “merge” events. In addition, the agile team undertook frequent integration and testing between the “merge” events (i.e., as part of each sprint). This allowed almost continuous integration and testing which resulted in problems being identified early (i.e., reduced PRs), before CIT was officially started with the merged waterfall and agile development components.

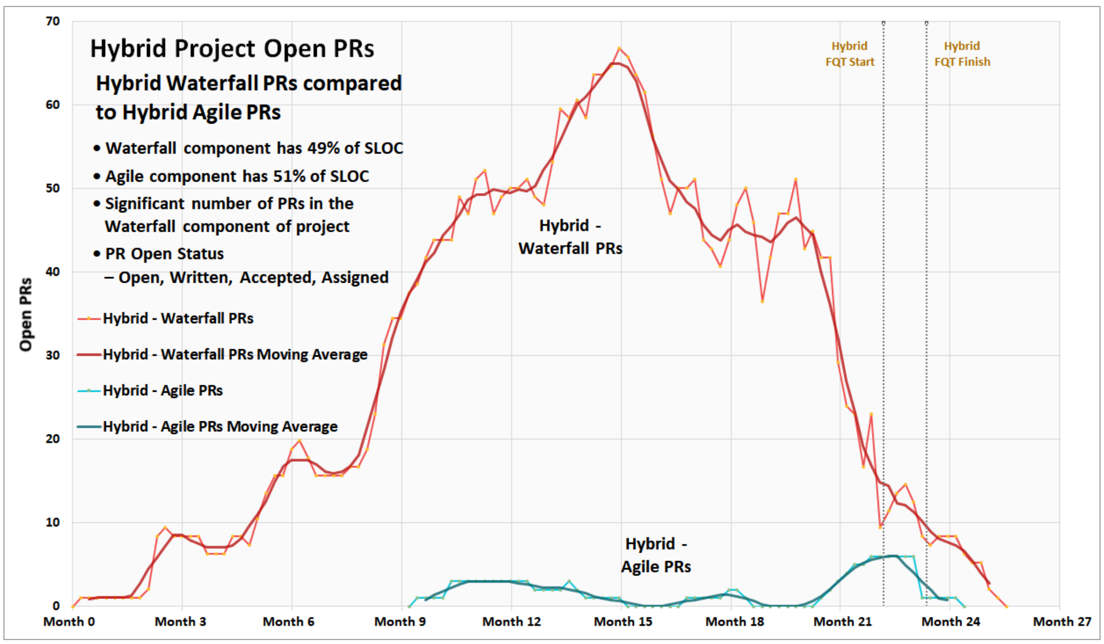

Figure 2. Comparison of PR Counts Between Waterfall and Agile Components of Project B (Hybrid)

(Orosz et al., 2021) Code complexity was judged to be the same for both efforts. Software lines of code (SLOC) were roughly the same for both projects. The red upper line is the PR trace for the waterfall effort. The dark blue lower line is the PR track for the agile effort. Note that the agile effort started 10 months after the program start and the project team was relatively inexperienced in working on agile projects or space programs in general.

As shown in Figure 2, the agile team in Project B produced considerably less PRs over the period of performance than the waterfall team. This was despite the agile team’s late start (delayed 10 months) and the experience level of the agile development team was less than that of the waterfall team members (i.e., the agile effort included “ramp-up” training time for the team).

Study and Project C

Project C is focused on enhancing an existing software platform that was developed using waterfall. Code complexity is very similar to projects A and B. Like the hybrid project (Project B), Project C exists within an acquisition management system that relies on waterfall metrics (lines of code written/tested, CDRLs, EVM, number of PRs reported and worked off, etc.).

Due to the size of Project C, the contractor has implemented a modified Scaled Agile Framework® (SAFe) development environment. The project is comprised of a separate 15-month study phase consisting of six 10-week program increments (PIs) followed by an approximate 51-month-long execution phase, consisting of 19 program increments (PIs), with the first three PIs covering a 10-week performance period divided into five two-week sprints (Figure 3) and the remaining 16 PIs each consisting of a 13-week performance period divided into four three-week sprints and a one-week "PIT Stop" (Figure 4) reserved for demonstrations, innovation exploration, training and PI retrospective activities. The change from a 10-week PI to a 13-week PI resulted from the contractor's observation that the ceremony cadence in a two-week sprint was impacting feature team performance, so a three-week sprint was adopted.

In the study phase, the contractor A) undertook technical trade studies, B) established and operated a SAFe® agile development environment and C) established an initial DevSecOps pipeline infrastructure. As part of establishing the agile development environment, the contractor focused on system requirements decomposition into capabilities and features (with some stories) and initially populated the project backlog in preparation for the execution phase. During the study period, the government team also "ramped up" to become agile/DevSecOps "smart" – including how to manage an agile/DevSecOps project within a waterfall acquisition world (e.g., contracting, staffing, monitoring, managing, etc.). As part of the "ramping up," contractor-provided SAFe® training was made available to both contractor and government personnel. In addition, the government provided topic-specific training to its government personnel (to help ramp up the government's team understanding of agile/DevSecOps work processes).

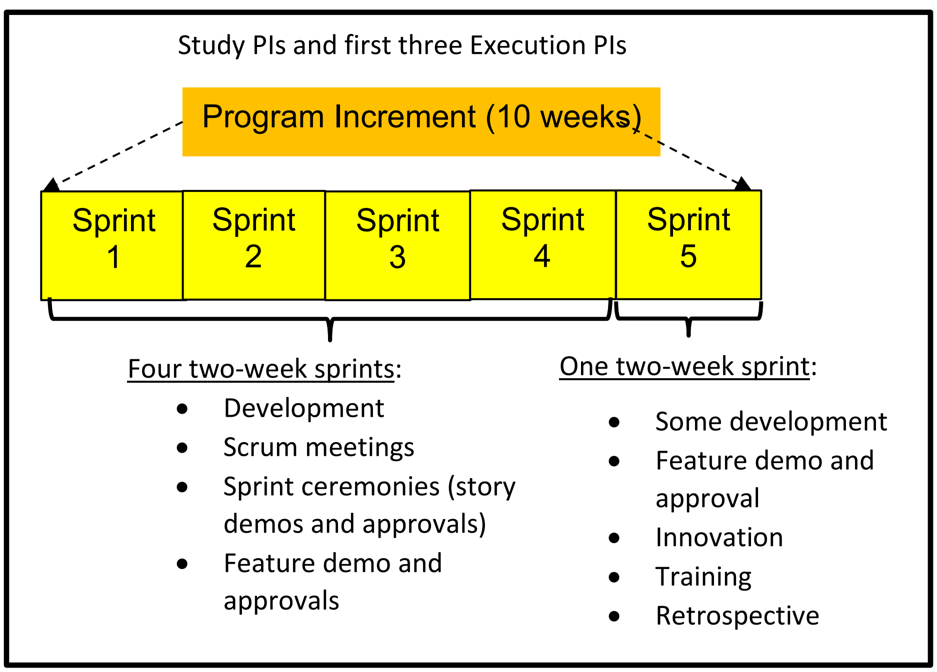

Figure 3. Project C relies on a modified SAFe development framework consisting of a 15-month study phase with six 10-week PIs and an approximate 51-month execution phase consisting of 19 program increments (PIs) with the first three PIs covering a 10-week performance period divided into five two-week sprints. From the study phase (initial 15-week effort), an initial project backlog was produced and divided into six team backlogs to coincide with the six development teams in the project.

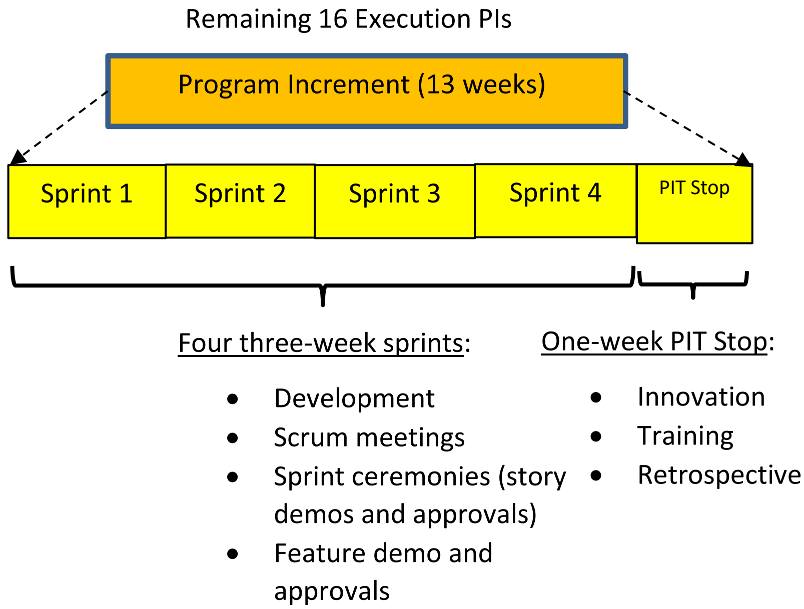

Figure 4. Project C relies on a modified SAFe development framework consisting of a 15-month study phase with six 10-week PIs and an approximate 51-month execution phase consisting of 19 program increments (PIs) with the first three PIs covering a 10-week performance period divided into five two-week sprints and the remaining 16 PIs each consisting of a 13-week performance period divided into four three-week sprints and a one-week "PIT Stop" reserved for demonstrations, innovation exploration, training and PI retrospective activities.

Tools Developed

During both the Project C study and initial eight months of the execution phase, the research team developed data extraction and analytic tools to help the government monitor and track program performance. These tools were developed to meet gaps in the availability of performance metric monitoring tools due to several reasons. First, the government team members could not access the contractor's implementation of Atlassian® Jira® and IBM Rational DNG platforms due to various cybersecurity and IT reasons. Second, many commercially available tools that provide similar capabilities are restricted from being used on the project due to import control protocols. In other cases, there are limits in license availability or the tools require a specific configuration in Jira or DNG that can't be supported by the contractor executing Project C. In any case, these challenges necessitated the need to develop inhouse monitoring and analysis tools.

Many of the tools rely on extracting feature and story status information from daily Jira exports from the contractor. Microsoft® Excel® (with Visual Basic developed scripts) are used to process the extracted data and visually presented for government review. Table 1 summarizes the tools developed to date on Project C.

Table 1. List of Tools Developed to Date in Project C

Tool Name	Tool Description
Status board	Presents list of capabilities, features and stories by status (done, in-progress, blocked, backlog, etc.) and MVP/MMP, PI, and Sprint.
Issue viewer	Allows detailed inspection of any Jira issue (e.g., review acceptance criteria, definition of done, dependencies, PI assigned, priority assigned, etc.)
Feature Team Plan	Shows features and status assigned by Feature Team and the current PI assignment.
MVP vs PI Summary	Graphical table view of feature quantities as assigned by PI, MVP/MMP, and Release.
MVP-MMP Plan	Shows features and status assigned by MVP and MMP and the current PI assignment.
MVP-MMP Trace	Displays a hierarchy organized by MVP/MMPs with child capabilities, features, and stories; provides associated Jira information such as PI and status.
DNG Jira Summary	Presents program requirements and linked features with associated Jira information. Combines information from DNG requirements module export, DNG feature module export, and Jira export.

In Figure 5, the MVP-MMP Plan tool shows progress (features completed) towards meeting the first MVP (68% complete) deliverable (1-a). The tool also shows that there are two features assigned to the first MVP that are assigned to PIs that occur after the planned release of the first MVP.

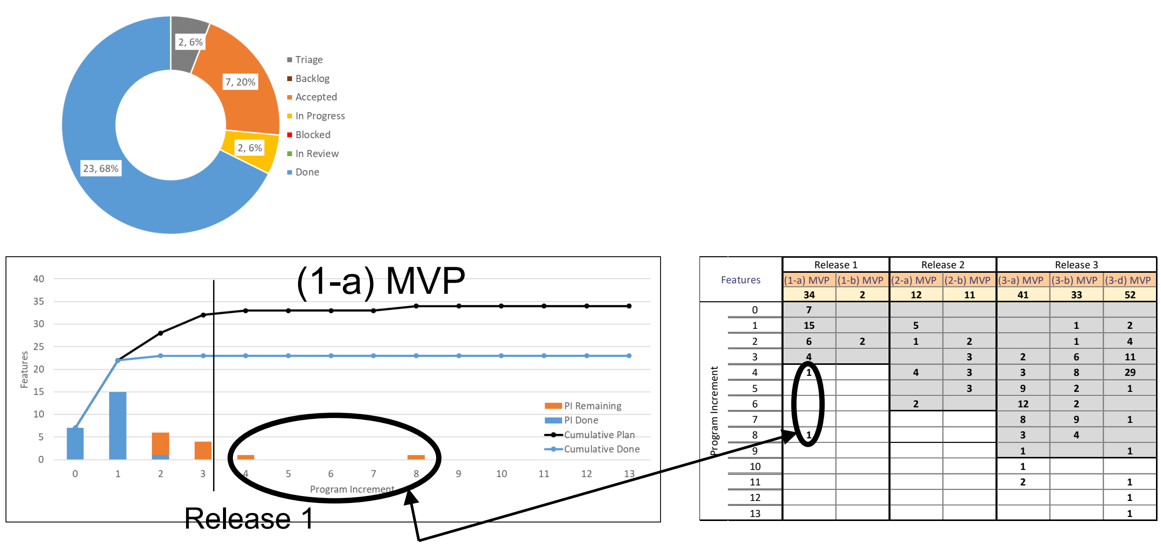

Figure 5. The MVP-MMP Plan Tool Showing Progress (Features Completed) on Meeting the First MVP (68% Complete). The tool also shows that there are two features assigned to the first MVP that are assigned to PIs that occur after the planned release date of the first MVP.

In Figure 6, the Feature Team Plan tool shows the current plan and progress (features completed, sized by story points) over time (PI) for a specific team. The tool shows that maximum PI capacity so far has been approximately 500 story points, PI 3 is in progress, and a surge of effort is planned for PI 4.

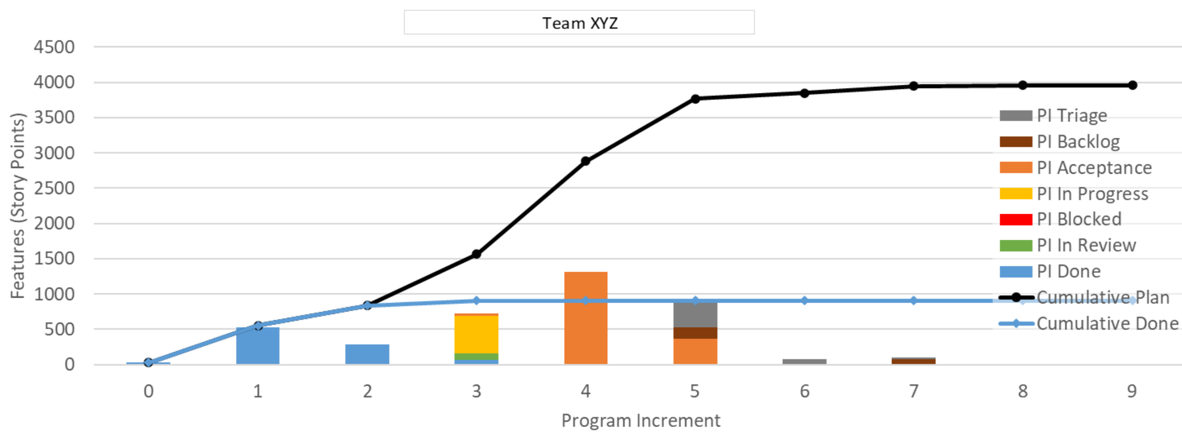

Figure 6. The Feature Team Plan Tool Shows the Current Plan and Progress (Features Completed, Sized by Story Points) Over Time (PI) for a Specific Team. The tool shows that maximum PI capacity so far has been approximately 500 story points, PI 3 is in progress, and a surge of effort is planned for PI 4.

Lessons Learned

During both the Project C study phase and during the initial eight months of the execution phase, the following lessons learned were observed.

Incongruity between agile and traditional programs with set budgets, requirements and timelines. The rigidity of the Capability Development Document (CDD) can cause considerable challenges during project RFP development, contract negotiations and program operation. For example, there is little "wiggle room" available to allow the contractor and government to *easily* shift priorities of requirements (via their decomposed features on the project backlog) and MVP/MMP release dates to account for temporary blockages (e.g., availability of an external dependency) or the introduction of a higher priority Request for Change (RFC) into the backlog. Undertaking such changes can be lengthy (in terms of time) as the proposed adjustments must be coordinated and approved up to the Joints Requirements Oversight Council or Service level. Additionally, with program funding matched to CDD threshold requirements level, the PM's flexibility is removed. A possible solution is to allow PEO trade space among non-KPP requirements. Another approach (which is the subject of future research) is to identify "gray" areas within the definition and decomposition of CDD requirements that may be able to be traded for higher-priority items during the agile development process while still meeting the basic standards of the CDD.

Need to do engineering up front. Often, project teams will assume that with agile, there is less need for up-front engineering as the details of the design will unfold as the project moves along. Doing this will result in several challenges. First, dependencies between features (internal or external to a project team or CI) can often be overlooked if the proper engineering is not done up front. Second, to fully prioritize features on the backlog, there must be a roadmap and an initial design to help guide the decision making behind assigning priorities to the features on the backlog. Finally, it is necessary to fully decompose CDD/spec requirements (up front) to determine if all features have been identified for the project. This decomposition process can be quite complex as each requirement may require multiple features that cross multiple feature development teams. Further, the translation of feature verification up to FQT completion is also a major challenge. These features don't have to have detailed designs behind them, but they do need sufficient detail so that when combined with other features, the requirement in which they are decomposed is fully covered. This upfront engineering and planning work is also critical for continually tracking the relationship between near-term, detailed plans and performance and higher-level plans for project completion.

Access to performance tools. As previously noted, government team members (at least initially) could not directly access the contractors' Jira and DNG platforms due to various cybersecurity and IT reasons. In addition, many commercially available performance tracking tools (e.g., Jira plug-ins) are not available to the contractor or government team members due to U.S. import restrictions. Many of these tools are developed and maintained by vendors outside of the United States. This is becoming a particularly difficult challenge as the performance metrics measuring tools marketplace continues to evolve with companies – many headquartered here in the United States – being acquired by foreign-owned companies. These challenges need to be addressed earlier in the program prior to the full ramp-up of the project.

PI length is too short. During the study phase, a 10-week PI divided into five two-week sprints was sufficient for technical innovation, project backlog population and in establishing an initial agile/DevSecOps acquisition framework. Once the execution phase started, however, the two-week sprint cadence, with its frequent planning, grooming/refinement and various ceremonies, didn't allow sufficient time for the feature teams to undertake the necessary work to complete stories within each sprint. The work on stories frequently spilled into and consumed most of sprint 5, leaving little time for feature demonstrations, innovation activities, training and retrospective activities. This realization led the contractor and government to extend the PI to 13 weeks divided into four three-week sprints followed by a one-week PIT Stop to allow for feature demonstrations, innovation and training activities. The key lesson here is that feature teams need the flexibility to adjust PI lengths and sprint cadence to meet the demands of the project. That said, it's important that all feature teams rely on the same PI length and sprint cadence to reduce synchronization and management challenges if teams are working different timelines.

Story Assignment Up Front. On multiple occasions, the project team observed that when stories are not initially (or tentatively) assigned to sprints in the upcoming PI, there is a high risk that the parent feature will not complete within its assigned PI. This is particularly a challenge with features that have many stories and story points. Much of the difficulty can be traced to not adequately matching anticipated team capacity to total story points assigned to the PI. In addition, keeping stories on the team backlog and not assigned to a sprint often resulted in the Product Owner (PO), scrum masters and team members overlooking these unassigned stories. When discovered later in the PI, it was often too late to adequately work the stories before the end of the PI. This often resulted in the feature team working stories through the last sprint/PIT Stop, allowing little or no time for adequate training, innovation and other non-development activities.

Too many story points in the PI. During PI planning, some feature teams allocated stories whose total story point count either met or exceeded the full capacity of the feature team. This resulted in no room for error in the event an assigned story took longer to complete than scheduled, a higher priority capability was added to the PI, there was reduced availability of manpower due to unexpected time off (e.g., sick leave), or some other unexpected event occurred. It is important that the PO leaves a buffer of capacity (say 20% of the total available capacity) to allow for unexpected events and activities.

Stay focused on MVP/MMP and the roadmap. Teams often drifted focus away from project priorities (meeting MVP/MMP and roadmap milestones) and instead to sprint planning activities and prioritizing completing as many features and stories as possible to meet velocity goals. This problem was often traced to PI planning where high-priority features are selected from the project backlog. The solution here is for the government to assign priorities to the project backlog based on MVP/MMP priorities and structure performance incentives based on progress towards the upcoming MVP/MMPs instead of on the number of features worked and completed. A roadmap should be developed and maintained in sufficient detail to continually identify the impacts on the total project caused by performance in near-term program activities.

Training. Members from both the contractor and the Government bring different experiences and expectations on agile and DevSecOps to the project team. In many cases, team members have little previous experience with either approach when on-boarding onto projects, are not familiar with scaling the approaches or bring prior experience from projects that have little resemblance to the current project (e.g., coming from industry). This challenge applies whether the team member is a software developer, a tester, or a project manager. In Project C, the government team is currently focused on establishing a training curriculum that starts with a focus on the foundational elements of agile and DevSecOps (e.g., what is agile, why use it, etc.), transitions to more advanced topics such as agile frameworks and contracting, and finishes out with a focus on the specific implementation of agile and DevSecOps to Project C. This training is targeting on-boarding of new team members and provides on-going training to address the evolving acquisition environment.

Need for an operations-like test environment as soon as possible. Since many projects are composed of both hardware and software components, with hardware lagging software in terms of availability, it is critical that a near operations test environment be available to the DevSecOps pipeline as soon as possible to facilitate continuous integration/continuous deployment (CI/CD) operations. This often means scheduling and prioritizing the development and acquisition of the near operations environment as early as possible while also putting in place backup plans in the event the planned near operations environment is not initially available when scheduled.

Next Steps

As of the writing of this paper, Project C is eight months into a 51-month effort. Software development is just underway, and the initial MVP deliverables are several months away. Going forward, the project team is focused on collecting and analyzing performance data such as DRs, cost data, DevSecOps pipeline performance and project velocities and other performance metrics. In addition, based on observations and lessons learned, the project team will continue to offer subject matter expertise to the government on monitoring and managing the agile/DevSecOps project.

Of particularly interest to the team is how to better transition from an environment that relies on well-defined waterfall performance metrics to an evolving agile software development environment that is focused on delivering value rather than traditional waterfall metrics, such as software lines of code. For example, a key area of research is in improving the synchronization of PI planning with the Integrated Master Schedule (IMS) which drives many EVM metrics. Finally, the development of more effective workforce training processes and materials will also be undertaken. Results will be published in a future paper.

References

Atlassian Jira. (n.d.). https://www.atlassian.com/software/jira/guides/getting-started/overview

DoD. (2020). *Operation of the adaptive acquisition framework* (DOD Instruction 5000.02). https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf

IBM DOORS Next Generation. (n.d.). https://www.ibm.com/docs/en/elm/6.0.6?topic=capabilities-rational-doors-next-generation

Roe, S., Novak, R., Staresina, P., & Raines, J. (2020). *Recommendations for injecting flexibility into acquisitions for software development and operations (DevSecOps) and agile software development* (MITRE Technology Report PRS-19-3551). https://apps.dtic.mil/sti/pdfs/AD1114449.pdf

Scaled Agile. (n.d.). https://www.scaledagileframework.com/

Orosz, M., Evans, J., Duffy, B., Charlton, C., & Mitchell, R. (2021). *WRT 1012: Global positioning systems - Mission engineering and integration of emerging technologies* (SERC Report SERC-2021-TR-001). https://sercuarc.org/publication/?id=231&pub-type=Technical-Report&publication=WRT%201012:%20Global%20Positioning%20Systems%20-%20Mission%20Engineering%20and%20Integration%20of%20Emerging%20Technologies

National Defense Authorization Act for Fiscal Year 2018, H.R. 2810. (n.d.). https://www.congress.gov/bill/115th-congress/house-bill/2810

Can the Next Generation Overhead Persistent Infrared Program Overcome an Aggressive Schedule Using the Middle Tier of Acquisition?

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Abstract

The U.S. defense and intelligence communities depend on data from overhead persistent infrared sensors. These sensors provide early warning of ballistic missile launches and contribute to other defense and intelligence missions. The planned Next Generation Overhead Persistent Infrared (Next Gen OPIR) system is intended to replace the Space Based Infrared System, which began in the mid-1990s. This presentation (1) identifies the challenges Next Gen OPIR acquisition efforts face and the extent to which the Space Force is addressing them, and (2) assesses the extent to which Next Gen OPIR capabilities will address missions supported by the current system.

Background

The U.S. Space Force plans to spend around $14.4 billion over the next five years to develop the Next Generation Overhead Persistent Infrared (Next Gen OPIR) system, comprised of satellites and a ground system to detect and track missiles, among other things. The Next Gen OPIR system is intended to replace the Space Based Infrared System (SBIRS), which began in the mid-1990s. The Air Force experienced significant problems when it developed SBIRS, and the program was roughly nine years late and cost more than three times its initial estimate.

The U.S. defense and intelligence communities depend on overhead persistent infrared sensors to provide essential launch detection, missile tracking, and reconnaissance data to mitigate, predict, track, and respond to a variety of threats. The Space Force plans to launch the first of five Next Gen OPIR satellites in 2025, an aggressive launch requirement validated by the Joint Requirements Oversight Council.

Objectives, Scope and Methodology

This report (1) identifies the challenges Next Gen OPIR acquisition efforts face and the extent to which the Space Force is addressing them, and (2) assesses the extent to which Next Gen OPIR capabilities will address missions supported by the current system. GAO reviewed program documentation, acquisition strategies, and Air Force and DoD acquisition guidance, and interviewed DoD officials. GAO assessed this information against acquisition and collaboration best practices.

Summary

The Space Force is acquiring Next Gen OPIR Block 0 using a relatively new acquisition approach. Specifically, the Space Force initiated Next Gen OPIR Block 0 as a rapid prototyping middle tier of acquisition (MTA) program. The rapid prototyping MTA pathway provides for the use of innovative technologies to rapidly develop fieldable prototypes to demonstrate new capabilities and meet emerging military needs. The Next Gen OPIR MTA designation helped streamline and expedite the start of the program. Given the highly aggressive development and launch schedule validated by the JROC, hastening the start of the program was important for Next Gen OPIR.

Space Force officials recognized the significant development and schedule challenges at the inception of the Next Gen OPIR program and structured the program in several ways to address them. However, despite early gains in schedule and steps taken to speed up program development, the Next Gen OPIR program continues to face significant technical and managerial challenges—such as developing a new mission payload, integrating a novel payload onto a modified space vehicle, and serving as the lead system integrator for the first time in this area—that are likely to delay the initial launch.

See GAO-21-105249 for additional details

https://www.gao.gov/products/gao-21-105249

How is the DoD Addressing Challenges with Its Mobile User Objective System Program?

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Abstract

The Department of Defense (DoD) is not using the full capabilities of its latest ultra high frequency (narrowband) military satellite communications system, the Mobile User Objective System (MUOS). The full MUOS constellation has been on orbit for over 4 years, but the DoD has not been able to fully use the system's advanced capabilities—such as its 10-fold increase in communications capacity—primarily due to delays in fielding compatible radio terminals to users. The DoD faces other challenges to its narrowband communication capabilities, such as near-term reliance on oversubscribed communication systems that preceded MUOS. Additionally, on-orbit MUOS satellites have limited design lives, and while the DoD plans to buy and launch additional satellites to sustain the constellation, those additional satellites won't have legacy capability of the older system. See GAO-21-105283 for more information.

Why We Did This Study

The Department of Defense (DoD) has invested $7.4 billion to develop, build, and begin delivering the Mobile User Objective System (MUOS). However, longstanding gaps between the fielding of the satellite system and compatible user terminals have limited the DoD's ability to fully use the system.

The Senate Armed Services Committee report to the bill for the National Defense Authorization Act for Fiscal Year 2020 contained a provision for the Government Accountability Office (GAO) to review the DoD's use of MUOS capabilities and any plans for a MUOS follow-on capability. In this report, the GAO (1) provides information on the extent to which the DoD is using MUOS advanced communications capabilities, (2) assesses the DoD's challenges and steps taken in transitioning to these capabilities, and (3) assesses efforts the DoD has underway to meet future narrowband satellite communications needs.

The GAO reviewed DoD planning documents, system assessments, and test reports. The GAO also analyzed the services' terminal fielding and network transition plans. The GAO interviewed oversight and acquisition officials across the DoD.

What We Found

We found that the DoD was not using the full capabilities of its latest ultra high frequency (narrowband) military satellite communications system, MUOS. MUOS provides secure communications less vulnerable to weather conditions or other potential impediments. While the full constellation of MUOS satellites had been on orbit for over 4 years, we found that the DoD had not been able to fully use the system's advanced capabilities—such as its 10-fold increase in communications capacity. We found that this was due to delays in fielding MUOS-compatible terminals and transitioning communication networks. At the time of our review, the DoD had begun using the terminals in several military operations or exercises. Additionally, most of the services had begun using their terminals in testing, training, and evaluations over the past few years. The DoD was funding and developing plans to accelerate procurement and delivery of these terminals.

The DoD faced other challenges to its narrowband communications capabilities:

- In the near term, users continued to rely on the communications system that preceded MUOS, which was oversubscribed and will remain so while the DoD works to field terminals and transition to MUOS. Delays in MUOS development and fielding compatible terminals led to continued reliance on legacy UHF capabilities, the demand for which has exceeded supply. For example, a 2019 Navy analysis found that users across the DoD consistently used 100% of the available UHF SATCOM channels. The true extent of the oversubscription is unclear. According to U.S. Space Command officials, some users decide not to request legacy UHF services, anticipating that the requests will be denied. At the time of our review, the DoD had not explored and adopted narrowband communication options, which, if implemented, could help to meet unmet near-term communication needs.
- In the longer term, the five MUOS satellites that are on orbit have limited design lives (as do all satellites). The DoD planned to buy and launch additional satellites to sustain the constellation's availability, but without the legacy capability of the older system. In 2020, the Deputy Secretary of Defense directed the Navy to acquire additional satellites to extend the service life of the current MUOS system, MUOS 6 and 7, to be launched in the mid- to late-2020s. According to officials, the DoD planned for these satellites to have the same advanced MUOS capabilities as the original MUOS satellites, but they will not include the legacy UHF capabilities because of an assumption that the services would be able to accelerate the fielding of MUOS-compatible terminals and transition most networks by the mid-2020s. However, according to Navy officials, the mid-2020s launch date for MUOS 6 was based on an expedited time frame that is no longer feasible. Additionally, officials told us that funding delays contributed to starting development efforts one year later than planned. As a result, MUOS program office officials expect that MUOS 6 and 7 development efforts will likely not start until the early 2020s, with the first satellite launch not occurring before the late 2020s.

At the time of our review, the DoD had not determined its future narrowband satellite communication needs after MUOS. Over the past 7 years, DoD reports recommended that the Navy identify and assess potential solutions for meeting users' future narrowband SATCOM needs. The DoD has not updated its narrowband requirements since 2010 and has no plans to do so, although the uses, technology, and threats to communications have changed. For example, user needs had evolved as a result of (1) space becoming a contested operational environment for future satellite-based communications systems, (2) increased communication needs of users, and (3) advances in communication and related technologies. Our review found that reexamining its narrowband communications needs would enhance the DoD's ability to field a timely replacement for MUOS and ensure warfighters have needed communications tools in the future.

What the GAO Recommended

The GAO recommended the DoD (1) explore and implement an option for narrowband satellite communications capabilities to meet near-term needs and (2) reexamine its future narrowband satellite needs. The DoD concurred with our recommendations.

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