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VOLUME I

**Acquisition Research:
Creating Synergy for Informed Change**

May 8–9, 2024

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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 Associate Chair Department of Defense Management Acquisition Sciences, a Professor of the Practice, and the Principal Investigator, Acquisition Research Program at the Naval Postgraduate School. Mortlock 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: ANN E. RONDEAU, ED.D, VADM, 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: HONORABLE NICKOLAS H. GUERTIN, ASSISTANT SECRETARY OF THE NAVY FOR RESEARCH, DEVELOPMENT AND ACQUISITION

Honorable Nickolas H. Guertin—was sworn in as Assistant Secretary of the Navy for Research, Development, and Acquisition (ASN RD&A) on December 20, 2023. A Presidential appointee confirmed by the United States Senate, he leads the Department of the Navy's (DON) Research, Development, Acquisition, and Sustainment programs and the DON's contracting community. Prior to this role, Mr. Guertin served as the senior advisor to the Secretary of Defense on operational and live fire test and evaluation of Department of Defense weapon systems (Director, Operational Test and Evaluation).

Mr. Guertin has an extensive four-decade combined military and civilian career in submarine operations; ship construction and maintenance; development and testing of weapons, sensors, combat management products including the improvement of systems engineering; and defense acquisition. Most recently, he has performed applied research for government and academia in software-reliant and cyber-physical systems at Carnegie Mellon University's Software Engineering Institute.

Over his career, he has led organizational transformation, improved competition, and increased application of modular open-system approaches, prototyping, and experimentation. He has also researched and published extensively on software-reliant system design, testing, and acquisition. He received a Bachelor of Science in Mechanical Engineering from the University of Washington and an MBA from Bryant University. He is a retired Navy Reserve Engineering Duty Officer, was Defense Acquisition Workforce Improvement Act (DAWIA) certified in Program Management and Engineering, and is a licensed Professional Engineer (Mechanical).



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PANEL 1. RESOURCING INNOVATION: ENSURING THAT THE DEFENSE INDUSTRIAL BASE IS POSTURED TO SUPPORT PRODUCING INNOVATION AT SCALE

Wednesday, May 8, 2024	
9:10 a.m. – 10:20 a.m.	<p>Chair: Hon. David Berteau, President & CEO, Professional Services Council</p> <p>Panelists:</p> <p>Scott Sendmeyer, Acting Director of Policy, Analysis, and Transition (PA&T)</p> <p>Maynard Holliday, Performing the Duties of Assistant Secretary of Defense for Critical Technologies (PTDO, ASD(CT)) in the Office of the Under Secretary of Defense for Research and Engineering</p> <p>Christine Michienzi (Ph.D.), former Chief Technology Officer for the Undersecretary of Defense for Acquisition and Sustainment</p> <p>Cynthia Cook (Ph.D.), Director, Defense-Industrial Initiatives Group and Senior Fellow, International Security Program, CSIS</p>

Hon. David Berteau—became the President and Chief Executive Officer of the Professional Services Council (PSC) on March 28, 2016. With more than 400 members, PSC is the premier advocate of and resource for the federal services industry. As CEO, Mr. Berteau focuses on legislative and regulatory issues related to government acquisition, budgets, and requirements by helping to shape public policy, leading strategic coalitions, and working to improve communications between government and industry, focusing on outcomes and results for the government.

Prior to PSC, Mr. Berteau was confirmed in December 2014 as the Assistant Secretary of Defense for Logistics and Materiel Readiness. He oversaw the management of the \$170 billion in Department of Defense logistics funding.

Previously, Mr. Berteau served as Senior Vice President at the Center for Strategic and International Studies (CSIS), where his research and analysis covered federal budgets, national security, management, contracting, logistics, acquisition, and industrial base issues.

Mr. Berteau is a Fellow of the National Academy of Public Administration and a Director of the Procurement Round Table. He also served as an adjunct professor at Georgetown University, at the Lyndon B. Johnson School of Public Affairs, and at Syracuse University's Maxwell School.

Scott Sendmeyer—is Acting Director of Policy, Analysis, and Transition (PA&T). He is a retired Military officer with over 27 years of experience with the Department of the Army, with years of experience supervising, leading, and managing organizations in increasingly dynamic environments. Extensive experience in project management to include, developing guidance and strategies, planning, advising, and communicating complex concepts for senior executives at the military strategic and operational levels. A recognized expert in supervising diverse multi-functional project teams during contingency, deliberate and institutional planning. Proven leader in combat, humanitarian, security cooperation, and steady-state operations. Experienced manager at multiple levels of responsibility for training,



administration, and organizational transformation. My primary focus has been creating, testing, deploying, and evaluating strategic guidance and risk analysis. This requires me to be knowledgeable, driven, and goal-oriented. A career that has challenged me has given me the opportunity to learn how to manage resources and accomplish complex goals.

Maynard Holliday—is the Deputy Chief Technology Officer for Critical Technologies. Mr. Holliday has over 30 years of professional experience leading technological innovations, in both government and the private sector. Most recently, he was a Senior Engineer at the RAND Corporation, and previously, he served as Senior Technical Advisor and Special Assistant to Frank Kendall, Under Secretary of Defense for Acquisition, Technology and Logistics.

Christine Michienzi, PhD—is a former senior government executive with extensive national and international leadership experience. Her strategic advice and counsel are regularly sought on issues relating to global supply chains and defense industrial base resiliency and security.

Today, she provides consulting services - bringing innovative solutions that allow companies to successfully address supply chain and technical issues using strategy, policy, and investment approaches.

Previously Dr. Michienzi served in the Office of the Secretary of Defense as the Senior Technology Advisor for the Undersecretary of Defense for Acquisition & Sustainment and the Chief Technology Officer for the Industrial Base Policy office. Her expertise includes industrial base/supply chains and technology for critical defense capabilities such as missiles and munitions, microelectronics, critical chemicals, hypersonics, nuclear modernization, and the Defense Production Act.

She received the Secretary of Defense's Medal for Civilian Career Service, the Secretary of Defense's Medal for Exceptional Civilian Service, the Naval Sea Systems Command Scientist of the Year Award, and the Assistant Secretary of the Navy for Research, Development and Acquisition Scientist of the Year Award.

Dr. Michienzi received her Doctorate in Analytical Chemistry and Bachelor of Science in Chemistry from the University of Maryland.

Cynthia Cook, PhD—Cynthia Cook is director of the Defense-Industrial Initiatives Group and a senior fellow in the International Security Program at the Center for Strategic and International Studies. Her research interests include defense acquisition policy and organization, the defense-industrial base, new technology development, and weapon systems production and sustainment. Dr. Cook is a member of the editorial board for the Defense Acquisition Research Journal and is an adjunct professor at the Pardee RAND Graduate School. From 1997 to 2021, Dr. Cook worked as a senior management scientist at RAND, where she oversaw, led, and worked on a wide range of studies for components across the U.S. Department of Defense, along with the Australian Department of Defense and the UK Ministry of Defense. Previously, Dr. Cook was a research specialist at the Massachusetts Institute of Technology, working on the Lean Aerospace Initiative. Before her graduate studies, Dr. Cook worked in New York as an investment banker, specializing in high-yield finance. She holds a PhD in sociology from Harvard University and a BS in management from the Wharton School of the University of Pennsylvania.



PANEL 2. HOW SPACE ACQUISITION STAYS AGILE

Wednesday, May 8, 2024	
10:30 a.m. – 11:45 p.m.	<p>Chair: Howard Pace, Professor of the Practice, Acquisition Management, Naval Postgraduate School</p> <p>Panelists:</p> <p>Dr. James Newman, Space Systems Academic Group, Naval Postgraduate School</p> <p>LTC Gary “Grinch” Thomason (Ret.), Chair, Naval Space Systems Engineering and Acquisition (SSEA), Naval Postgraduate School</p> <p>Mr. Bill Joo, APM Special Projects, PMW 170 NAVWARCOM</p> <p><i>Managing Resources in a DoD Space-based Agile/DevSecOps Program</i></p> <p>Michael Orosz, USC Information Sciences Institute</p>

Howard Pace—serves as Professor of the Practice at the Naval Postgraduate School, Graduate School of Business and Public Policy. His teaching and research interest are in acquisition, program management and acquisition reform. He is also a sole proprietor of Pace Enterprises where Mr. Pace consults on space, cyber and RF networking technologies, acquisition and strategies. Before joining NPS, Mr. Pace served in several Industry positions as Vice President. He was responsible for creating, communicating, planning and executing strategic initiatives and business development opportunities.

Mr. Pace enlisted in the Navy, rising to the rank of Chief Petty Officer while serving in the Submarine Force. He graduated from the University of Washington with a degree in Mechanical Engineering where he received his commission. He qualified as a Surface Warfare Officer in USS ELROD (FFG-55) and served during Operation Desert Storm, Southern Watch, Joint Endeavor, and Support Democracy. He also served aboard USS SAN JACINTO (CG-55) and USS GEORGE WASHINGTON. Mr. Pace was selected as an Engineering Duty Officer, Acquisition Professional and graduated from NPS with a Master’s degree in Electrical Engineering. He spent his subsequent assignments at the Space and Naval Warfare Systems Command (SPAWAR) in San Diego, CA serving as the Chief Engineer of Naval Communications. Mr. Pace retired from the U.S. Navy and began his career as a civil servant, serving as Technical Director of PEO C4I and Space and as the Navy’s IA Certification Authority for all Naval C4ISR systems. Mr. Pace began his joint service as the Deputy Joint Program Executive Officer (DJPEO), Joint Tactical Radio System (JTRS) and was selected as a Member of the Senior Executive Service. Mr. Pace assumed the role of Joint Program Executive Officer and was responsible for the acquisition, operational testing and initial deployment of JTRS across joint forces.

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.

LTC Gary “Grinch” Thomason (Ret.)—Mr. Gary “Grinch” Thomason, lectures in the Naval Postgraduate School’s Space Systems Academic Group as the sponsored Space Systems Engineering and Acquisitions Chair educating the next generation of Space-enabled Warfighters. In past positions including at the US Army’s Space and Missile Defense Command (SMDC) as the Marine Corps Space Operations Liaison and SMDC’s Military Deputy Director for Strategy and Plans, he was an original planning team member of Task Force - Sierra to re-establish US Space Command and is considered a founding member of the Space Forces for helping plan the new service and service components' creation. He previously consulted with the United States Military Training Mission (USMTM) Transformation Action Group to Saudi Arabia - a unique security assistance (SA) and security cooperation (SC) organization under the authority of the chief of the U.S. diplomatic mission – providing US Government recommendations to the Ministry of Defense for development of a new Royal Saudi Space Force.

Mr. William Joo—is the Special Projects Engineer and Science & Technology Assistant Program Manager for U.S. Navy NAVWAR (formerly SPAWAR System Command) PEO C4I PMW/A 170. Mr. Joo has over 30 years of DoD experience in protected satellite communications systems, Joint Tactical Radio System (JTRS), and science & technology projects. Mr. Joo works closely with commercial LEO and MEO SATCOM for DoD applications; the primary means is through the administration of the SATCOM LEO and MEO (SLaM) Technical Information Meetings and Exchange (TIME) with the Naval Postgraduate School. Mr. Joo is currently working to shape the technical capabilities of the Satellite Terminal (transportable) Non-Geostationary (STtNG) system.

Mr. Joo received his Electrical Engineering degrees from Monmouth University (Bachelor) and Stevens Institute of Technology (Master).



Managing Resources in a DoD Space-based Agile/DevSecOps Program

Michael Orosz—directs the Decision Systems Group at the University of Southern California's Information Sciences Institute and is a Research Associate Professor in USC's Sonny Astani Department of Civil and Environmental Engineering. Dr. Orosz has over 30 years' experience in government and commercial software development, systems engineering and acquisition, applied research and development, and project management, and has developed several successful products in both the government and commercial sectors. Dr. Orosz received his BS in engineering from the Colorado School of Mines, an MS in computer science from the University of Colorado, and a PhD in computer science from UCLA.. [mdorosz@isi.edu]

Lt Col Jacob M. Hempen—is Squadron Commander and Materiel Leader for the PNT Integrated Mission Delta, Software Engineering Squadron, Los Angeles AFB, CA, where he is responsible for three GPS Command and Control programs. Lt Col Hempen's career spans UAS flight test operations in Afghanistan/Iraq, cyber development, GPS Navigation Warfare programs, and High-Altitude SIGINT satellite development. Recently, Lt Col Hempen led an NSC-chartered missile and space launch technology committee under the State Department. In his last assignment, he was the GPS User Equipment Program Element Monitor for the Assistant Secretary of the Air Force for Space Acquisition and Integration. [jacob.m.hempen@spaceforce.mil]

Lt Col John "Mack" Turner—joined the Space Force in 2022 after 15 years in the U.S. Army. He has held all Artillery positions at company level including both Battery and Company Command. After supporting PEO Ammunition, he joined PEO C3T modernizing Mission Command software. In his last assignment, he oversaw Artillery software requirements for the Fires Center of Excellence. Since entering the Space Force, Mack has supported the follow-on effort for the Next Generation Operational Control System (OCX 3F). He holds a BS in Electronic and Information Technology Systems and an MA in Defense and Strategic Studies.

Brian Duffy—is a Senior Systems Engineer with the University of Southern California's Information Sciences Institute (USC/ISI). He conducts research and analysis to determine system engineering methods and metrics necessary to transition Major Defense Acquisition Programs from a traditional waterfall development to Agile/DevSecOps processes. Prior to USC/ISI, Brian retired from the United States Air Force with multiple assignments related to National Security Space acquisition programs, and command and control systems. Brian holds a Master of Aeronautical Science from Embry-Riddle Aeronautical University and a Bachelor of Aeronautical and Astronautical Engineering from the University of Washington.

Craig Charlton—is a Senior Systems Engineer at the University of Southern California's Information Sciences Institute (USC-ISI) and has provided acquisition support at Space Systems Command (SSC) at the Los Angeles AFB during the past 20 years on several leading-edge satellite systems. Prior to his position at SSC, Charlton acquired more than 25 years of experience as a software engineer and in managing software projects in the commercial world, primarily in the fields of engineering and of law enforcement. Charlton received a BA in mathematics from California State University, Long Beach.

Abstract

The University of Southern California's Information Sciences Institute (USC/ISI), along with funding and the active support and engagement of the USAF and USSF, has undertaken a series of case studies focused on developing lessons learned and identifying best practices when agile and DevSecOps methodologies are introduced into the space-based software-only acquisition environment.

A major focus of this research is discovering challenges and exploring solutions to managing resources throughout the agile/DevSecOps system development process. Such challenges include managing dependencies on external and internal systems; staff loading and



specialties over the course of the program; the introduction of new capabilities; and the availability, collection, and analysis of performance metrics for improved situational awareness. It is important to efficiently manage a program as it progresses toward the later stages of the development effort. The stories and features with low resource demand typically are already completed by the later stages, leaving stories and features with high resource demand to be addressed late in the program.

Introduction

Funded by the USAF and then by the USSF, the University of Southern California's Information Sciences Institute (USC/ISI) has led a series of case studies focused on developing lessons learned and identifying best practices when agile and DevSecOps methodologies are introduced into the space-based software-only acquisition environment. Although much has been written in applying agile and DevSecOps to DoD acquisition programs, much of this research has taken a broad view of project management (e.g., Proctor & Daniels, 2020). The research described in this paper is focused on the day-to-day (in some cases almost hour-by-hour) operations of several agile/DevSecOps-based projects with a major focus on discovering challenges and exploring solutions to managing resources throughout the agile/DevSecOps system development process. Such challenges include managing dependencies on external and internal systems; staff loading and specialties over the course of the program; the introduction of new capabilities; and the availability, collection, and analysis of performance metrics for improved situational awareness. It is important to efficiently manage a program as it progresses toward the later stages of the development effort. The stories and features with low resource demand typically are already completed by the later stages, leaving stories and features with high resource demand to be addressed late in the program.

The seven-year effort (to date) involved three major projects that span a fully waterfall effort (serving as the baseline) to a predominantly agile/DevSecOps hybrid project. The focus of this paper is primarily on the predominantly agile/DevSecOps hybrid project that is currently about mid-way through scheduled completion. Initial observations and lessons learned include:

- Perform necessary upfront systems-engineering to help populate the initial agile project backlog, map features with compliance requirements, identify staff loading and specialties, and to identify dependencies as early as possible in the program.
- Establish early in the program a near operational environment with high-fidelity simulators for system-wide integration and testing.
- Plan sprints with sufficient margin to manage unexpected events such as emerging technology insertion or unexpectedly complex stories.
- Ensure that licensing, intellectual property (IP), accreditation, certification and other programmatic issues are resolved early in the program.
- Plan for on-board and continuous training to ensure a productive workforce.
- Be prepared to create customized performance tracking tools.

Funding Support

The material covered in this paper is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Office of the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) under Contract HQ003419D0003. The Systems Engineering Research Center (SERC) is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology.



Any views, opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the United States Department of Defense or ASD(R&E).

Multiple Projects

As reported in Orosz et al. (2022), the study covers three software-focused acquisition programs summarized in Table 1.

Table 1 List of projects in the study

Project	Description	Waterfall/ Agile	Comments
A	Added new capability to an existing space-based command and control application.	100% waterfall	178K Software lines of code. Serves as the baseline for the multi-case study. Project completed.
B	Added new capability to Project A.	50% agile/50% waterfall	128K Software lines of code. Similar code complexity as Project A. Project completed.
C	Add new capability to a system that itself is in the final stages of development.	70% agile/30% waterfall	150K Software lines of code (estimated). Similar code complexity as Projects A and B. The 30% waterfall portion is primarily in support of EVM (DAU, n.d.), CDRLs (AcqNotes, 2024a) and IMS (AcqNotes, 2024b) activities that are normally associated with a DoDI 5000.02 waterfall effort.

Although this paper is a summary of lessons learned and best practices for all three projects, the findings reported predominantly reflect the efforts from Project C. The development effort in Project C relies on a nuanced implementation of SAFe® (Scaled Agile Framework, 2024) agile process along with multiple DevSecOps pipelines. As noted in Table 1, the 30% waterfall portion is primarily in support of activities involved with the Integrated Master Schedule (IMS), Earn Value Management (EVM), and the completion of multiple documents listed in the Contract Data Requirements List (CDRL; AcqNotes, 2024a).

Methods

Project Immersion

To fully understand the resource challenges in agile/DevSecOps-based projects, members of the USC/ISI team fully immersed in each of the projects. USC/ISI researchers are members of multiple integrated project teams (IPTs; AcqNotes, 2024c) and participate in all events and activities associated within a space-based agile effort. This includes participating in sprint and program increment ceremonies, reviews, planning sessions, scrums, Kanbans, demonstrations, working groups, technical evaluations, trade studies, management meetings such as PMRs, and other activities associated with an agile-based project.

In addition, immersion includes interacting with prime contractors and their subcontractors as well as other government agencies that compose the overall (system of systems) enterprise. As part of the immersion, USC/ISI researchers collect and analyze project performance data and provide systems engineering subject matter expertise. The USC/ISI team also collects lessons learned from both the government and the prime contractor.



Data Collection

Data collection involves both observations (from day-to-day immersion activities) and the collection of project performance data which includes the daily tracking of completed story points, features, and system requirements, as well as progress toward minimum viable product (MVP) and minimum marketable product (MMP) milestones. Much of the performance data was collected via customized tools that extracted sprint and program increment (PI) data from the prime contractor's Jira® (Atlassian, n.d.) issue tracking system and the DOORS Next Generation (DNG; IBM, n.d.) requirements tracking systems.

The collected data was analyzed and compared against MVP and MMP milestones based on an Integrated Master Schedule (IMS). Performance tracking also included tracking the number of stories and features that are not completed within the assigned timebox and "spill over" from one sprint or PI to the next (or future sprint or PI). Observations include tracking workforce movements (on and off the project) and the availability of external resources to the project. As Project C matures, the USC/ISI team will be collecting bug and discrepancy reports (DRs) that result from the integration and testing component of the DevSecOps pipeline.

Results and Lessons Learned

Upfront Engineering

As noted in Orosz et al., (2023) it is important to perform the necessary upfront systems-engineering to help populate the initial agile project backlog, map features with compliance requirements, and identify the initial "scaffolding" of the system design. From a resource management perspective, undertaking initial systems engineering is also important to help identify staff loading and specialties, and to identify dependencies (e.g., high-fidelity simulators, algorithm development, or interfaces), as well as the availability of alternatives if those resources are not available (i.e., build a simulator). This is also the time to establish the necessary policies and practices that promote one or more of the eight aspects of systems engineering agility (Dove et al., 2023) such as identifying the types of performance data to collect to improve program situational awareness. As noted in Dove et al. (2023), such measures can greatly mitigate systems rework and other challenges as the program evolves.

It is important to note that this upfront systems-engineering effort is not about undertaking a detailed design (common in waterfall efforts); rather the effort involves making high-level design trades and defining the system's architecture down to "black box"-like descriptions (preferably in a MBSE application such as Cameo (CameoMagic Solution, n.d.)). These descriptions should define interfaces (internal and external) and performance windows.

An output of the upfront systems engineering effort is the initial population of the project backlog (list of features and associated sizes) – along with priorities. Project backlog priorities should focus on developing useful functionally (a tenet of agile), instead of advancing multiple MVPs at the same time. During the upfront engineering process, it is important to recognize that for most acquisition projects, particularly software-based efforts, there will come a point in the effort when a decision could be made to eliminate or defer capability. These decisions must be made early, or quickly once encountered, to avoid wasting development resources. Although in an agile environment, eliminating capabilities normally involves removing or reducing the priorities of work on the project backlog, the challenge is for programs where a portion of the capability to be removed or deferred has already been developed (i.e., developed code). In many of these DoD programs, there is



usually a security requirement (Nord et al., 2021; SD-Team, n.d.) that specifies that no code should be delivered in the operational system. In such cases, additional cost may be involved to rework the existing baseline to remove this dead-code. Although this situation is not uncommon in systems engineering and acquisition, failure to consider this situation when first developing the outlines of the system architecture and project backlog sequencing can lead to resource challenges later in the program. This challenge is particularly an issue for hybrid waterfall/agile programs where multiple MVPs are planned in parallel (e.g., to take advantage of available resources). If one or more MVPs are dropped from the program, the developed source code may have to be removed from the system.

Adequate upfront systems engineering is also important for projects where the workforce frequently changes, and the resulting “corporate knowledge” is lost. In this case, the underlying reasoning and rationale behind the creation of the initial feature definition and priority on the project backlog is lost too and often hampers future feature refinement activities. What typically happens on larger programs is the initial systems architecture, use cases, and project backlog are defined; however, backlog features lack detail (or high-level detail). These under-defined features are assigned to be worked in the future, long after the original team members involved in the original design have left the program. In such cases, considerable effort is required for the existing development team to “understand” the system or MVP – including the intent of the system requirements.

Not All Staff Skillsets Are Equal

In complex projects with evolving requirements (usually based on changing customer needs and priorities) or unavailable resources, the project backlog is usually subject to frequent changes. This usually involves a shuffling of features or stories within the project backlog with lower priority features/stories promoted in priority, completable with what is ready at the time, while higher priority features/stories are demoted in the project backlog and blocked until a specific resource is available. Often, certain requirements and their linked features (i.e., the work) require specific skill sets that may be unique to a handful of developers.

In many agile implementations, it is assumed by management that developers can easily jump from one feature to another. While a team of interchangeable skillset developers is a program manager’s goal, in practice this is rarely the case, and can result in situations where a sprint team has staff, often experienced and expensive, that are not familiar with the current high-priority features at the top of the project backlog. Also, newer staff may not have the requisite experience with a highly technical area of the system. Adding new personnel often results in project delays as the prime contractor or government must find and hire a developer with the required skillset. In many cases, it can take up to a year – from the initial position announcement (the req) to the day the individual is hired, and this does not include any training that may need to be included before the new hire is productive.

To reduce the impact to the project development efforts from key personnel transitioning on and off a project, there are a few steps a program can take.

- Implement a continuous training program to help quickly ramp up new staff and help keep existing staff up to date on the project and on evolving technologies and system acquisition processes.
- Rely on MBSE and other digital engineering processes and applications to capture the decision-making behind the system design. It is not enough to capture the design of the system; it is also important to capture the decision-making behind the system design.



Near Operational Test Environments

Most DoD acquisition programs are quite complex and consist of a system of systems configuration involving both internal and external elements (i.e., systems and subsystems). To adequately test various elements requires access to all elements of the enterprise. This is particularly true in operations that involve DevSecOps pipelines that frequently (daily, weekly, etc.) undertake integration and testing runs to ensure content recently added to the system does not “break” existing development content. In addition, to sell off a system requirement (i.e., confirm that the system meets the specifications of the requirement), the system must be executed in the actual operating environment (which is almost impossible) or in a near operational environment that closely simulates the actual operating environment.

The challenge, as noted in Orosz et al. (2023) is that one or more of these internal and external elements may not be available (either in the form of the actual system or as a simulator). The element may currently be under development (often by a third-party vendor) or is in use by other programs or the operating environment. This can result in program schedule slippage or delay due to the lack of an adequate integration and test environment. These delays also often result in key personnel with high-demand skills being pulled to support other programs with no guarantee of returning to the program – necessitating the need to hire replacements, and thus adding an additional source of schedule delay.

This necessitates the need for high-fidelity simulators and near-operational environments much earlier in an agile program than in waterfall. Due to the fast-paced nature of agile/DevSecOps, a program cannot wait for these systems to materialize. Simulators and near-operational environments need to be developed as soon as possible, as enablers for system integration, testing, and ultimately rapid delivery of new functionality. It is recommended that this criterion be part of the contract language and that contract performance be linked to the completion of these systems. In addition, the project backlog and MVP/MMP sequence need to reflect the availability of the simulators/near-operational environment to help drive the development of these elements. Doing this will also allow the program to complete stories/features when the appropriate integration and test environment is available (a form of risk management). Ideally, these simulators should be part of the system model (i.e., MBSE).

Sprint Margins

As noted in Orosz et al. (2023), there is a tendency by developers to completely fill a sprint or program increment timebox with work (e.g., features/stories) leaving no margin for unexpected work, unexpected code complexity, or unplanned staff challenges. If margin is not present, there is an increased risk of stories/features slipping into the next development interval (i.e., sprint or program increment) causing the schedule to stretch/extend. A continuing cascade of slipped stories/features will cause a bow wave of work to emerge in the project backlog, resulting in some work being addressed later, possibly months or even years into the future. Such delays may require additional personnel to be hired, or worse, there is a risk that key personnel with the necessary skillsets will be “loaned out.” While the program waits for the delayed work to begin, there is a possibility of the loaned personnel never returning to the project. This can be a particular challenge where subcontractors must leave a project when a contract ends, and they are no longer available when the delayed work can finally be addressed.

Licensing and Other IP Considerations

Also as noted in Orosz et al. (2023), it is critically important to address licensing and Intellectual Property (IP) considerations up front prior to the start of system development. It



is surprising how easy it is to underestimate the amount of time required to address IP and licensing issues. Although such issues are typically part of a vendor's proposal, often there is insufficient understanding of the full scope of the project, which often leads to a bill of material (BOM) being inadequately defined. When new licensing and IP needs are identified later in the development process, the delays in negotiating terms can greatly impact project performance. Although it is impossible to fully understand every need of an agile program upfront, considerable "pain" can be avoided in the future if some upfront engineering is undertaken (as already discussed).

Also be aware that some third-party vendor solutions may be A) incompatible with the current or evolving system and/or B) foreign developed and restricted from use on the project due to the classified nature of the environment. In addition, there are also security issues that need to be addressed when introducing new tools and IP into a system. For example, in classified programs, time needs to be allotted to the screening of applications for security and safety reasons. All these delays can result in the development schedule shifting to the right, putting stress on costs and on the available workforce.

Costing

There are many costing challenges in agile-based acquisition projects (e.g., EVM lagging the project backlog, etc.), but a particularly challenging area is in the use of T-shirt sizing, used in some agile projects for gauging capacity, but then extended to estimate labor hours and cost for a particular task. Costing using T-shirt sizes can be misleading as the method is typically based on a "one-size" fits all approach to estimating labor hours. This is particularly a challenge in programs where the T-shirt size approach includes development, integration & testing, and discrepancy report (DR) work off an all-in-one quote.

Often, a contractor will estimate the effort using a range of T-shirt sizes: extra-small, small, medium, large, extra-large, and so on. These sizes often cover a range of hours (e.g., extra-small may involve tasks that range from 1–300 hours to complete, a large T-shirt may range from 1,000–3,000 hours, etc.). These T-shirt sizes are usually based on the proposing contractor's experience on similar projects. For a new project, these estimates are probably suitable as there are many unknowns and so relying on the contractor's best judgment is reasonable. The challenge can emerge when new capability is inserted into the project backlog.

Presumably, as a system is developed, the contractor (and the government) will have a better understanding of what effort is required to complete tasks of various complexities. As such, the contractor will have a better understanding of what an extra-small T-shirt size of effort really involves. When new capability is added to a project (via a Request for Change (RFC)), the T-shirt sizes quoted rarely reflect experience gained on actual costs. This is particularly a challenge when T-shirt sizes include development, integration and testing, and DR work-off.

In addition, when RFCs are placed on contract, often the capability added is similar to capability that has yet to be developed on the original contract. In some cases, integration and testing could cover multiple capabilities – existing and new RFC capabilities thus reducing the workforce costs for undertaking individual I&T efforts for each individual capability.

If T-shirt sizing is used, it is recommended that an estimation system should be maintained by updating the capability T-shirt sizes when "as run" information becomes available.



Customized Performance Tracking Tools

As noted in Orosz et al. (2023), program management will need to be prepared to develop performance tracking tools. Although there are third-party performance tracking tools, many of these tools cannot be used due to licensing or import control issues (i.e., foreign owned applications). In other cases, existing performance tracking tools, particularly those that are waterfall oriented (such as EVM and IMS applications) present data that often lags the actual project performance by months. By the time a problem is recognized using these tools, it is often too late for corrective action, resulting in significant cost and schedule delays.

Developing or customizing performance tools typically involves leveraging a program's existing data sources. For example, in agile-based projects, Jira is often used to track day-to-day performance of the project backlog, DNG is used for requirements, and MS Project the IMS (tied into EVM). Readily available applications, like MS Excel, Visual Basic for Applications, and Python, can be used to create customized tools tailored to produce specific performance-tracking information, which can be created from the fusion of these data sources. In many cases, these tools can be developed and applied across multiple programs.

For Project C, several tools were developed and integrated to provide the following performance metrics.

- Intra-program historical information: features and PI assignments, story and sprint assignments, feature and MVP/MMP assignments, and status changes (Figures 1 through 4).
- Identification of features mapped to compliance requirements (Figure 5).
- If a ticket management system (e.g., Jira) and an IMS are used, then a tool is needed to synchronize data or determine if the systems are showing different entries.

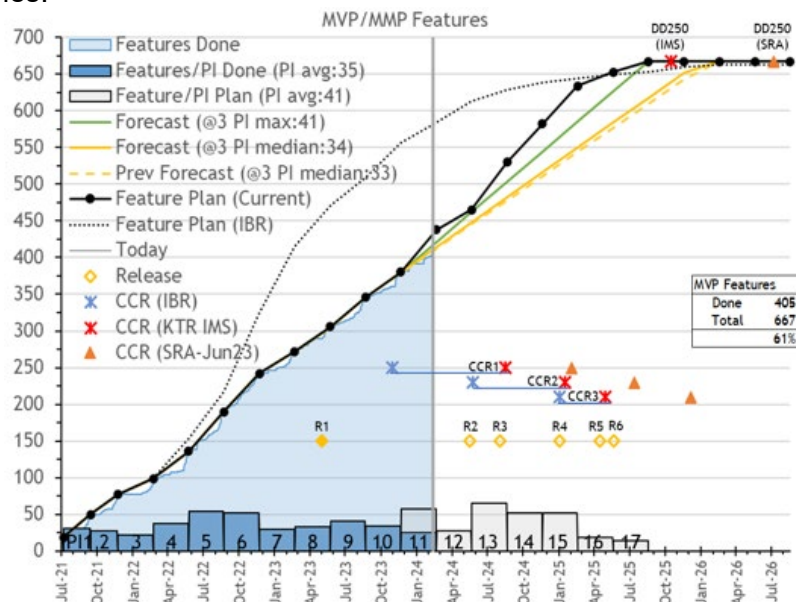


Figure 1 – MVP/MMP Plan and Progress Chart. (Orosz et al., 2023b)

The graphic in Figure 1 shows the progress the project is making toward completing features linked to assigned MVPs and MMPs (i.e., a “burn down” chart). The dotted black line is the original feature to Program Increment (PI) allocation plan created at the time of

the program's Integrated Baseline Review (IBR). The solid black line is the current cumulative plan for features assigned to PIs and becomes the "as run" when PIs complete. The blue fill area shows the cumulative completion of features. The green and yellow lines show forecast completions at maximum and median rates, and as a comparison the previous PI's median forecast is also displayed. A breakout of the individual PIs (features planned and done) is along the bottom of the graphs. The milestones show Critical Capability Releases (collection of MVPs and MMPs releases) from the IBR, latest Schedule Risk Assessment (SRA), and contractor's Integrated Master Schedule; and incremental software releases (collection of MVPs/MMPs). What is not shown in Figure 1 is current and planned workforce (available but removed as sensitive information). Of note is that the contractor FTE (Full Time Equivalent) count remained relatively steady (+/- 5%) from PI 4 through PI 11.

Figure 1 shows that if the project continues at the current "burn up" rate, the development will not be complete until what looks like PI19. The original plan called for the bulk of the features to be completed by PI 13 with "clean-up" features to follow.

Feature Team	Key	Status	Δ Date	Points	%	MVP/ MMP	PI History	MVP History	Linked Rqmts (DNG)	PI	Issue Type	Updated	
TMC	DEV2C-8843	F	In Progress	28-Nov-23	34 38	89	(6-b)	(-06),PI10(2023-03-26),PI11(2023-07-11)	(4-a) 2022-08-09,(6-b) 2023-10-19	RQ4342	11	Feature	02-Feb-24 13:23
SIM	DEV2C-477	F	In Progress	07-Sep-23	12 18	67	(3-b)	(-27),PI10(2023-04-11),PI11(2023-11-22)	08-29,(4-c) 2022-02-05,(3-b) 2022-02-11	RQ3279, RQ4439	11	Feature	02-Feb-24 13:23
SIM	DEV2-8386	F	In Progress	26-Oct-23	23 31	74	(4-c)	(-27),PI10(2023-04-11),PI11(2023-05-04)	Non-M 2022-07-06,(4-c) 2023-01-18	RQ4386	11	Feature	02-Feb-24 13:23
SIM	DEV2-8385	F	Done	15-Dec-23	9 9	100	(4-c)	(-13),PI10(2023-04-11),PI11(2023-07-11)	Non-M 2022-07-06,(4-c) 2023-01-18		11	Feature	02-Feb-24 13:23
SIM	DEV2-813	F	Done	01-Feb-24	33 33	100	(3-b)	(-13),PI10(2023-08-23),PI11(2023-11-22)	(3-b) 2021-08-29	RQ4380, RQ4381, RQ4384, RQ4385, RQ4386	11	Feature	01-Feb-24 18:48
SIM	DEV2-1675	F	Done	01-Feb-24	28 28	100	(3-b)	(-22),PI10(2023-08-23),PI11(2023-11-22)	(3-b) 2021-08-29	RQ2750, RQ4398	11	Feature	01-Feb-24 18:43
TMC	DEV2-554	F	In Progress	10-Apr-23	44 47	94	(5-a)	(-12),PI10(2023-04-10),PI11(2023-07-10)	(5-a) 2021-08-29	RQ1008, RQ1235, RQ370, RQ4050, RQ4051	11	Feature	01-Feb-24 16:03
SFG	DEV2C-4430	F	In Review	01-Feb-24	0 1		(6-c)	(-11),PI12(2023-01-04),PI11(2023-07-07)	(3-d) 2021-10-04,(6-c) 2022-01-10		11	Feature	01-Feb-24 11:45
SFG	DEV2C-4429	F	In Review	01-Feb-24	0 1		(6-c)	(-06),PI10(2023-01-04),PI11(2023-07-10)	(3-d) 2021-10-08,(6-c) 2022-01-10		11	Feature	01-Feb-24 11:44
TMB	DEV2C-13770	F	In Progress	28-Nov-23	25 41	61	(6-b)	PI11(2023-10-10)	(4-a) 2023-10-10,(6-b) 2023-10-12		11	Feature	01-Feb-24 11:04
TMB	DEV2C-2268	F	In Review	01-Feb-24	16 16	100	(5-a)	(-10),PI12(2023-09-14),PI11(2023-10-09)	(5-a) 2021-08-29		11	Feature	01-Feb-24 11:01
TMA	DEV2C-1551	F	In Progress	20-Nov-23	56 72	78	(4-a)	(-18),PI10(2023-02-06),PI11(2023-07-12)	(4-a) 2021-10-29		11	Feature	01-Feb-24 10:13
MET	DEV2C-13005	F	In Progress	28-Nov-23	25 37	68	Non-M	PI11(2023-09-19)	Non-M 2023-09-19		11	Feature	01-Feb-24 10:13
MET	DEV2C-13086	F	In Progress	27-Nov-23	52 76	68	Non-M	PI11(2023-09-21)	Non-M 2023-09-21		11	Feature	01-Feb-24 10:13

Figure 2 – Status Board of Features in Current PI

The graphic in Figure 2 shows a status board of daily collected Jira data for status, status change date, assigned cumulative story points, percent complete, and assigned MVP/MMP (orange columns) filtered for features in the current program increment (ending 20 Feb 24, column removed for brevity) and sorted by update date (green columns). Jira exports, collected daily, allow for off-line analysis such as tracking a feature's assigned PI or MVP and change date (left and center blue columns). Off-line analysis tools also enable data fusion such as the association of requirements information from DNG and features maintained in Jira (right blue column).

While the prime contractor's Jira platform natively contains this information, it is only available while logged into platform. Collection of data for off-line display and analysis enables the government program management team to have an independent historical record.

Feature Team	Key	Status	Δ Date	Points	%	MVP/ MM	Milestone ID	IMS Start	IMS Finish	IMS&PI Matcl	PI	Issue Type	Updated	
TMC	DEV2-8843	F	In Progress	28-Nov-23	34 38	89	(6-b)	DEV2.4241	04-Dec-23	13-Feb-24		11	Feature	02-Feb-24 13:23
SIM	DEV2-477	F	In Progress	07-Sep-23	12 18	67	(3-b)	DEV2.1975	13-Sep-23	09-Feb-24		11	Feature	02-Feb-24 13:23
SIM	DEV2-8386	F	In Progress	26-Oct-23	23 31	74	(4-c)	DEV2.3686	25-Oct-23	22-Jan-24		11	Feature	02-Feb-24 13:23
SIM	DEV2-8385	F	Done	15-Dec-23	9 9	100	(4-c)	DEV2.3685	25-Oct-23	15-Dec-23		11	Feature	02-Feb-24 13:23
SIM	DEV2-813	F	Done	01-Feb-24	33 33	100	(3-b)	DEV2.2717	10-Jul-23	08-Feb-24		11	Feature	01-Feb-24 18:48
SIM	DEV2-1675	F	Done	01-Feb-24	28 28	100	(3-b)	DEV2.1969	23-Nov-22	08-Feb-24		11	Feature	01-Feb-24 18:43
TMC	DEV2-554	F	In Progress	10-Apr-23	44 47	94	(5-a)	DEV2.3791	10-Apr-23	13-Feb-24		11	Feature	01-Feb-24 16:03
SFG	DEV2-4430	F	In Review	01-Feb-24	0 1		(6-c)	DEV2.3343	03-Jan-24	13-Feb-24		11	Feature	01-Feb-24 11:45
SFG	DEV2-4429	F	In Review	01-Feb-24	0 1		(6-c)	DEV2.3442	22-Nov-23	13-Feb-24		11	Feature	01-Feb-24 11:44
TMB	DEV2-13770	F	In Progress	28-Nov-23	25 41	61	(6-b)	DEV2.4265	14-Nov-23	05-Feb-24		11	Feature	01-Feb-24 11:04
TMB	DEV2-2268	F	In Review	01-Feb-24	16 16	100	(5-a)	DEV2.2858	22-Nov-23	13-Feb-24		11	Feature	01-Feb-24 11:01
TMA	DEV2-1551	F	In Progress	20-Nov-23	56 72	78	(4-a)	DEV2.3745	27-Nov-23	12-Apr-24		11	Feature	01-Feb-24 10:13
MET	DEV2-13005	F	In Progress	28-Nov-23	25 37	68	Non-M	DEV2.4273	22-Nov-23	13-Feb-24		11	Feature	01-Feb-24 10:13
MET	DEV2-13086	F	In Progress	27-Nov-23	52 76	68	Non-M	DEV2.4287	22-Nov-23	13-Feb-24		11	Feature	01-Feb-24 10:13

Figure 3 – Status Board of Features with IMS Flags



Figure 3 shows the same PI features as before, with monthly IMS data incorporated and the results of an automated “IMS & PI Match” analysis displayed – IMS Start and Finish dates are compared with PI start and finish dates to flag if the IMS activity occurs within or outside the planned PI timebox. In this figure many features began before the current PI (unfinished from a prior PI); however, DEVC2-1551 (third from last) is scheduled to finish after the current PI.

Feature Team	Key	Status	Δ Date	Points	%	MVP/MM	Sprint History		PI	Issue Type	Updated
SIM	DEVC2-14735	S	In Review	05-Feb-24	3	100	(3-b)	PI11-SP4(2024-01-24)	11	Story	05-Feb-24 08:09
SIM	DEVC2-14728	S	In Review	04-Feb-24	1	100	(4-c)	PI11-SP4(2024-01-23)	11	Story	04-Feb-24 22:10
TRN	DEVC2-13645	S	Done	02-Feb-24	3	100	Non-M	PI11-SP4(2023-10-09)	11	Story	02-Feb-24 16:26
SIM	DEVC2-14724	S	Done	02-Feb-24	1	100	(4-c)	PI11-SP4(2024-01-23)	11	Story	02-Feb-24 14:31
TMB	DEVC2-10961	S	In Review	02-Feb-24	3	100	Non-M	PI12-SP2(2023-10-09),PI11-SP4(2024-01-09)	11	Story	02-Feb-24 12:01
TMB	DEVC2-10756	S	In Progress	02-Feb-24	4		Non-M	PI12-SP3(2023-10-09),PI11-SP4(2024-01-21)	11	Story	02-Feb-24 12:01
SIM	DEVC2-14729	S	In Progress	29-Jan-24	3		(4-c)	PI11-SP4(2024-01-23)	11	Story	02-Feb-24 11:17
SIM	DEVC2-14002	S	In Review	02-Feb-24	1	100	Non-M	PI11-SP4(2023-11-08)	11	Story	02-Feb-24 10:55
TMA	DEVC2-13472	S	In Progress	02-Feb-24	1		(4-a)	PI11-SP4(2023-10-10)	11	Story	02-Feb-24 10:46
TMA	DEVC2-13474	S	In Progress	02-Feb-24	1		(4-a)	PI11-SP4(2023-10-10)	11	Story	02-Feb-24 10:46
TMA	DEVC2-13473	S	In Progress	02-Feb-24	1		(4-a)	PI11-SP4(2023-10-10)	11	Story	02-Feb-24 10:46
TMA	DEVC2-13470	S	In Progress	02-Feb-24	1		(4-a)	PI11-SP4(2023-10-10)	11	Story	02-Feb-24 10:46
TMA	DEVC2-13468	S	In Progress	02-Feb-24	1		(4-a)	PI11-SP4(2023-10-10)	11	Story	02-Feb-24 10:46
TMB	DEVC2-11377	S	In Progress	02-Feb-24	1		Non-M	PI10-SP3(2023-07-07),PI11-SP4(2023-10-09)	11	Story	02-Feb-24 10:40

Figure 4 – Status Board of Stories in Current Sprint

Figure 4 shows a status board of collected Jira data (orange columns) filtered for stories in the current sprint and sorted by update date (green columns). Similar to tracking a feature’s PI history, a story’s assigned Sprint is displayed with change dates (blue columns). This view shows two stories that were pulled early from PI 12 into PI 11; the last story was previously assigned to PI 10 – Sprint 3, and later reassigned to PI 11 – Sprint 4.

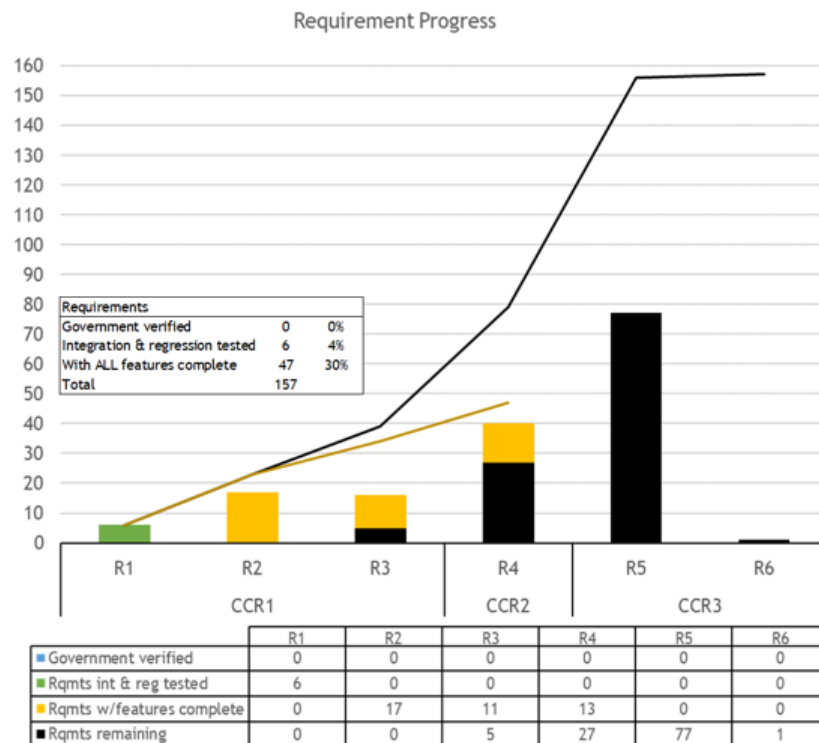


Figure 5 – Requirements Completed Toward Critical Release Chart. (Orosz et al., 2023b)

The chart in Figure 5 shows the requirement completion plan and to-date progress. Each release (R1, R2, ... R6) represent one or more MVPs/MMPs in the project. Critical Capability Releases (CCR1, CCR2 and CCR3) consist of multiple releases. For each planned release (e.g., R1, R2, etc.) a histogram shows how many requirements are assigned, requirements that have been verified by the government (blue – zero so far on Project C), requirements whose features have been completed and individually verified/tested (green), requirements with completed features but not yet individually verified by the government (gold) and requirements that have features that have yet to be completed (black).

Next Steps

As of the writing of this paper, Project C is 30 months into a 51-month effort. Software development has been underway for roughly 18 months, and the initial MMP deliverables are several months away. Going forward, the USC/ISI project team is focused on collecting and analyzing performance data such as bugs/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 particular 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. The agile environment is focused on delivering value rather than the traditional waterfall metrics, such as software lines of code. For example, a key area of research is 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.

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PANEL 3. ACQUISITION WORKFORCE FROM THE SERVICE DIRECTORS, ACQUISITION CAREER/TALENT MANAGEMENT

Wednesday, May 8, 2024	
10:30 a.m. – 11:45 a.m.	<p>Chair: James P. Woolsey, President, Defense Acquisition University</p> <p>Panelists:</p> <p>Ronald R. Richardson, Jr., Director, U.S. Army Acquisition Support Center and Director, Acquisition Career Management (DACM)</p> <p>Marianne Lyons, U.S. Navy Director, Acquisition Talent Management (DATM)</p> <p>Ruben Rios, U.S. Air Force Director, Acquisition Career Management (DACM)</p> <p>Otis Lincoln, 4th Estate Director Acquisition Career Management (DACM)</p>

James P. Woolsey—serves as the President of Defense Acquisition University (DAU), a position he has held since January 2014. In this role, Mr. Woolsey leads one of the largest corporate universities in the world-responsible for the training and talent development of roughly 186,000 Department of Defense (DoD) employees. DAU's students represent a cross-section of the Department's Acquisition functions, including contracting, business, engineering, logistics, and program management. For the past several years, Mr. Woolsey has led DAU's transformation to a modern learning platform that employs the full range of training modes and that empowers the workforce to tailor learning to their current job needs and future career goals.

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 required for a small staff to quantitatively assess the progress of all Major Defense Acquisition Programs. These analyses produced improved portfolio visibility for the Under Secretary of Defense for Acquisition, Technology and Logistics, and were also used to investigate specific areas of interest as programs moved through the acquisition life cycle.

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-767 A 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 has a bachelor of science in aerospace engineering from Virginia Polytechnic Institute and State University, a master's in business administration from George Mason University and was a Fellow in the Massachusetts Institute of Technology Seminar XXI on International Relations.

Ronald R. Richardson— is the Director of the U.S. Army Acquisition Support Center (USAASC) and the Army Director of Acquisition Career Management (DACM). In this role, he oversees the Army Acquisition Workforce (AAW) and supports the Army's Program Executive Offices in the areas of human resources, resource management, program structure, acquisition information management and program protection.



Mr. Richardson has 40 years of medical, information and weapon system acquisition experience in a multitude of Military, Civilian and Private Sector positions. Before coming to USAASC, he was the Director of Acquisition and Operations for Program Executive Office (PEO) Soldier. Prior to that, he was the Deputy Project Manager for the DOD Healthcare Management System Modernization (DHMSM®) Program, a \$14B Major Automated Information System (MAIS) acquisition to replace the DOD legacy Electronic Health Record (EHR) with MHS GENESIS.

Mr. Richardson received his M.S. in Biomedical Engineering from Duke University, and his M.S. in National Resource Strategy from the Industrial College of the Armed Forces. He is also a graduate of the U.S. Army Command and General Staff College. He is the recipient of the Superior Civilian Service Medal (3), the Meritorious Civilian Service Medal (2), the Civilian Service Achievement Medal, the Army Staff Identification Badge and the Order of Military Medical Merit (O2M3). Mr. Richardson holds multiple professional memberships and certifications, including Advanced Defense Acquisition Workforce Improvement Act (DAWIA) Certification in Program Management (previously Level III).

Marianne Lyons—is the Department of the Navy Director, Acquisition Talent Management (DATM). She is the Navy and Marine Corps' lead for the professional development and management of over 54,000 civilian and military acquisition workforce members. Ms. Lyons is the chief advisor to the Assistant Secretary of the Navy for Research, Development, and Acquisition, and guides all matters relating to initiatives and other strategic efforts that improve the acquisition workforce through education, training, and career development. She began her career with the Navy in 1989 as a naval architect and progressed to ship design management. In 2003, she transitioned to Program Management and later became an Action Officer at the Office of DASN Ships for the Auxiliary and Amphibious Ships portfolio. Prior to the DATM she was the Deputy Program Manager for the LPD 17 Amphibious Transport Dock Ship Program in PEO Ships. Ms. Lyons has a Civil Engineering degree from Virginia Tech and a Masters in Business from the Florida Institute of Technology. She is PM Advanced and ETM Practitioner DAWIA certified.

Ruben Rios—is the Director of Acquisition Career Management Directorate, Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics (SAF/AQH). Mr. Rios is responsible for the integrated management of the acquisition workforce across all functional areas. He provides acquisition human resources policy and strategic planning while managing the training and development of civilian and military acquisition personnel across the department's acquisition enterprise. Mr. Rios is also designated as the Career Field Manager for both military and civilian Scientists, Engineers, and Acquisition Program Managers. His team also provides personnel management services to the SAF/AQ Headquarters Staff and is the Department of the Air Force's Acquisition Demo Program Management Office.

Otis Lincoln—serves as the Director, Acquisition Career Management for the 4th Estate (31 defense agencies/field activities) with oversight of statutory training, professional credentialing, continuous learning, and career development for more than 31,000+ acquisition workforce members. He entered federal since in 2009 as a Contract Specialist within the Office of the Chief Financial Officer (CFO) of the Defense Intelligence Agency (DIA). After serving as a Contract Specialist and a warranted Contracting Officer on several procurements supporting multiple Directorates across DIA, he continued to expand his aperture within the acquisition community moving into the project and program management realm. In multiple capacities, he was responsible for the successful planning and execution of several multi-million-dollar programs that included increasing acquisition exposure to industry, training and career development of the agency's acquisition workforce. He also played an integral part in the hiring and placement of new acquisition workforce members, setting career paths in the Finance and Acquisition field. Mr. Lincoln utilized his Defense Acquisition Workforce Improvement Act (DAWIA) expertise in support of the Navy Systems Management Activity (NSMA) having served as their DAWIA Program Director overseeing and managing their workforce by expanding their training, certification, and career development. Following his tenure at NSMA, Mr. Lincoln assumed a senior leadership position as a Section Chief in the Contracting Office within CFO supporting the Mission Service's and Command Element's global procurement requirements.



PANEL 4. LESSONS IN SHIPBUILDING: PAST, PRESENT, AND FUTURE

Wednesday, May 8, 2024	
10:30 a.m. – 11:45 a.m.	<p>Chair: Jill J. Boward, Executive Director, Combatants Program Executive Office, Ships</p> <p><i>SSBN Columbia Class Submarine Case Study</i> Robert Mortlock – Naval Postgraduate School</p> <p><i>Industrial Assessment Directorate: Impact of the Navy's 30-Year Shipbuilding Plan on US Industrial Base</i> Shelley Gallup – Naval Postgraduate School</p> <p><i>Ship Shaping: How Congress and Industry Influenced U.S. Naval Acquisitions from 1933-1938</i> Henry Carroll - CSIS</p>

Jill J. Boward—serves as the Executive Director, Combatants, Program Executive Office, Ships where she provides executive leadership in complex, new construction shipbuilding programs defining the 21st century surface combatant fleet. Ms. Boward's responsibilities span acquisition efforts to design, develop, engineer, produce and deliver the Navy's current and future combatants. Program offices within this portfolio include: the DDG 51 program (PMS 400D), the DDG 1000 program (PMS 500), the DDG(X) program (PMS 460), the Government Equipment Management (GEM) office, as well as the Team Ships Corporate Operations office. Additionally, she serves as a co-champion of the NAVSEA Journey Level Leadership Program.

Ms. Boward was appointed to the Senior Executive Service in September 2015. As a senior executive, she also served as the Executive Director, Program Executive Office for Integrated Warfare Systems (PEO IWS) from 2019 to 2021 and was responsible for an organization of over 400 civilian and military personnel and 128 programs (combat systems, weapons, radars, and related international and foreign military sales). From 2015 to 2019, she served as the Director of the Naval Sea Systems Command's Cost Engineering and Industrial Analysis Group (NAVSEA 05C), and as the Navy's competency lead for cost estimating, providing cost estimating and industrial base analyses for all shipbuilding, weapon and combat systems for submarines, carriers, and surface ships.

Prior to her SES appointment, she served as the Director for Amphibious and Auxiliary Ship Programs for the Deputy Assistant Secretary of the Navy, Ships, supporting the Assistant Secretary of the Navy for Research, Development and Acquisition, from 2011 to 2015. She spent the majority of her career within NAVSEA 05C, serving in various positions prior to her 2015-2019 assignment as the Director, to include: Deputy Director; Industrial Planning and Analysis Division Director; Surface Combatants Division Director; DDG 51 cost team leader and analyst; and combat and weapon system cost analyst. She also worked as a COR and the Staff Engineer for the Contracts Management Division in the U.S. Army Garrison - Directorate of Engineering and Housing, Republic of Panama. She started her career as a Naval Acquisition Development Program cost analysis intern at NAVSEA.

She earned both a Bachelor of Science in Industrial Engineering and Operations Research, and a Master of Engineering Administration from Virginia Tech, and a Master of Science in National Resource Strategy from the Industrial College of the Armed Forces, National Defense University.



SSBN Columbia Class Submarine Case Study

Dr. Robert F. Mortlock, COL, USA (Ret.)—is a professor of the practice and Associate Chair for Acquisition Sciences for the Department of Defense Management at the Naval Postgraduate School in Monterey, CA. He holds a PhD in chemical engineering from the University of California, Berkeley, an MBA from Webster University, an MS in national resource strategy from ICAF, and a BS in chemical engineering from Lehigh University. [rfmortlo@nps.edu]

Benjamin Field, LCDR, USN— is the Engineer Officer on USS Wyoming (SSBN 742) (Blue). He holds an MS in Program Management from the Naval Postgraduate School and a BA in Business and Economics from the Virginia Military Institute. [fieldbr@wyoming-blue.navy.mil]

Abstract

This case study is written to produce an active learning environment to increase the capability of acquisition/program management professionals and senior leaders regarding program planning, decision-making, and affordability. Ballistic missile submarines (SSBNs) are a stealthy, survivable launch platform that contributes to strategic deterrence. Ohio-class SSBNs, which have filled the role of sea-based deterrence for the last 40 years, are nearing the end of their planned service life. To prevent a gap in nuclear deterrent capability, the successor to the Ohio-class, the Columbia-class, must be built to meet the Navy initial operating date requirements. However, the Columbia-class submarine is experiencing setbacks due to multiple issues with requirements, software development, funding, industrial base capacity and capability, and quality assurance with shipyards and manufacturers. This case study analyzes the Columbia-class submarine acquisition program and the path forward for the Navy.

Keywords: ship building, affordability, decision-making, critical thinking, project management

Introduction

Admiral (ADM) Michael Gilday, Chief of Naval Operations (CNO), sat at his desk facing a difficult problem in the first quarter of 2022. As the CNO, Admiral (ADM) Gilday is responsible to the Secretary of the Navy (SECNAV) for the “command, utilization of resources, and operating efficiency of the operating forces of the Navy” (United States Navy, n.d.). In carrying out his charge, the CNO is consistently facing numerous difficult challenges for the Navy. However, one challenge stood out this morning: ensuring the timely delivery of the Columbia-class submarine. He had just gotten off a phone call with Rear Admiral (RADM) Pappano, Program Executive Officer (PEO) Strategic Submarines, who was responsible for the Columbia-class submarine program. RADM Pappano called to inform the CNO of the release of the Congressional Research Service (CRS) report on the Columbia-class submarine and to provide his viewpoint on the most pressing obstacles to delivering the future USS Columbia on time. The CNO knew the success of the program was a matter of national security. Failing to deliver the Columbia-class submarine on time would result in a nuclear strategic deterrence gap for the United States. However, with little schedule margin remaining and additional pressures to minimize program cost growth, the path moving forward was unclear. Were adjustments necessary for the cost, schedule, and performance requirements of the approved acquisition program baseline (APB)?

Background

Deep under the ocean’s waves and across the globe, U.S. Navy nuclear ballistic missile submarines (SSBN) are on silent patrol performing the nation’s “highest priority mission”—strategic deterrence (Lopez, 2021). This mission is conducted by Ohio-class submarines. Each Ohio-class SSBN, one of which is depicted in Figure 1, carries up to 24 Trident II submarine-launched ballistic missiles (SLBMs) and serves to dissuade U.S.



adversaries from conducting a nuclear attack for fear of retaliation from an un-locatable source (Submarine Industrial Base Council, 2017). After decades of service, the Ohio-class SSBNs are beginning to reach the end of their already extended 42-year service life (Eckstein, 2020b, para. 1). To continue the legacy of strategic deterrence, the Department of Defense (DOD) is developing a replacement for the Ohio-class Submarine: the Columbia-class submarines.



Figure 1. USS Wyoming (SSBN 742). (Rebarich, 2008)

The Columbia-class SSBNs, the named successor to the Ohio-class SSBNs and depicted in Figure 2, are under construction. The first SSBN in the Columbia class, the USS Columbia, is set to be completed by 2030 and ready to execute its first strategic deterrence patrol in 2031 (Government Accountability Office [GAO], 2021, p. 1). According to ADM Gilday, “[the] Columbia-class is our number one acquisition priority” and “these submarines need to be delivered on time, on budget, and ready for the fight—we have no margin to fall behind” (U.S. Navy Office of Information, 2022). However, program delays for the USS Columbia threaten its on-time scheduled delivery. If USS Columbia is not delivered on time and conducting its first patrol by 2031, the United States faces the unpalatable outcome of having an insufficient amount of SSBNs to fully perform the strategic deterrence mission at sea.



Figure 2. Artist's rendering of the future Columbia-class ballistic missile submarine. (U.S. Department of Defense, n.d.)

Strategic Deterrence

SSBNs play an integral role in strategic deterrence. Fourteen SSBNs currently patrol the world's oceans and provide an undetectable launch platform, discouraging the worldwide use of nuclear weapons by U.S. adversaries. As of 2022, nine countries had access to nuclear weapons (Federation of American Scientists, n.d., para. 1). In addition to the United States, the United Kingdom (U.K.), France, Israel, Pakistan, India, China, Russia,



and North Korea contain nuclear weapon stockpiles that, in total, amount to approximately 9,400 warheads that are ready for military use (Federation of American Scientists, n.d., para. 5). The detonation of a nuclear warhead has a destructive power that can unleash a fatal level of radiation, a catastrophic pressure wave that can topple buildings, a superheated fireball and accompanying thermal flash capable of creating a sweeping firestorm, and a large amount of damaging, long-lasting nuclear fallout that will remain in the days, weeks, and years following the explosion (Wolfson & Dalnoki-Veress, 2022). However, despite such a large number of nuclear weapons available for use, no strategic nuclear weapons have been used against another country in or outside of warfare since the bombing of Hiroshima and Nagasaki at the end of World War II (United Nations Office for Disarmament Affairs, 2021, para. 1). The most likely reason for this enduring nuclear peace is strategic deterrence.

The aim of strategic deterrence, the “highest priority mission of the Department of Defense,” is to dissuade another country from launching nuclear weapons at the United States out of fear of a retaliatory strike (Lopez, 2021). The United States uses a “nuclear triad” to provide a credible and capable source of strategic deterrence. The nuclear triad is composed of three components: air, land, and sea-based deterrence. Air-based deterrence is accomplished by the U.S. Air Force by outfitting airframes with nuclear weapons. More specifically, the Air Force B-52 Stratofortress bombers and B-2 Spirit bombers carry gravity-based nuclear bombs, and the F-15E Strike Eagle fighters carry nuclear cruise missiles (OSD Nuclear and Missile Defense Policy, 2020, p. 7). The Air Force is also responsible for land-based strategic deterrence. Minuteman III intercontinental ballistic missiles (ICBMs) are “spread out over 400 hardened, underground silos” (OSD Nuclear and Missile Defense Policy, 2020, p. 3), ready to strike. Sea-based deterrence is the responsibility of the SSBNs of the U.S. Navy.

Each portion of the nuclear triad offers its own unique advantages, and together they establish a formidable source of strategic deterrence. The land-based strategic deterrence afforded by U.S. ICBMs represents the most “responsive” leg of the nuclear triad. The president of the United States can, at any time, give the order to launch ICBMs through methods of “assured connectivity” (OSD Nuclear and Missile Defense Policy, 2020, p. 3). ICBMs are manned by Air Force personnel and can respond immediately to a launch order (OSD Nuclear and Missile Defense Policy, 2020, p. 3). Meanwhile, air-based deterrence provides the most “flexible” (OSD Nuclear and Missile Defense Policy, 2020, p. 7) leg of the nuclear triad. Air Force nuclear weapon-capable airframes are a mobile, visual strategic deterrent that patrol forward-deployed air space, serving as a reminder of the “U.S. commitments to its security and the security of its allies and partners” (OSD Nuclear and Missile Defense Policy, 2020, p. 7). If required to launch a nuclear payload, air-launched cruise missiles (ALCMs) offer a large degree of flexibility through their advanced targeting capabilities. According to the article “Importance of Modernizing the Nuclear Triad,” B-52s can “carry up to 20 ALCMs, allowing one bomber to threaten 20 geographically separated targets” simultaneously (OSD Nuclear and Missile Defense Policy, 2020, p. 7). The U.S. Navy’s SSBN fleet, which conducts the sea-based strategic deterrence mission, is the only platform that represents a clandestine, survivable threat to U.S. adversaries. According to the Center for Arms Control and Non-Proliferation, the “sea-leg of the triad is often considered most essential, since submarines are difficult to track and destroy” (Schumann, 2021, para. 8). Given this noteworthy distinction, SSBNs have and will continue to receive a significant amount of attention and funding. To appreciate the state-of-the-art capabilities that will allow the Columbia-class submarine to execute the sea-based leg of the nuclear triad, it is important to understand the state-of-the-practice class Ohio-class SSBNs.



Ohio-Class Ballistic Missile Submarine

The first ship of the Ohio class, USS Ohio (SSBN 726), was commissioned on November 11, 1981 (General Dynamics Electric Boat, n.d.). The Ohio-class submarine was the successor to the “41 for Freedom” fleet ballistic missile (FBM) submarines, which were comprised of five different classes: the George Washington, Ethan Allen, Lafayette, James Madison, and Benjamin Franklin (Naval History and Heritage Command, 2021). Each of the earlier variants of FBM submarines could carry 16 Polaris missiles, and in later variants, Poseidon C-3 or Trident I C-4 missiles (Strategic Systems Platforms, n.d.). The FBM submarines provided successful strategic deterrence patrols for years. However, advances in submarine technology and the desire to equip vessels with substantial numbers of Trident ICBMs led to the development of the Ohio-class submarines.

Eighteen Ohio-class SSBNs were commissioned between 1981 and 1997 (General Dynamics Electric Boat, n.d.). The first four Ohio-class SSBNs, which completed numerous strategic deterrence patrols, were converted into guided nuclear missile submarines (SSGNs) from 2000 to 2010. SSGNs are SSBNs that are outfitted with Tomahawk land attack missiles (TLAMS) instead of ICBMs. The remaining 14 SSBNs provide the sea-based leg of strategic deterrence today.

Ohio-class submarines, an example of which is depicted in Figure 3, are 560-foot-long nuclear-powered warships that can carry up to 24 Trident I C-4 or Trident II D-5 missiles. They are homeported in either Kings Bay, GA, or Bangor, WA. Each SSBN has two crews (known as the blue and gold crews), which operate the submarine on its nominal deployment cycles. One crew takes the submarine to sea for a strategic deterrence patrol that lasts approximately 75 to 90 days. Once the strategic deterrence patrol is complete, the submarine returns to port, and a crew turnover occurs. Once the new crew has taken responsibility for the submarine, a 30-day maintenance period begins. When the maintenance period is complete, the submarine goes back to sea. The crew that has returned from sea and is in port operates submarine simulators, conducts training, and plans for the upcoming maintenance period following crew turnover.



Figure 3. Ohio-Class Submarine, USS Henry M. Jackson (SSBN 730). (U.S. Navy, 2015)

Columbia-Class Ballistic Missile Submarine

The decision to replace the Ohio-class submarine with another “sea-based strategic deterrent” originated out of an agreement between President George W. Bush and U.K. Prime Minister Tony Blair in 2006 to have their “next generation SSBNs carry the Trident II D-5 Submarine Launches Ballistic Missiles (SLBMs)” (O’Rourke, 2022, p. 37). After the Joint



Requirements Oversight Committee approved an initial capabilities document (ICD), the Ohio Replacement Program (ORP) office was established in 2008 (O'Rourke, 2022, p. 37). Milestone A for the ORP was approved on January 10, 2011 (O'Rourke, 2022, p. 38). Following the approval of Milestone A, in 2016 the ORP was renamed the "Columbia Class Program" (O'Rourke, 2022, p. 4). Milestone B was approved on January 4, 2017 (O'Rourke, 2022, p. 38), and the Navy officially started construction of the first Columbia-class submarine in November 2020 (Eckstein, 2020a, para. 1). A list of the major developments for the Columbia-class submarine can be seen in Table 1.

Table 1. History of significant developments for the Columbia-class submarine. (U.S. Department of Defense, 2019)

History of Significant Developments Since Program Initiation	
History of Significant Developments Since Program Initiation	
Date	Significant Development Description
July 2008	USD AT&L issues ADM directing entry into the Concept Refinement Phase and conduct of an Analysis of Alternatives.
October 2008	Secretary of Defense sends letter to United Kingdom (UK) Secretary of State for Defense to affirm the U.S.-UK Mutual Defense Agreement and cost sharing for the Common Missile Compartment.
September 2010	SCP approved with new design SSBN based on 12 ships with 16 - 87" missile tubes.
January 2011	Milestone A ADM issued which authorized entry into Technology Maturation and Risk Reduction (TMRR) phase to complete a new design SSBN based on 12 ships with 16 - 87" missile tubes.
February 2012	PB 2013 shifts lead ship construction from FY 2019 to FY 2021; the two year recapitalization delay removed all margin during the OHIO-OHIO Replacement (OR) transition period (FY 2027- FY2042), any delay in OR delivery or unexpected aging impact to OHIO will have significant impacts on SSBN Ao.
December 2012	RDT&E Design Contract issued to General Dynamics – Electric Boat.
December 2014	National Sea-Based Deterrence Fund established by Public Law 113-291.
November 2015	Incremental funding authority and authority to enter in contracts for Advance Construction and economic order quantity provided by Public Law 114-92.
January 2017	Milestone B APB approved (Program Initiation).
September 2017	Award of the Integrated Product and Process Development (IPPD) contract. The Navy has transitioned all design efforts from the OHIO Replacement Research & Development (R&D) Design contract to the IPPD contract.
September 2018	Award of the Two Year Advance Procurement Funding modification to the IPPD contract.
February 2019	APB updated to reflect actual award of IPPD contract (September 2017) and align affordability targets with approved CDD.

The Columbia-class submarine will be the world's state-of-the-art SSBN. Some of these innovative technologies can be seen in Figures 4 and 5. The Columbia class will feature a nuclear reactor that, unlike that of the Ohio class, requires no refueling for the lifetime of the submarine (Larson, 2021). The new submarine class also features the first electric-drive propulsion system and an X-shaped stern configuration, which will increase the ability of the submarine to remain undetected (Osborn, 2018). The Columbia-class submarine will carry up to 16 Trident D-5 missiles. This is eight fewer missiles than the Ohio-class submarine, which carries up to 24 Trident D-5 missiles. However, Columbia-class submarines will maintain the same number of overall missiles at sea because the Columbia-class submarines will not need to conduct mid-life refueling of the nuclear reactor. Fewer lengthy refueling periods result in fewer Columbia-class submarines in port and an increased number of SSBNs at sea (O'Rourke, 2022, p. 5).



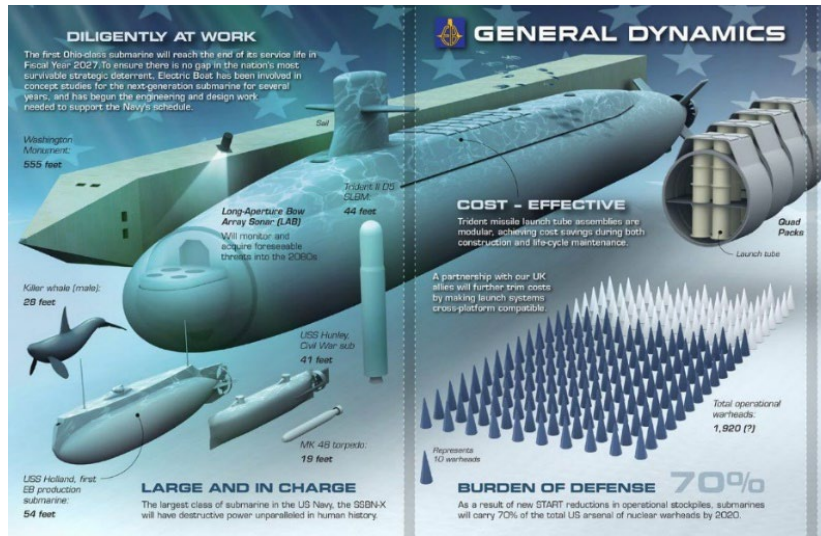


Figure 4. Columbia-class submarine size and deterrent capability. (General Dynamics, n.d.)

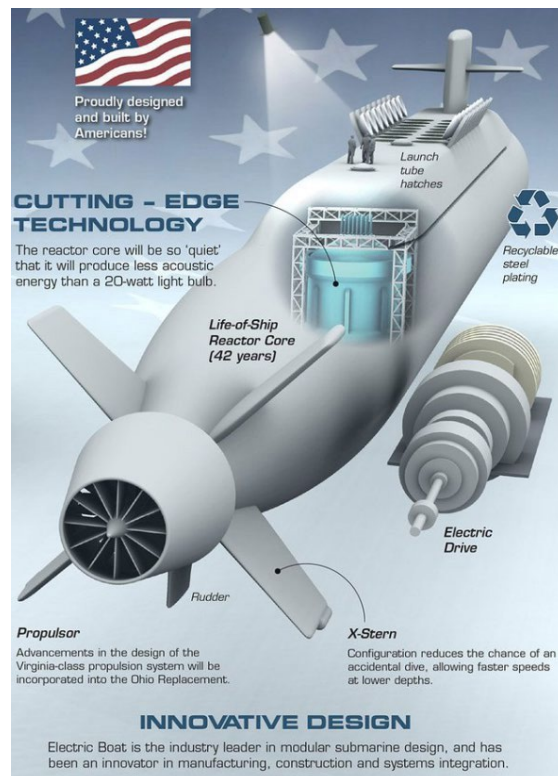


Figure 5. Cutting-edge technology on the Columbia-class submarine. (General Dynamics, n.d.)

12 Columbia-class SSBNs are set to replace the 14 active Ohio-class SSBNs over the next 20 years, with the lead submarine to be delivered to the Navy no later than 2030 with the first strategic deterrence patrol no later than 2031. The Columbia-class SSBNs offer a large upgrade in capability over the Ohio-class SSBNs. Some of the most notable upgrades include a nuclear reactor that requires no mid-life refueling, an electric-drive propulsion system, an X-shaped rudder and stern plane system, the most modern sonar suite, and the most advanced sound silencing capabilities. In addition to the major

upgrades, the Columbia-class submarine carries the Trident II D-5 Submarine Launched Ballistic Missiles (SLBMs) as seen in Figure 6. These are the same nuclear weapons that are carried by the Ohio-class SSBNs. Utilizing this capable weapon reduces the risk of a delay of the first Columbia-class strategic deterrence patrol in 2031 by avoiding the development and acquisition of a new nuclear weapon.



Figure 6. Unarmed Trident II D-5 missile launched from a ballistic missile submarine. (U.S. Navy, n.d.)

Nuclear strategic deterrence is one of the most important missions of the DOD, making the Columbia-class submarine acquisition program critical for national security. As the Ohio-class submarines begin to reach the end of their useful service life, Columbia-class submarines must be ready to replace them. In the worst case, if the first Columbia-class submarine is not ready to conduct its first strategic deterrence patrol by 2031, there is a potential for a nuclear strategic deterrence gap, which could potentially jeopardize the national security.

Big “A” Acquisition

The CNO knew the difficulties RADM Pappano was facing. The PEO was responsible for managing the “triple constraint” of the program’s acquisition program baseline: cost, schedule, and performance. Though a simple concept, the CNO knew there was more to it than met the eye. At most, a PEO or PM could optimize the triple constraint for two of its three variables and would be required to make concessions for the other. As an example, RADM Pappano could focus on delivering a quality submarine on time if he were able to increase the overall cost of the program. Conversely, RADM Pappano could also choose to drastically cut costs for the program and risk decreasing quality or performance. None of these decisions concerning the triple constraint, however, can be made in isolation. A PEO or PM finds themselves eternally in the middle of the Big “A” acquisition system. Big “A” acquisition consists of three interacting systems: the Joint Capability Integration and Development System (JCIDS), the Programming, Planning, Budgeting and Execution System (PPBE), and the Defense Acquisition System (DAS), commonly referred to as Little “a” acquisition or more recently, the Adaptive Acquisition Framework (Moran, 2008). Figure 7 provides a visual representation and summary of the Big “A” concepts.



Figure 7. Big “A” acquisition. (Mortlock, 2021)

The JCIDS process is responsible for requirements generation and is a needs-driven process. The need assessed by the JCIDS process is defined in the initial capabilities document (ICD), and discrete operational requirements are derived from the ICD in the capability development document (CDD). In the case of the Columbia-class program, that need is providing a source of sea-based strategic deterrence. The PPBE process is responsible for the allocation of resources to programs. Unlike the other two parts of Big “A” acquisition, the PPBE process is a calendar-driven system. The final portion of Big “A” acquisition is the DAS or defense acquisition management system, which is an events-driven system. The PEO or PM guides their programs along one of the pathways of the Adaptive Acquisition Framework (AAF), as seen in Figure 8. The Columbia-class submarine program follows the major capability acquisition pathway that entered the engineering and manufacturing development (EMD) phase following an approved milestone B decision in 2017. RADM Pappano had his work cut out for him—operating within the Big “A” framework for one of the most important programs in the country was far from an easy task. His major challenge was to manage the APB (cost, schedule, and performance constraints) within the Big “A” environment.

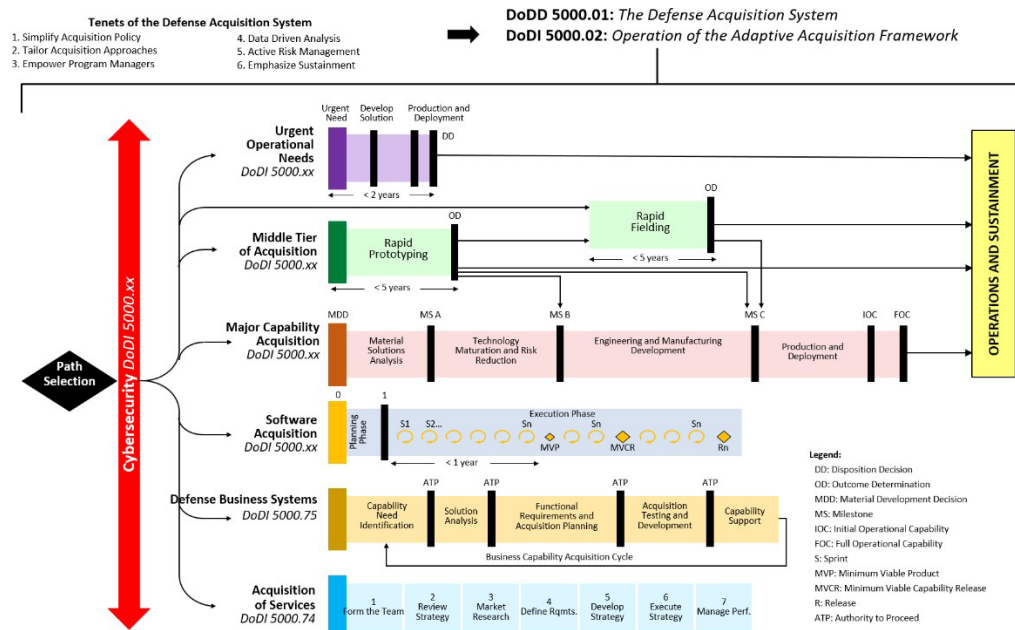


Figure 8. Adaptive acquisition framework. (Defense Acquisition University, n.d.)

Columbia-Class Acquisition Program Baseline

The current acquisition program baseline (APB) for the Columbia-class submarine was approved on February 25, 2019. An APB is developed by the Navy, is approved by the milestone decision authority (MDA), and details the threshold and objective values for cost, schedule, and performance requirements. These cost, schedule, and performance sections from the Columbia program APB are presented in Tables 2, 3, and 4 respectively.

Table 2. Cost summary. (U.S. Department of Defense, 2019)

Total Acquisition Cost						
Appropriation	BY 2017 \$M			BY 2017 \$M	TY \$M	
	SAR Baseline Development Estimate	Current APB Development Objective/Threshold	Current Estimate		SAR Baseline Development Estimate	Current APB Development Objective
RDT&E	12648.1	12648.1	13912.9	12646.7	13020.3	13020.3
Procurement	87426.5	87426.5	96169.2	86117.0	115044.3	115044.3
Flyaway	--	--	--	84275.3	--	--
Recurring	--	--	--	79217.1	--	--
Non Recurring	--	--	--	5058.2	--	--
Support	--	--	--	1841.7	--	--
Other Support	--	--	--	1841.7	--	--
Initial Spares	--	--	--	0.0	--	--
MILCON	147.3	147.3	162.0	156.0	173.4	173.4
Acq O&M	0.0	0.0	0.0	0.0	0.0	0.0
Total	100221.9	100221.9	N/A	98919.7	128238.0	128238.0

Current APB Cost Estimate Reference

SCP dated September 26, 2016

Cost Notes

No cost estimate for the program has been completed in the last year.

Total Quantity			
Quantity	SAR Baseline Development Estimate	Current APB Development	Current Estimate
RDT&E	0	0	0
Procurement	12	12	12
Total	12	12	12

Table 3. Schedule of events. (U.S. Department of Defense, 2019)

Events	SAR Baseline Development Estimate	Current APB Development Objective/Threshold	Current Estimate	
Milestone A	Dec 2010	Dec 2010	Dec 2010	
Pre-RFP Release DAB	Dec 2015	Dec 2015	Dec 2015	
Preliminary Design Review	Apr 2016	Apr 2016	Apr 2016	
Milestone B	Nov 2016	Jan 2017	Jan 2017	
Integrated Process and Product Development Contract Award	Jan 2017	Sep 2017	Sep 2017	
Two Year Advance Procurement Funding Modification	Oct 2018	Sep 2018	Sep 2018	(Ch-1)
Critical Design Review	Apr 2020	Apr 2020	Oct 2020	
Lead Ship Authorization / Construction Start	Oct 2020	Oct 2020	Apr 2021	
Block I Contract Award	Oct 2020	Oct 2020	Apr 2021	
Lead Ship Contract Delivery	Apr 2027	Apr 2027	Oct 2027	
Initial Operational Test and Evaluation Complete	Feb 2029	Feb 2029	Aug 2029	
Lead Ship First Deployment Start	Apr 2030	Apr 2030	Oct 2030	
Initial Operational Capability	Apr 2030	Apr 2030	Oct 2030	



Table 4. Performance characteristics. (U.S. Department of Defense, 2019)

SAR Baseline Development Estimate	Current APB Development Objective/Threshold		Demonstrated Performance	Current Estimate	
Operations and Support (O&S) Cost KSA					
Average annual O&S cost per unit of \$96M (CY 2010\$)	Average annual O&S cost per unit of \$119M (CY 2017\$)	Average annual O&S cost per unit of \$131M (CY 2017\$)	TBD	\$120.2M (CY2017\$)	(Ch-1)
Net-Ready KPP					
Meet the requirements defined within the OR SSBN PIIT of the Common Submarine Information Support Plan	Meet the requirements defined within the OR SSBN PIIT of the Common Submarine Information Support Plan	(T=O) Meet the requirements defined within the OR SSBN PIIT of the Common Submarine Information Support Plan	TBD	Meet the requirements defined within the OR SSBN PIIT of the Common Submarine Information Support Plan	
Training KPP					
OR SSBN crews are capable of being certified proficient for strategic patrol operations by the Group Commander upon completion of the normal PDTP in accordance with Fleet instructions	OR SSBN crews are capable of being certified proficient for strategic patrol operations by the Group Commander upon completion of the normal PDTP in accordance with Fleet instructions	(T=O) OR SSBN crews are capable of being certified proficient for strategic patrol operations by the Group Commander upon completion of the normal PDTP in accordance with Fleet instructions	TBD	OR SSBN crews are capable of being certified proficient for strategic patrol operations by the Group Commander upon completion of the normal PDTP in accordance with Fleet instructions	
Space, Weight, Power, and Cooling (SWAP-C) KSA					
Future Growth Margin: 3% of Condition A-1 weight Cooling Capacity: 10% cooling capacity over the chill water design heat load Power – 10% electrical power future growth margin for ship's electrical loads at full power while underway at delivery	Future Growth Margin: 3% of Condition A-1 weight Cooling Capacity: 10% cooling capacity over the chill water design heat load Power – 10% electrical power future growth margin for ship's electrical loads at full power while underway at delivery	(T=O) Future Growth Margin: 3% of Condition A-1 weight Cooling Capacity: 10% cooling capacity over the chill water design heat load Power – 10% electrical power future growth margin for ship's electrical loads at full power while underway at delivery	TBD	Future Growth Margin: 3% of Condition A-1 weight Cooling Capacity: 10% cooling capacity over the chill water design heat load Power – 10% electrical power future growth margin for ship's electrical loads at full power while underway at delivery	
Procurement Cost KCP					
Lead Ship End Cost Less Plans of \$6.3B (2010\$) using Navy	APUC of \$7.3B (CY 2017\$)	APUC of \$8.0B (CY 2017\$)	TBD	\$7.18B (CY2017\$)	(Ch-2)
Inflation / Deflation Indices Average Follow Ship Hulls 2-12 End Cost of \$4.9B (2010\$) using Navy Inflation / Deflation Indices					
Lead Ship First Deployment Key Schedule Parameter					
Third quarter of FY2030	Third quarter of FY 2030	First quarter of FY 2031	TBD	First quarter of FY 2031	

Government Accountability Office Report

Despite the major forward progress made on the Columbia-class submarine, delays in early construction are threatening timely delivery to the fleet (GAO, 2021, p. 1). These specific problems include a “supplier base that is roughly 70% smaller than in previous shipbuilding booms,” an “inexperienced shipyard workforce,” “continuing challenges with ... computer-aided software that ... is [being used] to design the submarine,” and “quality problems with supplier materials” (GAO, 2021, pp. 1, 20). If the Columbia-class submarine is



not ready to make its “first patrol in fiscal year 2031 ... [the United States will experience] a deterrence gap ... [that would have] far-reaching consequences for the nation’s defense” (GAO, 2021, p. 1).

Given the magnitude of the consequences of a delay in the construction of the Columbia-class submarine and the \$128 billion that the Navy plans to invest to create the 12 ships in the class, the Government Accountability Office (GAO) was tasked with “assessing the Navy’s efforts to complete the design for the lead Columbia-class submarine and actions that the shipbuilders and the Navy have taken to prepare for construction and ensure the lead submarine is delivered according to schedule and quality expectations” (GAO, 2021, p. 2).

The GAO released report GAO-21-257, *Columbia Class Submarine: Delivery Hinges on Timely and Quality Materials from an Atrophied Supplier Base*, on January 14, 2021. This report describes the major obstacles that threaten schedule delays for the Columbia program office.

Software Issues

Electric Boat, the Columbia-class SSBN program contractor, switched to a new computer-aided software tool for the Columbia-class SSBN because the software for the previous tool was “no longer supported by the original developer” (GAO, 2021, p. 6). The purpose of the computer-aided software tool is to design arrangements, disclosures, and material orders, which are required to develop the submarine (GAO, 2021, p. 7). The arrangements, which are completed first, are 3D models of the steel structure, the electrical systems, and the piping systems (GAO, 2021, p. 7). Once the arrangements have been completed, the next step is to design the disclosures. The disclosures “complete the design work for even the lowest-level items of the submarine, including material information” (GAO, 2021, p. 7). A completed disclosure lends way to the development of work instructions, which provide shipyard workers with the procedures and parts required to build any given part of the ship, and the material orders, which allow the generation of contracts to order all required parts (GAO, 2021, p. 7).

One major advantage of the new computer-aided design tool was that it was supposed to “reduce the average hours needed to complete design disclosures by almost half of the time required for the Virginia class program” (GAO, 2021, p. 13). This would enhance the ability of the Columbia-class to stay on schedule because completed disclosures allow the program office to accurately order parts and prepare workers for submarine assembly. Unfortunately, issues with the new software have resulted in delays in disclosure and work instruction completion. The GAO cites software trouble as the major cause of delay in the construction of the Columbia-class submarine (GAO, 2021, p. 13). In the absence of work instructions, the shipyard cannot begin building portions of the submarine because they do not have procedures for their workers to follow (GAO, 2021, p. 16). Additionally, delays in disclosure completion have resulted in delayed orders of construction materials and subsequent construction because “Electric Boat cannot order materials until they are sufficiently defined in a disclosure” (GAO, 2021, p. 17).

In 2021, the GAO estimated that “Electric Boat must increase its average work instruction completion rate by 29 percent in 2020 to support the planned construction pace.” Though not listed in the GAO report, the CRS report, updated in 2022, states that “the shipbuilder [did not meet] the goal for design disclosures” (O’Rourke, 2022, p. 17).



Submarine Supplier Base

The submarine supplier base is under significant strain to produce materials required for the timely production of the Columbia-class submarine. Electric Boat and Newport News, the only two private shipbuilders who construct nuclear-powered vessels for the U.S. Navy, “plan to deliver 39 nuclear submarines during the next 2 decades, which, if achieved, would represent a doubling in output over prior years” (GAO, 2021, p. 8). The 39 submarines account for continuing to produce “two Virginia Class submarines per year through 2033 and one Columbia Class submarine per year starting in 2026” (GAO, 2021, p. 8). This pace of submarine construction has been unmatched since the height of the Cold War. Complicating the problem of increased demand for materials, the submarine supplier base has “shrunk by roughly 70–80 percent since the 1970s and 1980s” (GAO, 2021, p. 9). The GAO (2021) estimated that the number of suppliers has decreased from approximately 17,000 to approximately 5,000 (p. 9). The program executive officer for the Columbia-class program, Rear Admiral Scott Pappano, stated that “our most significant risk at the top of the list is our supplier industrial base” (O’Rourke, 2022, p. 12).

In addition to having a smaller and more fragile supplier base that is working at maximum capacity to deliver critical materials for the Navy’s most important acquisition program, the number of experienced workers has declined (GAO, 2021, p. 20). This has resulted in some inexperienced workers delivering substandard quality materials to the Columbia-class lead shipbuilder, Electric Boat (GAO, 2021, p. 26). As a specific example, quality problems in the welds for the missile tubes that were discovered at the manufacturer “are likely to cause continued delays as formal construction begins” (GAO, 2021, p. 26).

Quality Assurance Issues

A strong quality assurance program not only is an industry best practice but also minimizes the probability of schedule delays and cost overruns. According to the GAO (2021), the “shipbuilder is responsible for delivering quality submarines that meet the Navy’s specifications and ... is tasked with ensuring and monitoring quality based on contract requirements” (p. 10). At this point, however, the GAO assessed that “supplier quality problems have persisted, but the Navy has not comprehensively reassessed when additional government inspections at suppliers are necessary” (GAO, 2021, p. 25), which is a major driver for schedule delays.

Congressional Research Service Report

In addition to the GAO report, the Congressional Research Service (CRS) published a report that provides additional “background information and potential oversight issues for Congress on the Navy’s Columbia class program” (O’Rourke, 2022, p. 2). Specifically, the CRS report details GAO, Navy, and Congressional Budget Office (CBO) perspectives on the risk of schedule delay in designing and building the lead boat, the risk of cost growth, program affordability, and industrial-base challenges (O’Rourke, 2022, p. 3).

The CRS released its most recent revision of report R41129, *Navy Columbia (SSBN 826) Class Ballistic Missile Submarine Program: Background and Issues for Congress*, on April 27, 2022. This report expands on the GAO report and provides the most up-to-date publicly available information for key issues facing the Columbia-class program office. These problems are split into two major categories: risk of schedule delay and risk of cost growth. This report encompasses the Navy and GAO perspectives on both issues.



Risk of Schedule Delay

The Columbia-class program office had “as little as two months of [schedule] margin” remaining according to Rear Admiral (RADM) Scott Pappano in October 2021, who was then the program executive officer (PEO) for the Columbia-class submarine and is now the PEO for strategic submarines. With so little margin remaining, clear identification of problems and prevention of future schedule slips are of the utmost importance. In addition to the problems identified by the GAO report, the CRS report adds technological risk and an aggressive production schedule as threats to schedule delay.

Technological Risk

The Columbia-class submarine will contain many technological upgrades over its predecessors. With each innovative technology introduced, there is a risk of schedule delay as the program office works through design and integration issues. According to the CRS, an example of a technological challenge that could threaten schedule is the electric-drive system, which is an upgrade from the steam-based propulsion system utilized on all other American nuclear submarines (O’Rourke, 2022, p. 12). Admiral Caldwell, the director of the Naval Nuclear Propulsion Program, stated that the electric drive system “performed flawlessly” under “the most stressing conditions that we think we would encounter” (O’Rourke, 2022, p. 14). However, the GAO warns that “based on leading acquisition practices, we consider technologies to be mature after successful testing of a prototype near or at the planned operational system configuration in a realistic environment” and that “additional development and testing are required to demonstrate the maturity of several technologies critical to performance” (O’Rourke, 2022, p. 15–16).

Aggressive Production Schedule

The lead ship of the Columbia-class is slated to be built in 84 months, approximately 7 months faster than the lead ship of any other submarine class (O’Rourke, 2022, 17). This record-breaking design and construction plan also comes at a time when General Dynamics and Huntington-Ingalls are building two Virginia-class submarines per year. According to the Virginia-class program office, in 2011 when production of Virginia-class submarines increased to two per year, they experienced “cost and schedule growth at shipyards” (O’Rourke, 2022, p. 17). It is also reasonable to conclude that adding a third submarine to the construction schedule will also result in additional schedule delays.

Risk of Cost Growth

Though the primary focus of the Columbia-class program office is delivering the new SSBNs on time, another concern addressed by the CRS report is the risk of cost overrun. The Columbia-class submarine is the Navy’s “top priority program” and, therefore, is a program that “will be funded” (O’Rourke, 2022, p. 18). However, costs exceeding the amount budgeted for the submarine could jeopardize other Navy construction efforts, which could affect the ability of the Navy to realize its strategic vision as currently planned.

The 2019 Congressional Budget Office (CBO) estimate showed that the cost of the first Columbia-class submarine would be “\$14 billion, \$700 million more than the Navy estimates” (O’Rourke, 2022, p. 20). Though there are many reasons why the Navy may be underestimating its costs according to the CBO, the GAO assesses it is due to at least two factors. The first factor is not being able to take advantage of planned cost savings in the detailed design phase due to delays in disclosure completion (O’Rourke, 2022, p. 15). Second, the GAO assessed that the Columbia-class program office had “overly optimistic assumptions about the labor hours needed to construct the submarines,” which were not factored into cost estimates (O’Rourke, 2022, p. 21). As time progressed, the Navy sought



to make up for these deficiencies to provide more up-to-date cost estimates. The Columbia program office incorporated the loss of cost savings in the design process and updated the estimates of labor required to complete the first Columbia-class submarine. However, even with these changes, it is important to note that accurate cost estimates are a particularly difficult challenge for any lead ship in a new class. This is primarily due to a host of unanticipated costs that are discovered during the acquisition process, which cause large changes from the initial estimates. From the FY21 budget, when the first Columbia-class submarine was first officially procured, to the most recent FY23 budget, estimated costs have been updated and are steadily increasing, as shown in Table 5.

Table 5. Change in estimated procurement costs since FY2021 budget (millions of then-year dollars, rounded to the nearest tenth). (O'Rourke, 2022)

Boat and budget	Estimated cost	Change from prior year	Cumulative change since FY2021
SSBN-826 (first boat)			
FY21 budget	14,393.4	—	—
FY22 budget	15,030.5	+637.1 (+4.4%)	+637.1 (+4.4%)
FY23 budget	15,179.1	+148.6 (+1.0%)	+785.7 (+5.5%)
SSBN-827 (second boat)			
FY21 budget	9,326.1	—	—
FY22 budget	n/a	n/a	n/a
FY23 budget	9,280.2	n/a	-45.9 (-0.5%)

Source: Table prepared by CRS based on Navy's FY2021-FY2023 budget submissions.

Note: n/a means not available.

These rising costs are concerning due to the impact they might have on the Navy's shipbuilding program at large. Another factor that could lead to increased program costs is the contract type for the first two Columbia-class submarines.

Contract Type

The first two ships in the Columbia-class are being built under cost-plus incentive fee (CPIF) contracts (O'Rourke, 2022, p. 21). A CPIF contract is a "cost-reimbursement contract that provides for the initially negotiated fee to be adjusted later by a formula based on the relationship of total allowable costs to total target costs" (FAR 16.405-1, 2022). CPIF-type contracts transfer cost risks to the government from the contractor, and the government funds development costs within the scope of the contract above the original baseline estimates. In the case of the Columbia-class program, the likelihood of the government incurring costs more than the baseline is high because designing the lead ship in a class is a challenging endeavor, pushing the state of technology and wrought with unforeseen obstacles not initially anticipated.

Potential Impact on Other Navy Shipbuilding Programs

Columbia-class submarines have the potential to represent a substantial portion of the Navy's shipbuilding budget. Discounting the cost of the first Columbia-class submarine, which is most expensive ship in a new class of ships due to including design/nonrecurring engineering costs, producing one Columbia-class submarine will cost about \$8 billion per year of the Navy's shipbuilding budget until FY35 when all 12 Columbia-class submarines are scheduled to be completed (O'Rourke, 2022, p. 23). The significance of the cost of the Columbia-class submarine on the shipbuilding efforts of the Navy depends on the actual cost of producing a Columbia-class submarine and the money budgeted in any given year for shipbuilding. The larger the percentage of the Navy's shipbuilding budget the Columbia-class submarine has, the greater the possible impact on overall shipbuilding efforts. In the



FY23 budget, the Navy is requesting a shipbuilding budget of \$27.9 billion (O'Rourke, 2022, p. 23). Assuming this budget is approved, the Columbia-class represents about 30% of the overall budget. Though how much impact receiving 30% of the allocated budget seriously affects the Navy's shipbuilding program at large is up for debate, it is important to recognize that this percentage could grow, given Columbia procurement cost increases or smaller budgets.

Path Forward

The CNO and the PEO summarized a host of issues standing in between the Columbia-class submarine program and a successful strategic deterrence patrol in 2031. Each issue provided a stressor to at least one side of the triple constraint.

Schedule problems are one of the significant issues facing the Columbia-class submarine program. These schedule delays were caused in part by problems with the software used to design the submarine. The prime contractor's use of a new computer-aided software tool experienced numerous issues, which resulted in delays. The next issue which has and may continue to cause schedule delays and affect performance is the significant strain on the submarine supplier base. The submarine supplier base represented a significant risk to the program. Not only is the construction of the Columbia-class submarine underway, but two Virginia-class submarines are being built per year to replace the aging fast-attack submarine fleet. This smaller supplier base is constantly competing for parts and skilled labor.

Another problem facing the schedule of the Columbia-class program office is the technological risk associated with the new SSBN. One specific risk was the maturity of the electric drive propulsion system. This system is a brand-new method of propulsion for American nuclear submarines, which had previously been powered by steam.

As if the schedule and technical pressures were not enough risk, cost risks existed. Pressure exists to improve the quality of cost estimates. Not accounting for the first submarine, which had an estimated cost of over \$14 billion, each subsequent Columbia-class submarine was estimated at \$8 billion apiece. The Columbia program represented a sizable portion of the Navy's overall shipbuilding budget, and in a worst-case scenario, would put pressure on other shipbuilding programs and potentially put the Navy's goal of 355 ships by the mid-2050s at risk.

The CNO carefully pondered workable solutions. His principal challenge was to determine who the major stakeholders were, figure out what their concerns were, and discuss with RADM Pappano how to manage within the triple constraints and technological risk for the Columbia-class program in a way that best addresses the most important concerns.

The schedule for the Columbia class was certainly strained. All assumptions for the timely delivery of the Columbia-class submarine were based upon the threat of a strategic deterrence gap in 2031. This need was determined by the JCIDS process and captured in the Columbia-class APB. Would the validity of the need change if the existing Ohio-class SSBNs could extend their service lives any further? The service life of Ohio-class SSBNs was previously extended to accommodate delays in the Columbia-class submarine. Also, would there be any willingness from senior leaders to tolerate a temporary strategic deterrence gap until the Columbia-class submarine is completed? Both choices would lessen schedule pressure.

In addition to seeking to alleviate the schedule strain, the CNO also considered accelerating the development of the Columbia-class submarine by strengthening the



submarine shipbuilding industrial base. A more robust industrial base would alleviate material supply issues. The larger industrial base can also increase the quality of its workforce, which would minimize rework, saving time, lowering costs, and increasing overall performance. One way the industrial base could be strengthened is by employing a targeted use of Title III of the Defense Production Act (DPA). According to 50 U.S.C., Title III of the DPA “provides the president a unique and broad authority to ensure the timely availability of essential domestic industrial recourses to support national defense and homeland security requirements through the use of highly tailored economic incentives.” Should a purchase commitment be utilized to “create a guaranteed demand to reduce the risk for industry to make their own investments?” (Lehman, n.d.). Should a direct loan be made to help accommodate for the “the risk tolerance being [beyond that of] the commercial market?” (Lehman, n.d.). Are there other incentives or provisions that should be considered?

A final risk to schedule came from the innovative technologies that were being introduced on the Columbia-class. There were different opinions regarding the technology and manufacturing readiness levels of critical technologies. Is conducting thorough development and operational testing to assess technical performance compliance, operational effectiveness, and operational suitability worth the time and cost investment? If a technical flaw is discovered early, it could save large schedule delays and costs in the future. And if minimizing technology risk was a primary consideration, would there be any interest in canceling the Columbia program and building new Ohio-class submarines? The Ohio-class are considered state-of-the-practice submarines. This would come from decreasing performance requirements, but a new line of Ohio-class submarines could certainly be created by 2031 and at lower cost than Columbia-class submarines.

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Industrial Assessment Directorate: Impact of the Navy's 30-Year Shipbuilding Plan on US Industrial Base

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Abstract

This research aims to thoroughly examine and define critical assumptions within the Defense, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) framework, focusing on the intricate relationships among ship maintenance, force structure, and industrial capacity. The overarching goal is to establish an optimized array of viable options, considering factors such as talent availability, the utilization of smaller industrial plants, and overall costs within the shipbuilding industrial base.

The primary focus is on determining an optimal force structure, particularly in the U.S. Indo-Pacific Command's area of responsibility (AOR), aligning with the directives outlined in the Chief of Naval Operation's Guidance. The study acknowledges the need for a 500-ship, multitiered Navy to effectively meet the challenges posed by peer nation advances, especially in the context of distributed maritime operations.

Recognizing the inherent limitations of the current Navy for distributed maritime operations, this research explores strategic options for integrating smaller ships and autonomous surface and subsurface vessels into the shipbuilding industrial base. The analysis is conducted within the framework of a proposed five-tiered fleet structure, encompassing large combatants,



aircraft carriers (CVs), guided-missile destroyers (DDGs), submarine forces, L-class ships, and smaller lightly manned/unmanned surfaced vessels. The research anticipates that decisions pertaining to force structure will have profound implications on talent management, the efficient use of industrial plants, and overall operational costs within the shipbuilding domain.

In conclusion, this research endeavors to contribute insights into optimizing force structure within the U.S. Indo-Pacific Command's AOR, with a specific emphasis on the shipbuilding industrial base. By addressing the intricate interplay between ship maintenance, force structure, and industrial capacity, the study aims to inform strategic decision-making, aligning force structure with the evolving landscape of naval warfare and ensuring the continued strength and resilience of the shipbuilding industrial base.

Key Terms: force design, force structure, industrial capacity, distributed capabilities, ship maintenance, budget constraints, risk management, national deterrence strategy

Introduction

This section introduces the primary problem statement concerning the United States Navy's (USN) insufficient force structure and shipbuilding infrastructure to effectively combat near-peer competitors. The declining shipbuilding output over the years, as exemplified by the decrease in ship tonnage output from 1977 to 2005 and the reduction in the size of the Navy fleet, underscores the urgency of the situation (Hendrix, 2023, p. 54). Furthermore, reports such as Eric Lipton's article in the New York Times highlight the challenges faced by the Navy in adapting to evolving threats and maintaining operational capabilities (Lipton, 2023).

Problem Statement

The core issue lies in the USN's inability to match the naval capabilities and capacity of adversaries like China and Russia. While historical examples, such as the rapid expansion of shipbuilding capacity during World War II, demonstrate the nation's potential to ramp up production, current constraints hinder similar efforts. Factors contributing to this limitation include the decline in the number of shipyards and the increased cost of naval shipbuilding compared to commercial shipbuilding (Hendrix, 2023, p. 56). Political and economic pressures have also influenced procurement policies, resulting in the production of powerful yet cumbersome warships ill-suited for contemporary challenges (Lipton, 2023). Additionally, the absence of government subsidies for shipbuilding further impedes industrial capacity expansion.

Analysis of Constraints

The reduction in shipbuilding capacity can be traced back to cost-cutting measures in the early 1990s, leading to industry consolidations and decreased availability of shipyards for Navy maintenance and construction (Hendrix, 2023, p. 56). Efforts to increase capacity, such as the unbundling of merged companies like Northrop Grumman and Huntington Ingalls, have shown promise (Hendrix, 2023, p. 56). However, funding challenges persist, with Congress allocating significant resources to conventional shipbuilding programs while neglecting repairs and maintenance (Lipton, 2023).

Current Operational Challenges

The USN's current concept of operations (CONOPS) lacks credibility in deterring potential adversaries like the People's Liberation Army Navy (PLAN) due to insufficient force presence and capability deployment. To address this, the Navy's Chief of Naval Operations (CNO) has outlined a wishlist for new guided missile frigates and unmanned surface and subsurface platforms to enhance operational effectiveness (Hendrix, 2023, p. 57). The potential for unmanned platforms, such as the Lightly Manned Autonomous Combat



Capability (LMACC), to fulfill strategic objectives underscores the need for innovative solutions (Hendrix, 2023, p. 57).

Research Objective

The overarching research question aims to determine the optimal force structure necessary for effective deterrence and success in war, considering regional influences, peacetime operations, and grey zone deterrence. Additionally, the study will explore options for integrating unmanned undersea capabilities into naval operations to support mission objectives (Hendrix, 2023, p. 57).

Further Discussion

Force structure decisions are pivotal and must align with national strategy, budgetary constraints, and operational requirements. The study will prioritize these factors to develop a comprehensive understanding of the optimal force structure, informed by critical assumptions and deeper resource analyses into the Defense, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) framework. The deliverables will include a technical report, cost model, options model, and journal article, aiming to enhance multi-domain deterrence and operational resilience in degraded environments.

Literature and Current State

The literature provides insights into the challenges and potential solutions related to the national shipbuilding industrial base, shedding light on various facets of the issue.

National Shipbuilding Industrial Base

Captain Nelson (1986) emphasized the significance of the National Shipbuilding Research Program in supporting the U.S. Navy and the broader industrial base. The shipbuilding industry is recognized as a national asset, necessitating measures to preserve its capabilities (Nelson, 1986).

Decline and Preservation Efforts

The U.S. shipbuilding industry has faced a decline since the mid-19th century, except during wartime production periods. Government interventions, such as enacted laws and programs like the National Shipbuilding Research Program, have aimed to sustain shipbuilding capabilities (U.S. Congress, 1995).

Challenges and Alternatives

Studies have identified the falling rate of Navy construction and lack of commercial demand for large ships as key challenges. Recommendations include integrating commercial and defense bases, exploring export market opportunities, and supporting foreign military sales (U.S. Congress, 1995). However, concerns arise regarding potential threats to national security and the need for policy adjustments to support the shipbuilding industry.

Commercial Shipbuilding and Naval Fleet Affordability

Commercial shipbuilding in the U.S. has been overshadowed by global competition, with the naval fleet facing affordability issues due to high unit costs (Alberto et al., 2005). Recommendations include stabilizing the shipbuilding program, removing funding requirements for ships in the year of authorization, and reviewing laws to strengthen domestic shipbuilding (Alberto et al., 2005).



Capacity and Competitiveness

Concerns about future ship construction orders and the capacity of shipyards have been raised, alongside challenges in competing with the global market. Restructuring the shipbuilding industry, revitalizing commercial shipbuilding, and stabilizing naval build rates are proposed solutions (Alberto et al., 2005).

International Perspectives and Industry Improvements

International counterparts, such as the U.K. Ministry of Defense, emphasize the importance of long-term industrial planning and investment incentives (Arena et al., 2005). Improvements within the industry, including technology advancements and government support, are highlighted to reduce construction costs and enhance competitiveness (Zimmerman et al., 2005).

Recommendations for Industrial Base Enhancement

To boost and maintain the industrial base, recommendations include stabilizing demand, improving acquisition processes, promoting competition, and implementing longer-term funding strategies (Boward et al., 2007). Additionally, the establishment of interagency coordination, centralized management of capital investment, and preservation of shipbuilding intellect are suggested to strengthen the industry (Boward et al., 2007).

U.S. Navy Ship Classes Currently in Service and Plans for the Future

As of June 2023, per the Congressional Research Service, Naval Federal Register, the U.S. Navy's battle-force ships are categorized as follows:

Aircraft Carriers: 11
Surface Combatants: 115
Submarines: 68
Amphibious Warfare Ships: 31
Mine Warfare Ships: 8
Combat Logistics Ships: 29
Fleet Support: 33
Auxiliary Support: 1
Combatant Craft: 0
Other: 0
Total Battle-Force Ships in Inventory: 296
Total Active Ships in Commission: 251

This count includes commissioned ships that may not be battle-ready, such as the USS Constitution, and excludes most combat logistics and fleet support vessels. The Navy's future plans include significant investments in shipbuilding. The proposed FY2024 budget requests \$32.8 billion for shipbuilding, aiming to procure nine new ships, including one Columbia class ballistic missile submarine, two Virginia class attack submarines, two Arleigh Burke class destroyers, two Constellation class frigates, one AS(X) submarine tender, and one John Lewis class oiler. Furthermore, the Navy's FY2024 five-year shipbuilding plan outlines the acquisition of a total of 55 ships, averaging 11 ships per year. Sustaining this rate for 35 years would lead to an increase in the Navy's size to 385 ships by the 2060s. These plans reflect the Navy's commitment to modernize and expand its fleet to meet evolving security challenges and maintain a robust presence in maritime domains. For real-time updates on fleet size, the Chief of Naval Operations staff should be contacted.



U.S. Naval Shipyards

Public shipyards in the United States have a long history dating back to the nation's earliest days, primarily operated by the U.S. Navy. At one point, there were 13 public shipyards, but currently, only four remain active. Additionally, eight naval stations, one in the U.S. and seven overseas, possessed shipbuilding capabilities. However, after World War II, the Navy terminated or canceled most new ship construction contracts, resulting in the closure of several shipyards. In 1972, a report revealed that ships built in naval shipyards cost about 30% more than those constructed by private-sector shipbuilders. Consequently, all new ship construction in naval shipyards ceased, and five of the remaining nine yards were closed. Presently, the U.S. Coast Guard maintains its own shipyard in Baltimore, primarily serving as a maintenance facility. While naval shipyards have historically played a significant role in ship construction, their focus has shifted towards maintenance and repair operations rather than new construction.

Table 1. Current Naval Shipyards (Shipbuilding History, n.d.)

Active Public Shipyards (5)					
<i>Shipyard</i>	<i>Location</i>	<i>State</i>	<i>Est.</i>	<i>Closed</i>	<i>Disposition</i>
Norfolk NSY	Portsmouth	VA	1767		Maintains ships of the Atlantic Fleet
Pearl Harbor NSY	Honolulu	HI	1908		Maintains ships of the Pacific Fleet
Portsmouth NSY	Kittery	ME	1800		Maintains nuclear submarines
Puget Sound NSY	Bremerton	WA	1901		Decommissions nuclear-powered submarines
Coast Guard Yard	Baltimore	MD	1899		Maintains Coast Guard cutters and craft

The Five Public Shipyards

Norfolk Naval Shipyard, Portsmouth, VA

Norfolk Naval Shipyard (NSY), established in 1767, is a critical facility in the shipbuilding landscape of the United States Navy. Located in Portsmouth, Virginia, it is the oldest, most multifaceted, and largest industrial facility within the U.S. Navy. With a workforce of approximately 12,000 military and civilian personnel, NSY plays a vital role in repairing, modernizing, and inactivating ships within the Atlantic Fleet. The shipyard's capabilities include dry-docking, overhauling, and repairing various naval vessels, including submarines and aircraft carriers. Through state-of-the-art technology and a skilled workforce, NSY is known for its ability to tackle complex projects efficiently and within budget constraints.

Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility, Honolulu, HI

Established in 1908, Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility (PHNSY & IMF) is strategically located in Honolulu, Hawaii, providing essential support to the Pacific Fleet. With a mission to repair, maintain, and modernize the fleet, PHNSY & IMF accommodates the largest ships in the Navy, including aircraft carriers and submarines. The shipyard boasts certified graving drydocks capable of servicing various naval vessels, ensuring operational readiness and effectiveness of the fleet. Through ongoing infrastructure improvements, PHNSY & IMF continues to enhance its capabilities to meet evolving maritime needs.

Portsmouth Naval Shipyard, Kittery ME

Portsmouth Naval Shipyard (PNSY), established in 1800, is dedicated to maintaining and modernizing the U.S. Navy's nuclear-powered attack submarines. Located in Kittery, Maine,



PNSY employs a civilian workforce of approximately 8,000 professionals, supported by 1,000 officer and enlisted personnel. With a mission to support and defend the Constitution of the United States, PNSY focuses on ensuring the readiness of submarines to engage in missions effectively. The shipyard's expertise in submarine overhaul and repair positions it as a cornerstone in the nation's naval defense strategy.

Puget Sound Naval Shipyard & IMF, Bremerton WA

Puget Sound Naval Shipyard & Intermediate Maintenance Facility (PSNS & IMF), established in 1891, serves as a critical naval asset on the West Coast. Located in Bremerton, Washington, PSNS & IMF maintains, modernizes, and retires the Navy's fleet, encompassing various classes of ships. With six drydocks and extensive pier space, the shipyard provides comprehensive maintenance services, supporting fleet operations across multiple locations. Its strategic location and diverse capabilities contribute significantly to the Navy's operational readiness in the Pacific region.

U.S. Coast Guard Yard, Baltimore MD

The U.S. Coast Guard Yard, established in 1899, serves as the sole shipbuilding and major repair facility for the U.S. Coast Guard. Situated in Baltimore, Maryland, the Yard has a long history of building, repairing, and renovating ships for the Coast Guard. With a focus on quality, cost-effectiveness, and timeliness, the Yard operates as a revolving fund activity, generating annual revenue of approximately \$100 million. Its capabilities and commitment to excellence ensure the Coast Guard's fleet remains mission-ready and effective in safeguarding the nation's maritime interests.

Private Shipyards

Private shipyards in the United States are crucial components of the maritime industry, contributing significantly to the nation's economy and defense capabilities. As of the latest data, there are 154 active private shipyards spread across 29 states and the U.S. Virgin Islands. These shipyards are engaged in various activities, including shipbuilding, ship repair, and renovation.

There are two main categories of private shipyards: mid-sized to large shipyards capable of building naval ships, submarines, oceangoing cargo ships, drilling rigs, and high-value, high-complexity mid-sized vessels; and smaller yards capable of building simpler types of commercial vessels such as tugs, towboats, offshore service vessels, fishing vessels, ferries, and barges.

Private shipyards play a vital role in supporting the nation's maritime infrastructure, providing essential services such as building and repairing ships for military, commercial, and governmental purposes. They also contribute significantly to the nation's gross domestic product (GDP), with a reported \$42.4 billion in GDP supported by private shipyards in 2019. Additionally, private shipyards provide more than 107,000 direct jobs across the country. For a complete list, please see Appendix B.

Summary of U.S. Builders of Small Vessels

Since World War II, approximately 600 U.S. shipyards have been involved in the construction of smaller types of governmental and commercial vessels. These vessels include patrol craft, research vessels, tugs, towboats, offshore service vessels, fishing vessels, ferries, tour boats, and barges. The shipyards are categorized into four groups:

(1) 15 yards actively building significant numbers of more complex types of small vessels.



(2) 71 yards actively building significant numbers of simpler types of small vessels, such as towboats and inland barges.

(3) 107 yards are active but have only constructed a few boats in recent years.

(4) 195 yards have built a significant number of boats since WWII but are no longer active.

Additionally, there are at least 200 more yards that have constructed governmental and/or commercial boats since WWII, but they are not included in this section due to their smaller size. This summary excludes builders of recreational or other non-commercial boats unless they also produce commercial variations or operate waterfront boatyards. For a complete list, please see Appendix C.

Conclusion

The literature underscores the multifaceted challenges facing the national shipbuilding industrial base and proposes a range of solutions to enhance its resilience and competitiveness in the global market. Implementing these recommendations requires coordinated efforts from government agencies, industry stakeholders, and policymakers to ensure the long-term viability of the shipbuilding sector.

Proposed Methodology

Portfolio Optimization of Ships

Appendix A summarizes the current U.S. Naval fleet (as of June 2023). Additional details for the private sector are available in Appendix B and C. Appendix A summarizes the current ship portfolio of 239 active in-commission vessels, segregated by their ship class. The list is by no means comprehensive but presents the data that is available, such as the number of ships in a specific class, the approximate cost to build, time to build (starting from award dates to keel date, launch date and commission date), length, displacement, personnel (ship's company, air wing, Flag Staff, officers, and enlisted), as well as the ship's armament. The information in the table, as is, would be insufficient in building a portfolio optimization model, but with further refinement, optimization can be run. The following section provides some notional datasets and formulation that can be helpful and used to run the portfolio optimization.

Suppose that for each (i) of the different classes (C_i) of Navy ships (e.g., nuclear carriers, guided missile cruisers, guided missile destroyers, ballistic missile submarines, littoral combat ships), there are (j) different characteristics (x) such as tonnage (displacement), length, sailors (officers and enlisted), armaments (e.g., number of CIWS, RAM, guns, launch bays, missiles, torpedoes), and so forth, where we have

$$C_i(x_{i,1}, x_{i,2}, \dots, x_{i,n}) \text{ or } C_i(x_{i,j}) \in \mathbb{R} \quad \forall i \in I \text{ and } \forall j \in J.$$

Also, each class of ship has a probability distribution of cost to acquire, build, and maintain over time (ϕ_t). And from various stakeholders' points of view, we have an estimated military value (v). These values are a function of mission use (y) such as command ships, joint carriers, mine countermeasure, tenders, joint high-speed vessels, sea fighters, submersibles, surveillance, and so forth, such that we have

$$v_i(y_{i,1}, y_{i,2}, \dots, y_{i,m}) \text{ or } v_i(y_{i,m}) \in \mathbb{R} \quad \forall m \in M.$$

The portfolio optimization is to hence



$$\begin{aligned}
& \text{Max}_{j,k} \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} C_i(x_{i,j}) v_i(y_{i,k}) \\
& \text{s. t.} \sum_{i \in I} \phi_{i,t} C_i \leq \Phi_{i,t} \\
& \text{s. t.} \sum_{i \in I} x_i \geq \mathbf{X} \\
& \text{s. t.} \sum_{i \in I} y_i \geq \mathbf{Y}
\end{aligned}$$

In simple terms, the portfolio is optimized multiple times, each time with respect to each stakeholder's point of view for strategic value, mapped against their characteristics for all ship classes in the portfolio. The objective function can also be a weighted average of all the various strategic value points of view. The typical constraints will be to optimize the portfolio subject to the time series cost cash outflow based on a total ownership cost from the cradle to the grave (throughout the acquisition process, build phase, commission, operations and maintenance, upgrades, and disposition) throughout its life cycle, to be under the projected total shipbuilding and ship maintenance budget. In addition, the portfolio will be optimized to exceed the minimal total characteristic requirements of all the ships in total (e.g., the total number of ships, the total number of missiles, the total number of planes, the total number of sailors, all the ships can carry must exceed a certain minimum threshold), or the various mission types (e.g., there must be at least 12 carriers, 85 guided missile destroyers) to be at the ready by the year 2030 and operational for the next 35 years.

Several types of algorithms have been created throughout the years to find the answers to optimization problems, ranging from basic linear optimization utilizing the simplex model to solving first partial differential equations in order to be thorough and inclusive. When more complicated real-world situations are imagined, however, these fundamental methods tend to fail, necessitating the use of more powerful algorithms. We used a combination of evolutionary algorithms, Lagrange multipliers, and taboo-based reduced gradient search approaches to solving our efficient frontier problem.

The Lagrange multiplier solution assumes a nonlinear issue of some kind.

$$\begin{aligned}
& \min \text{ or } \max f(x) \\
& \text{s. t. } g_i(x) = b_i \quad \forall i = 1, \dots, m
\end{aligned}$$

where equality is often replaced by some inequality values indicating a ceiling or floor constraint (Mun, 2015).

From this functional form, we first derive the Lagrange multiplier v for all i values:

$$\begin{aligned}
L(x, v) & \triangleq f(x) + \sum_{i=1}^m v_i [b_i - g_i(x)] \\
& \text{s. t. constraints } g_i(x) = b_1, \dots, g_m(x) = b_m
\end{aligned}$$

The solution (x^*, v^*) is a set of points along the Lagrange function $L(x, v)$ if it satisfies the condition:



$$\sum_i \nabla g_i(x^*) v^* = f(x^*) \text{ which requires } \sum_i \frac{\partial g_i}{\partial x_j} v_i = \frac{\partial f}{\partial x_j} \forall j \text{ and } g_i(x^*) = b_i$$

This method is straightforward and elegant, but it is confined to linear and quasi-linear functional forms of f , as well as some simple nonlinear functional forms (x). We need to add constraints to the solution set and use search techniques to cover a vast (and frequently infinite) set of optimal allocations in order to expand the functional form to generalized nonlinear applications. One restriction is that where nonlinear problems have a differentiable generic form, the Kuhn-Tucker condition must be satisfied:

$$\begin{aligned} & \min \text{ or } \max f(x) \\ \text{s. t. } & g_i(x) \geq b_i \quad \forall i \in \text{Feasible Set} \\ & g_i(x) \leq b_i \quad \forall i \in \text{Feasible Set} \\ & g_i(x) = b_i \quad \forall i \in \text{Feasible Set} \end{aligned}$$

And the inequality constraints will need to be active at a local optimum or when the Lagrange variable is set to null:

$$v_i[b_i - g_i(x)] = 0$$

In addition, mathematical algorithms for both ad-hoc and systematic searches of the optimal solution set will need to be developed. Even a supercomputer would take close to an unlimited number of years to outline all potential permutations using an enumeration method. As a result, search algorithms are frequently used in the optimization of an efficient frontier. The use of a reduced gradient search method is one basic method. To recap our strategy, we suppose

$$\nabla f(x) \cdot \Delta x$$

Where the functional form $f(x)$ is the objective function and is divided into two parts, a basic (B) and a nonbasic portion (N) that is multiplied by the change in vector direction x . Using a Taylor expansion, we obtain

$$\begin{aligned} \nabla f(x) \cdot \Delta x &= \nabla f(x)^B \cdot \Delta x^B + \nabla f(x)^N \cdot \Delta x^N \\ &= \nabla f(x)^B \cdot (-B^{-1}N\Delta x^N) + \nabla f(x)^N \cdot \Delta x^N \\ &= (\nabla f(x)^N - \nabla f(x)^B B^{-1}N)\Delta x^N \end{aligned}$$

The reduced gradient with respect to the solution matrix B is

$$r \triangleq (r^B, r^N)$$

where

$$\begin{aligned} r^B &\triangleq 0 \\ r^N &\triangleq \nabla f(x)^N - \nabla f(x)^B B^{-1}N \end{aligned}$$

When the number of decision variables is modest (usually less than four or five), a manual solution is doable; but, when the number of decision variables is big, as it is in most real-life situations, a manual solution is intractable, and computer search algorithms must be used. The following are the stages used in the general method:

1. Estimate a good set of starting points.
2. Continue estimating sample test points and the direction of the reduced gradient vector.
3. Test for feasibilities of constraints at extreme limits.



4. Solve the Lagrange optimal set.
5. Generate a new set of starting points.
6. Change the basis set if a better set of points is obtained or stop optimization.
7. Repeat iteration and advance or stop when the tolerance level is achieved.

Apart from purely financial and economic values, and strategic values, we can also apply operational, logistic, and other values that can be constructed and used in the prescribed modeling approaches as discussed in this report. The following provides some examples of alternative value metrics. These metrics can be applied in future and subsequent research with actual data collected.

Operational and Logistics

- **Inherent Availability (IA).** Measures operational percentage in an ideal support environment per design specifications.

$$IA = \frac{MTBF}{MTBF + MTTR}$$

- **Effective Availability (EA).** Probability a ship's system is available at any instant during the maximum operational period, accounting for all critical failures, repairable and nonrepairable at sea, and preventive maintenance.

$$EA = 1 - \frac{MTTR}{MTBF + MTTR} - \frac{MDT}{MT} - 0.5 \frac{MT}{MTTF}$$

- **Mission Reliability (MR).** Operational Ready Rate (ORR) at the start of a mission compared to its Inherent Reliability (IR).

$$MR = ORR * IR$$

- **Operational Dependability (OD).** Probability a system can be used to perform a specified mission when desired.

$$OD = \frac{MTTF}{MTBF}$$

- **Mean Down Time (MDT), Mean Maintenance Time (MMT), Logistics Delay Time (LDT),** and their combinations.
- **Achieved Availability (AA), Operational Availability (OA), and Mission Availability (MA)**

Alternative Financial and Economic

- **Cost Deterrence and Avoidance.** Soft or shadow revenue (cost savings) over the economic and operational life of the program or system. Milestones A, B, C.
- Traditional Financial Metrics. **Net Present Value (NPV), Internal Rate of Return (IRR), Return on Investment (ROI),** and other metrics, as long as there are financial and monetary values.
- **Budget Constraint.** FY Budget limitations and probabilities of budgetary overruns.
- **Total Ownership Cost (TOC) and Total Life Cycle Cost (TLC).** Accounting for the cost of developing, producing, deploying, maintaining, operating, and disposing of a system over its entire lifespan. Uses **Work Breakout Structures (WBS), Cost Estimating Categories (CEC),** and **Cost Element Structures (CES).**



- **Knowledge Value Added (KVA). Monetizing Learning Time, Number of Times Executed, Automation, Training Time, and Knowledge Content.**
- **Strategic and Capability.** Multiple value metrics can be determined by subject matter experts (SME), including:
 - **Expected Military Value**
 - **Strategic Value**
 - **Future Weapon Strategy**
- **Capability Measures (CM).** Difficult to quantify and needs SME judgment:
 - Innovation Index, Conversion Capability, Ability to Meet Future Threats
 - Force Structure (size/units), Modernization (technical sophistication), Combat Readiness, Sustainability
 - Future Readiness (ability to meet evolving threats, ability to integrate future weapons systems)
- **Domain Capabilities (DC)**
 - Portfolios are divided into different domains, and each domain is optimized separately and then combined at the enterprise level and re-optimized; example domains include Coastal Defense, Anti-Air Surface Warfare, Anti-Surface Warfare, Anti-Submarine Warfare, Naval Strike, Multi-Mission Air Control, Sea Control, Deep Strike, Missile Defense, and so on.
 - Constraints can be added whereby each domain needs to have a minimum amount of capability or systems, and within each domain, different “value” parameters can be utilized.

Conclusion, Limitations, and Future Research

This research has delved into the intricate relationships among ship maintenance, force structure, and industrial capacity, aiming to establish a potential optimization portfolio of ships. Strategic options, such as prioritizing the construction of numerous smaller vessels over a few large ships, have been identified, emphasizing the significant impact on talent availability, industrial plant utilization, and overall costs. The primary objective was to analyze force structure options, particularly in the Indo-Pacific region, aligning with directives from the Chief of Naval Operations and advocating for a 500-ship, multitiered Navy. Recognizing the evolving challenges posed by peer nation advances, an optimal force structure must encompass sufficient variety in distributed capabilities while considering budgetary constraints, risk management, national deterrence strategy, and operational requirements.

Portfolio optimization of ships offers a systematic approach, considering various Department of Defense stakeholders’ strategic viewpoints and ship characteristics across all classes. The objective function may entail a weighted average of strategic values, while constraints ensure the portfolio remains within budgetary limits and meets operational requirements throughout the ship’s life cycle.

Acknowledging the limitations of the current Navy for distributed maritime operations, the research advocates for the integration of smaller ships and autonomous vessels into the fleet, rather than moving away from traditional naval structures. Also, in the case of this research, the primary limitation of the study was the inability to collect the complete dataset



required to run the optimization methods to effectively assess the shipbuilding industry. Despite efforts to gather comprehensive data, certain variables or parameters were missing in publicly available data and thereby may have been missing or unavailable, hindering the accuracy and robustness of the analysis if it were to be run. This is because this study's scope was restricted by factors such as time constraints, resource limitations, or access constraints to certain data sources. Consequently, the research may not have fully captured all relevant aspects or dimensions of the shipbuilding industry, potentially affecting the comprehensiveness of the findings. Future research should acknowledge and address the limitations encountered in data collection, emphasizing the challenges and constraints faced in obtaining a complete dataset for optimization methods.

In conclusion, the research provides insights into optimizing force structure and shipbuilding within the context of evolving naval warfare. By addressing the complexities of ship maintenance, force composition, and industrial capacity, strategic decision-making can be informed to ensure the Navy's readiness and effectiveness in meeting future challenges.

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Appendix A: Current State of the U.S. Naval Fleet (Updated June 2023)

CLASS	COUNT	COST TO BUILD	BUILD TIME	LENGTH	DISPLACEMENT	PERSONNEL	ARMAMENT
CVN 68 (nuclear-powered)	10	USS George H. W. Bush (hull CVN 77; commissioned 2009) \$6.3 billion	(USS Nimitz award date: 1967, keel date: 1968, launch date: 1972, commissioned: 1975)	1,092 ft.	approx. 100,000 tons	ship's company:	4 Sea Sparrow launchers
multipurpose aircraft carrier			(USS George H.W. Bush award date: 2001, keel date: 2003, launch date: 2006, commissioned: 2009)			3,200 air wing: 2,480	3 Phalanx CIWS 20mm mounts [Nimitz & Ike] 4 Phalanx CIWS 20mm mounts [Vinson and later]
						other: 500	
CVN 78 (nuclear-powered)	1	USS Gerald R. Ford (hull CVN 78; commissioned 2017) \$13.3 billion	(USS Gerald R. Ford award date: 2008, keel date: 2009, launch date: 2013, commissioned: 2017)	1,092 ft.	approx. 100,000 tons	crew: 2,500 to 2,700	Evolved Sea Sparrow Missile
multipurpose aircraft carrier						aircrew [approx.]: 2,480 Flag Staff: 70	Rolling Airframe Missile Phalanx CIWS
CG 47 (guided missile cruiser)	17	USS Cape St. George (hull CG 71; commissioned 1993) approx. \$1 billion	(USS Cape St. George award date: 1988, keel date: 1990, launch date: 1992, commissioned: 1993)	567 ft.	9,992 tons	30 officers 300 enlisted	MK41 vertical launching system Standard Missile (MR) Vertical Launch ASROC (VLA) Missile Tomahawk Cruise Missile 6 MK 46 torpedoes (from two triple mounts) 2 MK 45 5-inch/54 caliber lightweight guns



							2 Phalanx close-in-weapons systems
DDG 51 (guided missile destroyer)	70	currently, about \$2.2 billion (from Navy DDG-51 and DDG-1000 Destroyer Programs: Background and Issues for Congress— Updated March 27, 2023)	(USS Frank E. Petersen Jr. award date: 2013, keel date: 2017, launch date: 2018, commissioned: 2022)	Flights I & II DDG 51- 78: 505 ft or 153.92 m Flight IIA and III (DDG 79 AF): 509 1/2 feet (155.29 meters)	8,230 - 9,700 Ltons	Flight IIA: 329 Total (32 Officers, 27 CPOs, 270 Enlisted) Flight III: 359 Total (41 Officers, 27 CPOs, 291 Enlisted)	Standard Missile Family Vertical Launch ASROC (VLA) missiles. Tomahawk 6 MK-46 torpedoes (from two triple tube mounts) Close In Weapon System (CIWS). 5- in. MK 45 Gun Evolved Sea Sparrow Missile (ESSM)
DDG 1000 (guided missile destroyer)	1	USS Zumwalt (com- missioned 2016) \$4.4 billion	(USS Zumwalt award date: 2008, keel date: 2011, launch date: 2013, commissioned: 2016)	610 ft.	15,761 tons	197	80 advanced Peripheral Vertical Launch (PVLS) cells for Tomahawk, Evolved Sea Sparrow Missile (ESSM), Standard Missiles, and Vertical Launch Anti- Submarine Rockets (ASROC) (VLA) Two 30mm Close-in Guns Systems (CIGS)
LCS (littoral combat ship; two variants: Freedom & Independence)	24	approx. \$500 million	(USS Santa Barbara award date: 2013, keel date: 2020, launch	388 ft.; 422 ft.	3,410 tons; 3,228 tons	ship's company: 40 mission crew: 35	1 - BAE Systems Mk 110 57 mm gun 4 - .50 cal (12.7 mm) guns (2 aft, 2 forward)



			date: 2021, commissioned: 2023)				1 - 11 cell Raytheon SeaRAM CIWS Other weapons as part of mission modules
SSBN 726 (ballistic missile)					16,764 surfaced	15 Officers	20 missile tubes (Trident II D5)
sub, nuclear powered)	14	about \$2 billion (the late 1990s)	(USS <i>Louisiana</i> hull 743; award date: 1990, keel date: 1992, launch date: 1996, commissioned: 1997)	560 ft.	18,750 tons submerged	140 Enlisted	4 torpedo tubes (MK48 torpedoes)
SSGN 726 (guided missile sub, nuclear powered)	4	Estimated in 2008 at about \$1 billion (including R&D and procurement)	(USS <i>Georgia</i> hull 729; award date: 1976, keel date: keel date: 1979, launch date: 1982, commissioned: 1984)	560 ft.	16,764 tons (17,033.03 metric tons) surfaced 18,750 tons (19,000. 1 metric ton) submerged	15 Officers 144 Enlisted	Up to 154 Tomahawk missiles 4 torpedo tubes (Mk48 torpedoes)
SSN 21 (Seawolf-class sub, nuclear- powered)	3	<i>USS Jimmy Carter</i> (commissioned 2005) \$3.5 billion	(<i>USS Jimmy Carter</i> award date: 1996, keel date: 1995, launch date: 2004, commissioned: 2005)	453 ft.	9,138 tons (9,284 metric tons) submerged	14 officers 126 enlisted	Tomahawk missiles 8 torpedo tubes (MK48 torpedoes)
SSN 688 (Los Angeles class sub, nuclear powered)	26	<i>USS Cheyenne</i> (com- missioned 1996) approx. \$900 million	(<i>USS Cheyenne</i> hull 773; award date: 1989, keel date: 1992, launch date: 1995, commissioned: 1996)	360 ft.	Approximat ely 6,900 tons (7011 metric tons) submerged	16 officers 127 enlisted	Tomahawk missiles VLS tubes (SSN 719 and later) 4 torpedo tubes (MK 48 torpedoes)



SSN 774 (Virginia class sub, nuclear powered)	21	<i>USS Montana</i> (com- missioned 2022) \$2.7 billion	<i>(USS Montana</i> hull SSN 794; award date: 2014, keel date: 2018, launch date: 2021, commissioned: 2022)	377 ft. or 114.8 m and 461 ft. or 140.5 m with VPM	Approximat ely 7,800 tons (7,925 metric tons) submerged 10,200 tons (10,363.7 metric tons) with VPM	15 officers 117 enlisted	Tomahawk missiles, twelve VLS tubes (SSNs 774-783) or two VPTs (SSNs 784 and beyond, and four additional payload tubes (SSNs 803 and beyond) 4 torpedo tubes (Mk 48 ADCAP torpedoes)
LHA 6 (amphibious assault ship, general purpose)	2	<i>USS Tripoli</i> (commis- sioned 2020) \$3.3 billion	<i>(USS Tripoli</i> hull LHA7; award date: 2012, keel date: 2014, launch date: 2017, commissioned: 2020)	844 ft.	4,4971 tons	1,059 (65 officers)	2 - Mk-29 NATO Evolved Sea Sparrow launchers 2 - MK49 Rolling Airframe Missile [RAM] 3 - 20mm Phalanx CIWS mounts 7 - .50 cal. machine guns
LHD 1 (amphibious assault ship, multipurpose)	7	approx. \$822 million	<i>(USS Makin</i> Island hull LHD 8; award date: 2002, keel date: 2004, launch date: 2006, commissioned: 2009)	847 ft.	41,684 tons	73 officers 1,009 enlisted	2 - MK29 launchers for NATO Sea Sparrow 3 - MK15 20mm Phalanx CIWS mounts 8 - MK33 .50 cal. machine guns
LPD 17 (amphibious transport dock)	12	approx. \$2 billion	<i>(USS Fort</i> Lauderdale hull LPD 28; award date: 2016, keel date: 2017, launch date: 2020, commissioned: 2022)	684 ft.	Approximat ely 24,900 long tons (25,300 metric tons) full load	383 Sailors 3 Marines	Two Mk 46 30 mm Close in Guns, fore and aft two Rolling Airframe Missile launchers, fore and aft ten .50 caliber machine guns
LSD 41 (dock landing ship)	6	<i>(USS</i> <i>Ashland [see</i> <i>next column])</i> \$149 million	<i>(USS Ashland</i> hull LSD 48; award date: 1985. keel date: 1988, launch date: 1989,	609 ft.	15,939 tons (16,194.79 metric tons) full load	22 officers 391 enlisted	Two 25mm MK 38 Machine Guns Two 20mm Phalanx CIWS mounts Six .50 cal. machine guns



			commissioned: 1992)				two Rolling Airframe Missile (RAM) mounts
LSD 49 (dock landing ship)	4	(<i>USS Oak Hill</i> hull LSD 51; award date: 1991, keel date: 1992, launch date: 1994, commissioned: 1996) about \$135 million	(<i>USS Pearl Harbor</i> hull LSD 52; award date: 1993, keel date: 1995, launch date: 1996, commissioned: 1998)	609 ft.	16,708 tons (16,976.13 metric tons) full load	22 officers 397 enlisted	Two 25mm MK 38 Machine Guns Two 20mm Phalanx CIWS mounts Six .50 cal. machine guns two Rolling Airframe Missile (RAM) mounts
MCM 1 (mine counter-measures ship)	8	[unable to find in a reasonable amount of time spent searching]	(<i>USS Chief</i> hull MCM 14; award date: 1989, keel date: 1991, launch date: 1993, commissioned: 1994)	224 ft.	1,372 tons	8 officers, 76 enlisted	Mine neutralization system Two .50 caliber machine gun two M60.7 62 mm machine guns two MK19 grenade launchers
AS 39 (submarine tender)	2	[unable to find in a reasonable amount of time spent searching]	(<i>USS Frank Cable</i> hull AS 40; award date: 1974, keel date: 1976, launch date: 1978, commissioned: 1979)	644 ft.	approximately 23,000 tons (23,865.02 metric tons) full load	292 officers and enlisted, 158 CIVMARs Frank Cable [hull AS40]: 206 officers and enlisted, 158 CIVMARs	Four 25mm Mk38 guns
ESB 3 (expeditionary sea base)	3	(<i>USS Miguel Keith</i> [see next column]) \$525 million	(<i>USS Miguel Keith</i> hull ESB 5; award date: 2016, keel date: 1/30/2018, launch date: 8/10/2018, commissioned: 2021)	785 ft.	90,000 tons (fully loaded)	44 Military Sealift Command personnel	None



LCC 19 (command ship)	2	[unable to find in a reasonable amount of time spent searching]	(USS Mount Whitney hull LCC 20; award date: 1966, keel date: 1969, launch date: 1970, commissioned: 1971)	634 ft.	18,874 tons (19,176.89 metric tons) full load	34 officers 564 enlisted	2 Phalanx CIWS 2 - 25mm Mk38 guns
CONSTITUTION	1	not applicable?	USS Constitution; award date: 3/1/1794, keel date: 11/1/1794, launch date: 1797, commissioned: 1797)	204 ft.	2,200 tons		Currently, a museum ship stationed at Boston Harbor
AGER 2 (environmental research ship)	1	converted cargo ship; not applicable?	(USS Pueblo hull AGER 2; award date: ?, keel date: ?, launch date: 1944, commissioned: 1967)	177 ft.	895 tons		Captured by North Korea in the Vietnam War era, now a museum/tourist attraction there
Total Active In-Commission	239						

Appendix B: US Private Shipyards – Major Shipbuilding and Repair Base Overview

EAST COAST

Active Shipbuilding Yards (4)

Bath Iron Works Corporation - Bath, ME
 Electric Boat Corporation - Groton, CT
 Kvaerner Philadelphia Shipyard, Inc. - Philadelphia, PA
 Northrop Grumman Newport News - Newport News, VA

Other Shipyards with Building Positions (1)

Atlantic Dry Dock Corporation - Jacksonville, FL

Repair Yards with Drydock Facilities (12)

Bayonne Dry Dock & Repair Corporation - Bayonne, NJ
 Boston Ship Repair, Inc. - Boston, MA
 Caddell Dry Dock & Repair Company, Inc. - Staten Island, NY
 Colonna's Shipyard, Inc. - Norfolk, VA
 Detyens Shipyards, Inc., Main Yard - North Charleston, SC
 Detyens Shipyards, Inc., Wando Division - Mt. Pleasant, SC
 GMD Shipyard Corporation - Brooklyn, NY
 Metro Machine Corporation - Norfolk, VA
 Metro Machine Corporation - Philadelphia Division - Philadelphia, PA
 Norfolk Shipbuilding & Drydock Corporation, - Norfolk, VA
 North Florida Shipyard, Inc. - Jacksonville, FL



SPEEDE Shipyard, LLC - Norfolk, VA

Topside Repair Yards (12)

Associated Naval Architects, Inc. - Portsmouth, VA
Kerney Service Group, Inc. - Norfolk, VA
Marine Hydraulics International, Inc. - Norfolk, VA
Metal Trades, Inc. - N. Charleston, SC
Moon Engineering Company, Inc. - Portsmouth, VA
Newport Shipyard Company, LLC - Newport, RI
Norfolk Shiprepair & Drydock Corporation - Norfolk, VA
Promet Marine Services Corporation - Providence, RI

Topside Repair Yards (12)

Reynolds Shipyard Corporation - Staten Island, NY
Steel Style, Inc. - Newburgh, NY
The General Ship Repair Corporation - Baltimore, MD
The Hinckley Company - Portsmouth, RI

EAST COAST TOTAL = 29 Yards

GULF COAST

Active Shipbuilding Yards (4)

Bender Shipbuilding and Repair Company, Inc. - Mobile, AL
Northrop Grumman Ship Systems, Avondale Operations - Avondale, LA
Northrop Grumman Ship Systems, Ingalls Operations - Pascagoula, MS
VT - Halter Marine Pascagoula - Pascagoula, MS

Other Shipyards with Building Positions (7)

Alabama Shipyard - Mobile, AL
AMFELS, Inc. - Brownsville, TX
Austal USA - Mobile, AL
Signal International, LLC - East Yard - Pascagoula, MS
Tampa Bay Shipbuilding & Repair Company - Tampa, FL
United Marine Enterprise, Inc., Port Arthur Shipyard - Beaumont, TX
VT - Halter Moss Point - Moss Point, MS

Repair Yards with Drydock Facilities (6)

Atlantic Marine - Mobile - Mobile, AL
Bollinger Gulf Repair, LLC - New Orleans, LA
Bollinger Houston, L.P. - Houston, TX
Gulf Marine Repair Corporation - Tampa, FL
International Ship Repair & Marine Services, Inc. - Tampa, FL
Signal International Texas, LP - D.O.C. Yard - Port Arthur, TX

Topside Repair Yards (17)

Boland Marine & Mfg. Company, Inc. - New Orleans, LA
Bollinger Algiers, LLC - New Orleans, LA
Bollinger Calcasieu, LLC - Sulphur, LA
Bollinger Lockport, LLC - Lockport, LA
Bollinger Texas City, L.P. - Texas City, TX
Buck Kreihs Company, Inc. - New Orleans, LA
CBH Services, Inc. - Orange, TX
Dixie Machine Welding & Metal Works, Inc. - New Orleans, LA
Gulf Copper & Manufacturing Corporation - Port Arthur, TX
Hendry Corporation - Tampa, FL
Houston Ship Repair, Inc., Brady Island Ship Repair Facility - Houston, TX
Newpark Shipbuilding & Repair, Inc., Brady Island Inc. - Houston, TX
Newpark Shipbuilding & Repair, Inc., Pasadena - Pasadena, TX



Newpark Shipbuilding & Repair, Inc., Pelican Island Inc. - Galveston, TX
Orange Shipbuilding Company, Inc. - Orange, TX
Sabine Shipyard, Inc. - Sabine Pass, TX
Signal International Texas, LP - Orange Yard - Orange, TX

GULF COAST TOTAL = 34 Yards

WEST COAST

Active Shipbuilding Yards (1)

National Steel and Shipbuilding Company - San Diego, CA

Other Shipyards with Building Positions (2)

Gunderson, Inc. - Portland, OR

Todd Pacific Shipyards Corporation - Seattle, WA

Repair Yards with Drydock Facilities (7)

Cascade General, Inc. - Portland, OR

Lake Union Drydock Company - Seattle, WA

MAR COM, Inc. - Portland, OR

Puglia Engineering, Inc. dba Fairhaven Shipyard - Bellingham, WA

San Francisco Drydock, Inc. - San Francisco, CA

Southwest Marine, Inc., San Diego Division - San Diego, CA

Southwest Marine, Inc., San Pedro Division - Terminal Island, CA

Topside Repair Yards (6)

Bay Ship & Yacht Company, Alameda - Alameda, CA

Bay Ship & Yacht Company, Richmond - Alameda, CA

Continental Maritime of San Diego, Inc. - San Diego, CA

Dakota Creek Industries, Inc. - Anacortes, WA

Everett Shipyard, Inc. - Everett, WA

Foss Shipyard dba Foss Maritime Company - Seattle, WA

WEST COAST TOTAL = 16 Yards

GREAT LAKES

Other Shipyards with Building Positions (5)

Bay Shipbuilding Company - Sturgeon Bay, WI

Fraser Shipyards, Inc. - Superior, WI

Marinette Marine Corporation - Marinette, WI

Metro Machine Corporation - Industrial Products Division - Erie, PA

Toledo Ship Repair Company, - Toledo, OH

Topside Repair Yards (2)

H. Hansen Industries - Toledo, OH

Nicholson Terminal & Dock Company - River Rouge, MI

GREAT LAKES TOTAL = 7 Yards

NON-CONUS

Repair Yards with Drydock Facilities (3)

Alaska Ship & Drydock, Inc. - Ketchikan, AK

Honolulu Shipyard, Inc. - Honolulu, HI

Marisco, Ltd. - Kapolei, HI

NON-CONUS TOTAL = 3 Yards



Appendix C: U.S. Builders of Small Vessels

Source: Dun & Bradstreet. (n.d.).

Group A - Major Active Builders of Complex Small Vessels (15)				
#	Builder	Builder Since	Location	State
1	All American Marine	1987	Bellingham	WA
2	Blount Boats	1949	Warren	RI
3	C. & C. Marine and Repair	1997	Belle Chasse	LA
4	Chesapeake Shipbuilding	1980	Salisbury	MD
5	Conrad Industries	1948	Morgan City/Amelia	LA
6	Dakota Creek Industries	1977	Anacortes	WA
7	Eastern Shipbuilding	1976	Panama City	FL
8	Gladding-Hearn Shipbuilding	1955	South Somerset	MA
9	Gunderson Marine	1944	Portland	OR
10	Master Boat Builders	1977	Coden	AL
11	Metal Shark Boats	1983	Franklin	LA
12	Nichols Bros. Boatbuilders	1964	Freeland	WA
13	Swiftships (inc. Sewart Seacraft)	1942	Morgan City	LA
14	Textron Marine Systems	1978	New Orleans	LA
15	Washburn & Doughty	1966	East Boothbay	ME
Group B - Other Active Builders of Small Vessels (71)				
#	Builder	Builder Since	Location	State
1	Aluma Marine	2004	Harvey	LA
2	Arcosa Ashland City (formerly Nashville Bridge, Trinity Ashland City)	1977	Ashland City	TN
3	Arcosa Caruthersville (formerly Caruthersville SY, Trinity Caruthersville)	1950s	Caruthersville	MO
4	Bay Welding	1974	Homer	AK
5	Blackwell Boat Works	1988	Wanchese	NC
6	Blakely Boat Works (formerly C. & G. Boat Works)	2001	Mobile	AL
7	John Bludworth Shipyard	1998	Corpus Christi	TX
8	Bourg Dry Dock (inc. Leboeuf Bros. Towing)	1975	Bourg	LA
9	Breaux Bros. Enterprises	1983	Loreauville	LA
10	Breaux's Bay Craft		Loreauville	LA
11	Brix Marine (formerly Armstrong Marine)	2002	Port Angeles	WA
12	Cooper Marine	1984	Saint Petersburg	FL
13	Corinthian Catamarans	1984	Tarpon Springs	FL
14	Corn Island Shipyard	1990	Lamar	IN
15	Duckworth Steel Boats	1972	Tarpon Springs	FL
16	Eagle Fabrication	2003	Sauget	IL
17	Eymard & Sons Shipyard	1972	Harvey	LA
18	Gold Coast Yachts	1983	St. Croix	VI
19	Gulf Craft	1965	Franklin	LA
20	Halimar Shipyard	2002	Morgan City	LA
21	Hansen Boat Company	1927	Everett	WA
22	Heartland Fabrication 1938-2003 (formerly Hillman Barge)	1938	Brownsville	PA
23	Heartland Fabrication 2004-present (formerly Brownsville Marine)	2006		
24	Hope Services	1990	Dulac	LA



25	Inland Boat Works (IBW)		Orange/Bridge City	TX
26	Intracoastal Iron Works		Bourg	LA
27	JamesBuilt	2007	Paducah	KY
28	Jemison Marine & Shipbuilding	1996	Bayou La Batre	AL
29	Main Iron Works	1947	Houma	LA
30	Marine Group Boat Works (formerly South Bay Multihulls and Knight & Carver)	1977	San Diego	CA
31	Marine Inland Fabricators (also known as Sisco)	1988	Panama City	FL
32	Master Marine	1961	Bayou La Batre	AL
33	Mavrik Marine	2010	La Conner	WA
34	Metal Shark Alabama (formerly Horizon SB)		Bayou La Batre	AL
35	Metalcraft Marine	1987	Cape Vincent	NY
36	Midship Marine	1989	Harvey	LA
37	Mobro Marine	1992	Green Cove Springs	FL
38	Moe Enterprises, Howard (formerly Little Hoquiam SY)	1967	Hoquiam	WA
39	Moose Boats	2003	Petaluma	CA
40	Newton Boats	1982	Slidell	LA
41	Orange Shipbuilding (division of Conrad Industries)	1974	Orange	TX
42	Patti Marine Enterprises	1977	Pensacola	FL
43	Progressive Industrial		Palmetto	FL
44	Rodriguez Boatbuilding	1976	Coden	AL
45	Rodriguez Boatbuilding	1976	Bayou La Batre	AL
46	Rozema Boat Works	1955	Mount Vernon	WA
47	SanJac Marine (formerly Sneed SB Channelview)	2000	Channelview	TX
48	Scarano Boat Building	1974	Albany	NY
49	Scarborough Boat Works	1977	Wanchese	NC
50	SENECO	1999	North Kingstown	RI
51	Serodino	1954	Guild	TN
52	Sneed Shipbuilding	1964	Orange	TX
53	Southwest Shipbuilding (formerly Todd Galveston Fab. Shop)		Galveston	TX
54	Southwest Shipbuilding (formerly three Brady Island yards)		Houston	TX
55	Spencer Yachts	1996	Wanchese	NC
56	St. Johns Shipbuilding (formerly Offshore SB)	1970	Palatka	FL
57	Steiner Construction	2005	Bayou La Batre	AL
58	Steiner Shipyard	1954	Bayou La Batre	AL
59	Sterling Shipyard	2009	Port Neches	TX
60	Thoma-Sea Marine (formerly Thoma-Sea Boatbuilders)	1993	Houma	LA
61	Thoma-Sea Marine (formerly Halter Lockport)		Lockport	LA
62	United States Marine	1987	Gulfport	MS
63	Verret Shipyard	1966	Plaquemine	LA
64	Vessel Repair (formerly Burton Shipyard)	1997	Port Arthur	TX
65	Vigor Ballard (formerly Kvichak Marine)	1981	Seattle	WA
66	Vigor Vancouver (formerly Christensen Yachts)	2018	Vancouver	WA
67	Fred Wahl Marine Construction	1988	Reedsport	OR
68	Wesmac Custom Boats	1995	Surry	ME



69	West Gulf Marine (formerly Kelso Marine, Galveston SB)	1966	Galveston	TX
70	Williams Fabrication	1998	Bayou La Batre	AL
71	Yank Marine (including Sunsplash Marina LLC)	1969	Tuckahoe	NJ
Group C - Other Builders Who Have Only Produced a Few Boats in Recent Years (107)				
#	Builder	Builder Since	Location	State
1	A & B Industries	1996	Morgan City	LA
2	ABL Fabricators	2005	Amelia	LA
3	Allen Marine	1985	Sitka	AK
4	Arcosa Madisonville (formerly Equitable Equipment, Trinity Madisonville)	1921	Madisonville	LA
5	Barbour JB Shipyard (formerly Barbour Metal Boat Works)	2017	Oakville	MO
6	Beoufway Contractors	2006	Houma	LA
7	Boconco	1997	Bayou La Batre	AL
8	Bonner Boats		Wetumpka	AL
9	Bordelon Marine Shipbuilders (formerly Mariner SY)		Houma	LA
10	Briggs Boat Works	1980	Wanchese	NC
11	Canal Boats	1996	Fort Lauderdale	FL
12	Candies Shipbuilders (formerly Houma Fab.)	1965	Houma	LA
13	Carolina Yacht Enterprises	2001	Wanchese	NC
14	Central Gulf Shipyard (formerly Oil Barges, Inc.)	1912	New Iberia	LA
15	Chesapeake Boats	1997	Crisfield	MD
16	Colonna's Shipyard	2005	Norfolk	VA
17	CTCO Shipbuilding	1972	Houma	LA
18	Custom Steel Boats	1981	Merritt	NC
19	Derecktor Connecticut (now Hornblower SY)	2001	Bridgeport	CT
20	Diversified Marine	1995	Portland	OR
21	Diversified Marine Services		Chauvin	LA
22	Donjon Shipbuilding (formerly Erie Marine)	2006	Erie	PA
23	Douglas Marine Services	1978	Franklin	LA
24	Edwing Boat		Chinook	WA
25	Elevating Boats	1955	Houma	LA
26	F. & S. Yachts (formerly F. & S. Boat Works)	1997	Bear	DE
27	Fairhaven Shipyard	2007	Fairhaven	MA
28	Feeney's Shipyard	1904	Kingston	NY
29	Fitzgerald Marine Fabricators	1998	Fairhaven	MA
30	FMT Shipyard	2017	Harvey	LA
31	Foss Shipyard	2003	Seattle	WA
32	G. & S. Marine (formerly Lockport Fab'n and R. & S. Fab'n)	1995	Lockport	LA
33	Geo Shipyard	1979	New Iberia	LA
34	Giddings Boat Works	1979	Charleston	OR
35	GNOTS Reserve	2008	Destrehan	LA
36	Great Lakes Towing	2008	Cleveland	OH
37	Gretna Machine & Iron Works (later Halter Gretna and Bollinger Gretna)	1935	Harvey	LA



38	Gulf Coast Steel (formerly J & J Marine, B & B Boat Builders)	1993	Bayou La Batre	AL
39	Gulfbound	2000	Chauvin	LA
40	Gulfstream Shipbuilding (formerly Freeport SB)	1981	Freeport	FL
41	Halter Gulfport (later Trinity Yachts, TY Offshore, now Harvey SY Group)	1992	Gulfport	MS
42	Halter Lockport (now Thoma-Sea Marine)		Lockport	LA
43	Halter Moss Point (later VTHM Moss Point)	1940	Moss Point	MS
44	Halter Pascagoula (later VTHM Pascagoula)	1968	Pascagoula	MS
45	Halter Port Bienville (formerly Gulf Coast Fabrication)	1981	Pearlington	MS
46	Harvey Shipyard Group (formerly TY Offshore)	2008	Gulfport	MS
47	Honolulu Shipyard	1982	Honolulu	HI
48	Intercoastal Marine Fabricators	2013	Larose	LA
49	Island Boats	2000	Jeanerette	LA
50	J-Built	1994	Bayou La Batre	AL
51	JANTRAN	2009	Rosedale	MS
52	JeffBoat (Boats) (formerly Howard's Shipyard)	1939	Jeffersonville	IN
53	JeffBoat (Barges) (being reworked)	1939	Jeffersonville	IN
54	JT Marine	2013	Vancouver	WA
55	Kennedy Construction (formerly Kennedy Ship & Repair)	2001	Galveston	TX
56	Kody Marine	1998	Harvey	LA
57	L A D Services	1980	Stephensville	LA
58	Leevac Shipyards (formerly Zigler SY, later Gulf Island Jennings)	1956	Jennings	LA
59	Madison Boat & Barge	1973	Madison	IN
60	Mann Custom Boats	1988	Manns Harbor	NC
61	Marine Builders	1972	Utica	IN
62	Marine Partners	2007	Bell City	LA
63	Maritime Applied Physics Corp. (MAPC)	2008	Baltimore	MD
64	Martinac Shipbuilding	1924	Tacoma	WA
65	May Ship Repair	1980	Mariners Harbor	NY
66	McDermott Shipbuilding (now Bollinger Marine Fab.)		Morgan City/Amelia	LA
67	Metal Trades	2007	Hollywood	SC
68	Miller Marine		Deltaville	VA
69	Moran Iron Works	2013	Port Calcite	MI
70	Moss Point Marine (later VTHM Escatawpa)	1978	Escatawpa	MS
71	Nashville Bridge (Boats)	1915	Nashville	TN
72	Nashville Bridge (Barges)	1915	Nashville	TN
73	Neuville Boat Works	1969	New Iberia	LA
74	New Generation Shipbuilding	2010	Houma	LA
75	New Orleans Shipyard	2017	Waggaman	LA
76	Newcastle Shipyards (formerly Keith Marine)	1977	Palatka	FL
77	NewSouth Marine Builders	2002	Greenville	MS
78	Nichols Boat Company	2005	Greenville	MS
79	North Shore Marine Terminal (formerly Basic Marine)	1979	Escanaba	MI



80	Noyo Boat Works (formerly Van Peer Boat Works)	1975	Fort Bragg	CA
81	Omega Protein	1967	Moss Point	MS
82	Ocean Marine (formerly Quality Marine)	1972	Bayou La Batre	AL
83	Penn Cove Shellfish/Everest Marine	2005	Coupeville	WA
84	Portier Shipyard	1977	Chauvin	LA
85	Progressive Industrial		Palmetto	FL
86	Quality Shipyards (formerly Quality Eqpmt., later Gulf Island Houma)	1969	Houma	LA
87	Queen Craft	1975	Panama City	FL
88	Raymond & Associates (formerly La Force SY)	1975	Bayou La Batre	AL
89	RiverHawk Fast Sea Frames (formerly Trident Yachts, now Lazzara Yachts)	2012	Tampa	FL
90	Rockland Marine (formerly Snow Shipyards)	1862	Rockland	ME
91	Schooner Creek Boat Works	1977	Portland	OR
92	SEMCO	1994	Lafitte	LA
93	Signet Shipbuilding (formerly Colle SB)	1995	Pascagoula	MS
94	SkipperLiner	1971	La Crosse	WI
95	Sundial Marine Construction	1977	Troutdale	OR
96	Susquehanna Santee Boat Works		Willow Street	PA
97	TEC Skanska (formerly Tidewater Equipment)	1947	Chesapeake	VA
98	Tell City Boat Works	2009	Tell City	IN
99	Tres Palacios Marine	2006	Palacios	TX
100	Trident Pontoons	1998	Tavares	FL
101	Trinity Port Allen (formerly Port Allen Marine Service)	1963	Port Allen	LA
102	U.S. Workboats	2015	Hubert	NC
103	Vigor Alaska (formerly Alaska Ship & Dock)	2002	Kodiak	AK
104	Western Towboat	1982	Seattle	WA
105	Westport Orange SY (formerly TDI Halter and Signal International)	1985	Orange	TX
106	Williams Boat Works	1975	Coden	AL
107	Zidell Marine (formerly Commercial Iron Works)	1960	Portland	OR



Ship Shaping: How Congress and Industry Influenced U.S. Naval Acquisitions from 1933-1938

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Abstract

Past studies of naval acquisitions during the late interwar period often focus on how President Franklin Delano Roosevelt and the Navy Department prepared the nation for the beginning of World War II. However, Congress and the shipbuilding industry played an often-overlooked role in creating the political support needed to expand the Navy during this tumultuous period. Self-interested domestic actors were the essential connectors of the parochial needs of local communities to the country's national interests and ultimately to the geopolitical situation of the interwar years. Studying shipbuilding politics across time can yield key insights into present-day shipbuilding acquisition issues, such as the effects of naval industry consolidation and potential “ally-shoring” of warship production on domestic political support for future naval funding.

Introduction

In the mid-to-late 1930s, the United States faced dueling realities as geopolitical tensions steadily rose while the American public remained resolutely opposed to rearmament. To square this circle, President Franklin Delano Roosevelt, a brilliant strategist with an understanding of the dangers soon to be facing his nation, needed to build the political will to rearm the country's military. The United States Navy, critically important given the nation's position behind two oceans, had few ships, and many of them were outdated. Historians have traditionally focused on FDR's indispensable role in preparing the nation for a second world war. However, Congress and the shipbuilding industry played an often-overlooked role in creating the political support needed to expand the Navy during the tumultuous late interwar period. By injecting domestic politics and parochial concerns into what is often considered a solely geopolitical issue, this legislative-industrial alliance helped prepare the nation and the Navy for World War II.

The geopolitical environment of the 1930s was precarious. The United States was faced with the aggressive actions of Germany and Japan, from the militaristic speeches of Hitler to the Japanese invasion of Manchuria. FDR was forced to confront the possibility of war with adversaries across both the Atlantic and the Pacific. At the same time, Britain and France, America's allies from World War I, were still exhausted from the previous conflict and were barely clinging to their empires. Italy seemed increasingly likely to align itself with Germany and Japan. American interwar naval planning was therefore an exercise in trying to achieve grand, ocean-spanning objectives with highly constrained domestic resources and few international partners.

Despite the looming dangers, many in the United States embraced isolationism and pacifism. After World War I and the protracted fight over membership in the League of Nations, Americans became much more suspicious of the world at large and more skeptical of the need to fight wars to defeat foreign militarism. In step with public opinion, presidents Harding, Coolidge, and Hoover all made abstention from European affairs a core principle of their administrations (Kagan, 2023, p. 262). A 1936 Gallup poll found that 82% of Americans



from across party lines supported banning the manufacture of war material for private profit (Wilson, 2016, p. 32). The public's pacifism contributed to years of military decline, leaving the U.S. Navy in stark need of many improvements. Nevertheless, the Navy was able to rise to the challenge. From fiscal year (FY) 1932 to FY 1939, the Navy would more than double from a force of 114 surface ships and 55 submarines to 242 ships and 125 submarines, with another 105 combatants under construction (Nofi, 2010, p. 41). This success in the face of political headwinds deserves close consideration.

This paper will explore how domestic political factors influenced U.S. naval acquisitions before World War II. Military policies in a democracy are the results of chaotic processes. The acquisition process during the interwar years was not the product of strategists operating in a vacuum to produce a theoretical "military ideal" solution, but rather it reflected complex interactions between rational actors in industry and Congress who were able to translate the grand concepts of American strategy into everyday political compromises.

Unlike what some historians have argued, Congress played a constructive role in building the interwar navy. It was neither a roadblock to action nor a passive receiver of policy. Congress did not just shape overall naval appropriations—as was its constitutional role—it also influenced what kind of ships were funded and where they were built, thereby playing an important role in the nation's strategic planning. Individual congressmen connected the parochial needs of local communities to the United States' national interests and ultimately to the geopolitical situation of the interwar years. All politics, even naval politics, are fundamentally local.

The role played by the shipbuilding industry has also been overlooked or misunderstood. Private shipbuilders have often been presented as either warmongers or war heroes. This paper aims to demonstrate the constructive role that the industry played in national defense policymaking. Through its interactions with regulators and Congress, it helped make clear the local benefits of greater military spending and ensured the survival of necessary defense production capacity. The domestic interests of congressmen in protecting and increasing employment in their districts dovetailed with the desire of the Navy and shipbuilding industry to construct ships, creating a Navy-Congress-industry alliance that was an essential component of the United States' preparation for World War II.

FDR's Navy? The National Industrial Recovery Act

The need for additional naval spending was painfully clear by the start of FDR's first term in 1933. In the previous administrations' search for efficiency, funding for fleet operations and maintenance had stagnated even as the Navy's needs had increased. Only in 1933 did the money spent on fleet maintenance and operation begin to approach its 1922 levels of \$192 million (Marolda, 1998, p. 77). A Navy memo to FDR from April 1933 notes that without sufficient maintenance funding "the material condition [of the fleet] steadily goes down" (*Expenditure 1934*, 1933, p. 2). Shipbuilding orders also plunged during the interwar years. The Washington and London Naval Treaties—international naval arms control agreements signed in 1922 and 1930 in response to global anti-war sentiment—put in place nation-specific limits on naval tonnage in certain warship categories and a 15-year freeze on new battleship construction (Kennedy, 2022, p. 21). However, in 1933 the United States was not close to its treaty tonnage maximums across many ship classes (Kennedy, 2022, p. 20).

Due to reduced orders, the shipyards which built and repaired the fleet suffered. The peacetime Navy relied heavily on both private and government-owned shipyards, which had to compete for contracts and their survival (Heinrich, 2020, p. 7). This competition led to many political disputes, which will be explored in detail later. Intense competition for a



limited number of contracts forced many shipbuilders to take contracts at a loss, and many did not survive the interwar years. Only six out of 54 of the shipyards that had started up to meet the increased demands of WWI would remain active in the interwar period. Even shipyards established before WWI suffered. Half ceased building new ships or closed during the interwar years (Heinrich, 2020, p. 11). Though many naval contractors also built civilian vessels, demand for these collapsed during the Great Depression. Unemployment at private concerns soared and shipbuilding capacity withered away as yards closed or converted to other industries like railcar manufacturing to survive (Heinrich, 2020, p. 13). The public shipyards were also under pressure. The aforementioned Navy memo to FDR stated that without major shipbuilding activities there is “no justification for the great number of Navy stations and yards now kept open” (*Expenditure 1934*, 1933, p. 3). By 1933, the nation’s shipyards were in desperate need of support.

High unemployment, common across the country during the Great Depression, was especially dangerous in shipyards as it compromised American defense capacity. Building warships is a specialized art that requires highly skilled workers and management teams (Heinrich, 2020, p. 8). The dearth of orders during the interwar years made it difficult for yards to retain their painstakingly assembled workforces. This was an issue of national security—without an existing shipyard industrial base, the nation could not be effectively mobilized for naval warfare.

In the face of this shipbuilding crisis, domestic politics impacted the foreign and military policies FDR was willing to support. FDR had campaigned for president in 1932 as no more of an internationalist than his Republican predecessors, but he had a clear vision of the geopolitical situation facing the United States and was aware of the need for the United States to be strong in a dangerous world (Gaddis, 2018, p. 281). Yet despite FDR’s internationalist instincts, many of the senators that Roosevelt relied on for his congressional coalition in his first term were progressive Republicans—and dedicated anti-internationalists (Kagan, 2023, p. 355). As a result, FDR was reluctant to appear too militaristic by pushing for increased spending and risk losing support for his legislative priority of domestic economic recovery (Kagan, 2023, p. 357).

FDR was nonetheless deeply involved in Navy affairs, a carryover from his years as President Woodrow Wilson’s Assistant Secretary of the Navy (Marolda, 1998, p. 4). FDR’s hands-on micromanagement was enabled by dysfunction at the top levels of military and civilian leadership in the Navy. FDR called himself “my own Secretary of the Navy” and selected a sickly 70-year-old, Claude Swanson, to ostensibly run the Department as the official Secretary (Heinrich, 2020, p. 31). FDR appointed Henry Roosevelt, a distant cousin who was also in poor health, to be Assistant Secretary of the Navy (Levine, 1988, p. 70). FDR worked closely with senior officers in the Navy Department, going so far as to order Rear Admiral Emory “Jerry” Land, the Chief Constructor of the Navy, to confer with the president before awarding any major shipbuilding contract (Land, 1958, p. 160).

FDR’s micromanagement dovetailed with macro concerns as he incorporated naval shipbuilding into his New Deal recovery plan. In May 1933, FDR submitted the legislation that would become the National Industrial Recovery Act (NIRA) to Congress. It stipulated, among other economic relief efforts, that public works funding could be used for the construction of naval vessels for the purposes of reducing unemployment in areas around shipyards (McGrath, 2019, p. 88). On June 17, 1933, the day after NIRA’s passage, FDR allocated \$238 million for the construction of 32 warships, including 22 destroyers and two aircraft carriers, with a later additional allocation of a further \$40 million for more shipbuilding (Marolda, 1998, p. 78). Some historians credit FDR’s use of NIRA funding as the key impetus behind the rebuilding of the Navy in the interwar period (McGrath, 2019, p. 89).



Supporting a major naval buildup was FDR's most controversial first-term foreign policy move, but his support for the Navy undoubtedly enhanced its ability to rebuild its readiness and was an act of political bravery in an isolationist political environment.

However, the idea to classify naval shipbuilding as public works did not originate in FDR's administration but instead with pro-shipbuilding members of the Navy Department and Congress. As early as 1932, Navy officers had begun discussing shipbuilding as unemployment relief, but the Hoover Administration rejected this initiative (Heinrich, 2020, p. 32). After FDR assumed office in 1933, the shipbuilding-as-public-works idea was revived by ADM. Land and his congressional allies. ADM. Land worried that private shipyards were at the "starvation point" and that east coast yards would fall apart leading to a loss of precious shipbuilding expertise and a rise in unemployment (Heinrich, 2020, p. 32). In his memoir, ADM. Land claims that he was "directly responsible" for FDR's allocating the \$238 million of NIRA funding to the Navy for ship construction. He notes that he, other naval personnel, and the Chief Clerk of the House Naval Affairs Committee, were responsible for having the words "ships and aircraft" written into the public works bills of the New Deal, thereby authorizing the money to be used for naval construction (Land, 1958, p. 145). The Navy Department was not particularly unified in the 1930s, which allowed for individual activism from officers who were not always speaking for the Department at large.

The main legislative advocate for the Navy was Representative Carl Vinson (D-GA), the chairman of the House Naval Affairs Committee. A longtime advocate of naval spending, Vinson folded the argument about the defense necessity of giving the shipyards work into the prevailing political movement for economic recovery (Cook, 2004, p. 63). In December 1932, he lobbied FDR to consider shipbuilding as a form of public works, arguing that extending the public works program to include shipbuilding would help stimulate the economy and create new jobs. He urged FDR to build the Navy up to treaty strength, championed keeping private shipyards active by awarding them most of the contracts, and called for retaining the east coast navy yards in at least an "active by minimum" state of commission as he argued that "unproductive overhead" should be considered part of the cost of defense (Levine, 1988, p. 371).

This joint Navy-Congress push led FDR's New Deal to include significant funding for shipbuilding. With Vinson's help, both the Economy Act for 1934 and the Credit Act for 1934—parts of the New Deal reform package—classified ships and aircraft as public works (Levine, 1988, p. 75). Furthermore, the Navy Department leveraged its personal relationships with FDR to push for pro-Navy positions within the Executive Branch (Levine, 1988, p. 72). ADM. Land knew FDR well from FDR's time as Assistant Secretary of the Navy in WWI (Land, 1958, p. 4). Personal appeals allowed the Navy to skirt the president's gatekeepers, and combined with FDR's own personal inclinations, ensured that FDR allocated a significant chunk of the NIRA funding to the Navy. Before any other NIRA allocations had been made, and before the economy-minded Director of the Budget Lewis Douglas could intervene, pro-shipbuilding figures from the Navy Department and Congress convinced FDR to give the Navy the aforementioned \$238 million to build 32 naval vessels (Levine, 1988, p. 93). Thus, while FDR obviously played a critical role in funding the Navy via NIRA, the pro-Navy alliance deserves more credit than it often receives for coming up with the idea, laying the legislative and political groundwork for its implementation, and pushing FDR to support it once in office.

Congress' s Formal Influence: The Vinson-Trammel Act

Congress had a large degree of constitutionally granted influence over the levels of naval funding. In practice, the precise amounts authorized to be spent on the Navy's various



expenses were decided by the House and Senate Naval Affairs Committees (Marolda, 1998, p. 78). The funding authorized by Naval Affairs Committees then had to be appropriated by the appropriations committees (Marolda, 1998, p. 78). The whole of Congress subsequently voted on authorization and appropriation bills. The legislature served as a conduit for public opinion to affect shipbuilding funding levels. Often in the interwar period this meant keeping spending down. The impact of the complex currents of public opinion on naval spending can best be seen in the almost simultaneous passage of the Vinson-Trammell Act and the commencement of the Special Committee on Investigation of the Munitions Industry, often called the Nye Committee.

The Vinson-Trammell Act of 1934 was the critical naval funding legislation of FDR's first term. Sponsored by Vinson and introduced in January 1934, the bill provided a blanket and long-term authorization for the Navy to build up to the Washington Naval Treaty limits—well above the Navy's then-current levels—and replace the fleet's rapidly ageing ships with newer vessels (H.R. 6604, 1934). The Vinson-Trammell Act did not technically fund these new ships, but as Vinson said “this act is not a mere piece of paper. It means real fighting ships” (Cook, 2004, p. 84).

Much like the NIRA shipbuilding funding, the Vinson-Trammell Act was the creation of Vinson, his congressional allies, and high-ranking members of the Navy Department. Vinson and ADM. Land, supported by Chief of Naval Operations Admiral William H. Standley, worked closely together to capitalize on the momentum created by the NIRA funding. There has been some historical dispute over the original source of the bill. Did Vinson's staff write it with ADM. Land's help, as ADM. Land claimed, or was it crafted by Navy Department staff for CNO Standley and then co-opted by Vinson, as CNO Standley maintained (West, 1980, p. 349)? The weight of evidence, including an analysis in a recent biography of Vinson, supports CNO Standley's claim that the Navy wrote the entire bill (Cook, 2004, p. 87). Regardless, it certainly originated out of an alliance between pro-Navy congressmen and the Navy's top brass. There is some irony, therefore, in the remarks with which Vinson introduced the Vinson-Trammell Act: “In this country the Army and Navy have practically nothing to do with shaping our national policies” (78 Cong. Rec. 1598, 1934).

Vinson introduced the bill instead of the Navy Department to maneuver around anti-naval spending officials within FDR's administration. These officials were led by Budget Bureau Director Douglas, who was opposed to any additional spending that might damage the administration's financial footing. In practice, any legislative proposal from the Department had to first be approved by Douglas. The Navy circumvented that requirement by encouraging Vinson to submit the bill as his own. Vinson, as chairman of the House Naval Affairs Committee, duly submitted the bill to Congress and then requested a Budget Bureau review, which forced the administration to stop prevaricating and announce its approval of the shipbuilding authorization (West, 1980, p. 372).

FDR generally declined to intervene in factional disputes within his administration until absolutely required. He did not support the Navy Department when they pushed for additional appropriations to be placed within the draft of the Vinson-Trammell Act to fund the authorized ships. Roosevelt was wary of the strength of the isolationist and anti-armaments factions in Congress and the anti-spending personalities within his own administration. Douglas wanted a balanced budget for FY 1935 and so opposed supplemental funding. The Budget Bureau suggested delaying the start of some ships or reducing the overall ship numbers while the Navy wanted to start all the ships immediately (Levine, 1988, p. 240). FDR let the bureaucracies clash while the bill was being considered until finally siding with the budget-conscious faction to avoid being seen as a warmonger (West, 1980, p. 373).



FDR played a passive role in the creation of the Vinson-Trammell Act. In addition to staying above the factional disputes in the writing of the bill, he also declined to offer much public support for the legislation during its consideration. When asked about the legislation right before it was introduced, FDR responded that “I never heard of it at all, except what I read in the papers. The Secretary of the Navy said nothing, the Assistant Secretary said nothing, and neither did the Chief of Operations” (*Press Conference #82*, 1933, p. 592). This was quite close to an outright lie, as FDR knew that legislation was being developed. In private, FDR played both sides and expressed approval for authorizing new funding, but he stayed silent on new appropriations and a shipbuilding schedule (West, 1980, p. 372). FDR stressed that the bill was just an authorization to mollify isolationists. He simultaneously reiterated his commitment to arms control by expressing hope for a naval conference to be held in 1935 to extend existing limitations and create new ones (Heinrich, 2020, p. 41).

FDR wanted Vinson to lead the charge on the shipbuilding bill because the early investigations of the Nye Committee into the activities of arms manufacturers were already underway. The 1934 publication of the best-selling book *Merchants of Death*, which argued that the private arms industry were warmongers who caused WWI, had stoked isolationist and anti-armaments attitudes (Kagan, 2023, p. 353). A drumbeat of findings of corporate malfeasance in the shipbuilding industry were made public, leading Senator Gerald Nye (R-ND) to ask the Senate on February 8, 1934, to investigate the role of the armaments industry in causing WWI and other conflicts. The Senate authorized this committee, with Nye as its chairman, on April 12, 1934—a mere two weeks after Vinson-Trammell Act was signed into law by the president (78 Cong. Rec. 6476, 1934; Levine, 1988, p. 233). FDR did not want to be seen as a booster of the military in this political climate. Historian Mark Wilson convincingly argues in *Destructive Creation* that the Nye Committee was not the creation of naïve isolationism but rather a concerted effort to rein in private industry’s role in defense production with the goal of the nationalization of the defense industry, including private naval shipbuilding (Wilson, 2016, p. 41).

The revelations that would spur the Nye Committee galvanized congressional opposition to the Vinson-Trammell Act amongst isolationists and congressmen whose districts were inland and did not contain maritime industries. As the bill was being considered, it became public knowledge that major private shipbuilders had coordinated their bids on NIRA naval contracts to increase their profits (West, 1980, p. 413). During debates on the Vinson-Trammell Act, opponents repeatedly referred to the discovery of a shipbuilding cartel that dated back to the 1928 heavy cruiser contracts (78 Cong. Rec. 3814, 1934). Nye and his allies built on this momentum by amending the Vinson-Trammel Act. Nye reinstated a clause from earlier shipbuilding measures which forced the Navy to order half of its warships from government shipyards (Levine, 1988, p. 234). Representative Charles W. Tobey (R-NH) introduced an amendment to cap private shipbuilder profits on government contracts at 10%, a number which he seems to have pulled from thin air (West, 1980, p. 403). Tobey’s 2nd District was not within commuting range of any naval shipyard.¹ Other anti-private industry amendments and verbal attacks came from Nye’s congressional allies from Oklahoma, Illinois, and Iowa, all areas which were unconnected to naval industries (78 Cong. Rec. 1602, 1934). One exception was Senator Homer T. Bone (D-WA) who argued to adopt an amendment guaranteeing a 50-50 split between private and government shipyards. Senator Bone’s district was home to a government yard, Puget Sound Naval

¹ See map “Congressional Districts and Commuting Distance to Shipyard (Northeast)” in a later section. While Tobey’s 2nd district was not within commuting distance of any major shipyard, New Hampshire’s 1st district was close to Bath Iron Works in Maine and its representatives often supported naval acquisitions funding.



Shipyard, which incentivized him to elbow the private yards out of his district's way (*Hearings on S. 2493*, 1934, p. 12).

By contrast, the proponents of the Vinson-Trammell Act were largely connected to the Navy or naval industries. A key supporter was Representative Patrick H. Drewry (D-VA) whose interests were aligned with the nearby private shipyard, Newport News. Congressmen representing shipyards would cross party lines to support key employers in their districts. Charles Wolverton (R-NJ) gave an impassioned speech in favor of the bill that explicitly mentioned that New York Shipyard in Camden, New Jersey lay within his district (78 Cong. Rec. 1612, 1934). Politicians unconnected to naval industries also supported the Vinson-Trammell Act for ideological (pro-Navy) or party alignment reasons. The most prominent of these was Vinson himself. His district in Georgia had few ties to the Navy, but he nevertheless was the Navy's most prominent supporter because of his belief in the importance of military preparedness (Cook, 2004, p. 26).

The passage of the Vinson-Trammell Act was also facilitated by path-dependency. Advocates of shipbuilding benefitted greatly from shipbuilding's ability to create its own momentum. The Navy had already started construction on new ships in 1933 with NIRA funding, creating around 20,000 jobs in shipbuilding districts (West, 1980, p. 445). The Vinson-Trammell Act was designed to supersede and expand upon this program. If the Vinson-Trammell Act did not pass to authorize the construction of even more ships, these newly created jobs would vanish and congressmen seeking reelection in these districts would face unhappy constituents.

Geopolitical concerns also influenced congressional debates on the Act. Opponents repeatedly demanded to know who exactly the United States intended to fight with an enlarged navy (78 Cong. Rec. 3812, 1934). Japan was the focus of both sides of the debate. Many congressmen worried that a naval buildup would provoke an arms race (78 Cong. Rec. 1620, 1934). Others—including some isolationists and pacifists—insisted that parity with Japan was the best way to ensure peace (Kagan, 2023, p. 359). Supporters of the bill argued that Japan's de facto near-parity with the U.S. Navy would encourage aggression in the Pacific (78 Cong. Rec. 1615, 1934). The Washington and London Treaties loomed large over these geopolitical discussions, with many Congressmen expressing both frustration with limits on American naval power and others supporting the principles of disarmament (78 Cong. Rec. 1610, 1934).

The Vinson-Trammell Act curtailed the powers of Vinson's own House Naval Affairs Committee (HNAC). The bill gave a blanket authorization for shipbuilding up to treaty limits, which meant that HNAC would no longer need to propose new shipbuilding authorizations annually. Only the naval subcommittees of the appropriations committees of the House and Senate would have any direct say on naval shipbuilding via the power of the purse. Historian Michael Allen West argues that HNAC took itself out of the annual congressional review process because it wanted decisive action on naval spending, it expected that the basic conservatism of appropriations would ensure authorizations were mostly funded each year, and because Vinson thought removing HNAC from the process would give him greater personal sway in the legislative implementation of the Vinson-Trammell Act (West, 1980, p. 488).

In addition to West's analysis, Vinson was arguably making a calculated decision to move naval appropriations out of an unfavorable political environment in Congress. Abrogating HNAC's authorizing prerogative sidelined the general membership of the House, who not need to vote annually on new shipbuilding authorizations. The general membership was less inclined to support the Navy than the members of the naval or appropriation



committees, especially after the Nye Committee's revelations. Vinson could well have been trying to maximize his gains while he still had support for shipbuilding. Moreover, Congress had already approved the use of NIRA funds for shipbuilding, and FDR's allotment of \$238 million of public works funding for shipbuilding was controlled by the executive branch. Some naval appropriations were therefore outside of Congress's direct control—at least until new funding for public works programs was needed (Levine, 1988, p. 160). Taken together, the Vinson-Trammell Act and NIRA funding were able to remove some elements of shipbuilding authorization and appropriation from Congress's control—at least for a while. This allowed the Navy and its congressional backers to minimize public scrutiny of the naval buildup to treaty limits, which had been an issue in the past and was looking troublesome again (Levine, 1988, p. 163).

The passage of the Vinson-Trammell Act would be the high point of congressional involvement with the Navy for the next several years. Through 1936, funding from regular appropriations for naval construction would take second place to funding from NIRA. Immediately after the bill's passage, Congress would appropriate a mere \$11.7 million for Navy's Bureau of Construction & Repair for FY 1935. This was less than half of FDR's request, less than the previous year's appropriation, and far less than the funding from NIRA (McGrath, 2019, p. 91; United States. Bureau of the Budget and United States. Office of Management and Budget, 1934, p. 432).

Table 1. Navy Expenditures on Fleet Replacement and Expansion, FY 1934 to FY 1937, in Dollars²

	FY 1934	FY 1935	FY 1936	FY 1937
Regular Funding	42,999,865	38,909,527	78,878, 274	152,815,953
Emergency Funding	28,457,056	98,829,106	108,017,106	35,094,576

Skeptics of the military understood the impact of the pro-Navy faction's maneuvers. During the debate over the Vinson-Trammell Act, Rep. Gerald Boileau (R-WI) declared that if the bill passed, "Congress at least will never again have anything to say about the number of ships that shall be in the Navy" (78 Cong. Rec. 1622, 1934). Rep. Wirt Hastings (D-OK) made an explicit appeal to the Western progressives who were both key Roosevelt supporters and staunch isolationists, saying that if the Act were to pass there would be "no further need of a legislative Naval Affairs Committee" (78 Cong. Rec. 1622, 1934). Both accusations were slight exaggerations, but Vinson did acknowledge that his bill would mean the "legislative committee is delegating its authority to the President to make his recommendation to the Bureau of the Budget" (78 Cong. Rec. 1622, 1934).

The NIRA Navy: Free From Congress but Not Politics

NIRA and the Vinson-Trammell Act may have altered where shipbuilding funding decisions were made, but they did not take the politics out of the process of appropriations. Shipbuilding and other kinds of big-ticket military spending are inherently political questions as policymakers' choices create winners and losers. Politics will inevitably occur when a limited resource must be divided across different groups. The pro-Navy faction thought that the new political environment would be more sympathetic to naval construction after much

² The underlying data for this chart comes from the FY 39 budget (United States. Bureau of the Budget and United States. Office of Management and Budget, 1938, p. 859). This line item is alternatively called Increase of the Navy or later Replacement of Naval Vessels. It was the main line for funding to build the Navy up to the strength authorized by the Vinson-Trammell Act, though it did not capture all funding spent on naval construction during these years. Additionally, some of these figures may not align with other noted shipbuilding appropriations in this paper as the table tracks expenditures by their original funding type, which can be slightly out of sync with appropriations for the same fiscal year as funding is not always instantaneously spent.



of the Navy's shipbuilding funding stream moved out of Congress and into the hands of the NIRA public works administrators (Levine, 1988, p. 94). However, this optimism did not last long.

The unshackling of Navy funding from congressional oversight did not free the Navy from skeptical paymasters. It just switched their antagonists. The overseeing entity of the Navy's new NIRA funding stream was the Public Works Administration (PWA). FDR had personally approved the \$238 million allocation to the Navy before he installed the Permanent Administrator for Public Works, Secretary of the Interior Harold Ickes. That turned out to be a good thing, because Ickes did not want to give the PWA's money to the armed forces; he felt that doing so did not solve the unemployment problem and unfairly favored the civilian workers of the military over everyone else (Ickes, 1953, p. 217). In his memoir, ADM. Land states that he felt that Ickes simply hated giving money to the Navy (Land, 1958, p. 145).

Robert H. Levine's *Politics of American Naval Rearmament, 1930–1938* masterfully illuminates the many problems the Navy faced in trying to squeeze money from the PWA. The parsimonious Ickes and the administrators of the various work relief programs—the PWA was just one of the many “alphabet soup” work relief agencies—were reluctant to grant money for naval construction as they felt it did not do enough to alleviate unemployment in the general population. The Navy and PWA addressed different kinds of unemployment: the former wanted to keep its skilled workers employed and the latter wanted to employ as much of the public as possible. Shipbuilding is an especially capital-intensive industry and requires its workers to have a high degree of skill which cannot be attained overnight. The work relief agencies generally sought to fund work programs which could employ a lot of people quickly and were labor, not capital, intensive (Levine, 1988, p. 205). Where the agencies did allocate funding to the Navy, it was typically for labor intensive but relatively low military value efforts like clearing the grass on naval bases or painting dormitories (Levine, 1988, p. 191).

FDR's influence on naval spending during this era is most visible in his direct interventions with the PWA over naval construction funding. After FDR allocated that first burst of \$238 million for ships in the FY34 program, the Navy repeatedly asked FDR to intercede with the PWA. As a result, the next major round of PWA funding to go to shipbuilding was again approved directly by FDR, not the reluctant Ickes. On June 29, 1934, FDR allocated \$40 million for naval shipbuilding in FY 35 from the public works funding in the FY 35 emergency budget (Cook, 2004, p. 102). These funds paid for the commencement of construction of the first 20 ships and 225 aircraft authorized in the Vinson-Trammell Act (West, 1980, p. 440). These contracts were awarded by November 1934, with nine going to private yards and 11 going to government yards (Claude Swanson to FDR, 1934; McGrath, 2019, p. 90). FDR had promised this additional funding to the Navy during the consideration of the Vinson-Trammell Act and announced it a month after the bill's passage (*Press Conference #121*, 1934, p. 347). The funding was compensation for FDR's not having backed the Navy in the dispute with Budget Director Lewis over including new appropriations in the Vinson-Trammell Act (Levine, 1988, p. 240). The Navy would continue to ask for FDR to intercede with the PWA, though without much success after the first two allotments. A typical request of this kind is the Navy's January 1935 memo to FDR asking for his help getting the PWA to allocate funding for an expansion of the Mare Island Naval Shipyard (Henry Roosevelt to FDR, 1935).



The Congress-Industry Symbiosis

Having directly allocated money for the major elements of the naval construction programs of FY 34 and FY 35, FDR was a major reason for the initial naval buildup of 1933–1934, but he hardly accomplished this alone. Congressmen actively influenced acquisitions that occurred under NIRA's auspices, even though these acquisitions were under the executive branch's authority. Congressmen with an economic or ideological interest in naval affairs routinely lobbied the PWA and Navy officials to get their desired policy outcomes. They might have had no formal control over NIRA allocations, but congressmen could credibly tie Navy or PWA actions on shipbuilding to their votes on other legislative issues.

Congressmen were keenly aware of how specific appropriations and regulations could benefit their districts' shipyards and workers. Past studies of shipbuilding politics have presented qualitative anecdotes of how the presence of a shipyard in a congressman's district might have led them to use their influence to support naval bills. This paper argues that these shipyard-linked congressmen exerted influence on naval shipbuilding policy with a degree of precision that has been previously overlooked. They used informal influence methods such as lobbying Navy and PWA officials that have not been fully explored. One kind of decision that would influence congressmen's behavior was the class of ship being funded. Because shipyard sizes varied, districts would benefit only if the ships ordered by Congress could be built in their yards. If the shipyard in a member's district was too small to construct heavy cruisers or battleships, they would therefore be far more willing to support funding for destroyers, for example. Funding clauses that determined if a contract would go to a private or government shipyard also incentivized congressional interventions. Spending issues like these distorted the composition of the fleet and where U.S. shipbuilding capacity was located. However, they also ensured that higher levels of naval funding could pass through the penny-pinching Congress by widening shipbuilding's base of political support.

Congressional lobbying was particularly pronounced regarding the Boston and Charleston Navy Yards. The Navy Department believed it had too much shipbuilding capacity on the east coast and viewed these two shipyards as excess to its requirements (*Expenditure 1934*, 1933, p. 3). However, both shipyards were championed by powerful congressional delegations. These congressmen lobbied the Navy to get more shipbuilding assigned to their local yards to keep high-paying jobs in their districts, and the Navy responded by asking them to help with the Navy's problems with the uncooperative PWA. Rep. John McCormick (D-MA) wrote to the Navy Department in 1933 asking for additional shipbuilding work for the Boston Navy Yard, which was in his district (Levine, 1988, p. 166). McCormick was a powerful Democratic congressman on the House Ways and Means committee, and his request carried the weight of a congressman who would vote on all future Navy appropriations. Even if allocating NIRA funding was not technically under his jurisdiction, he could still throw his weight around. The Navy told McCormick that he could help obtain work for the Boston Navy Yard by pressuring the PWA to approve funds for shipbuilding projects there (Levine, 1988, p. 167).

The Charleston Navy Yard is a particularly striking example of the influence of powerful congressmen. Charleston Navy Yard had not constructed many ships since WWI (Carroll, 2023).³ However, both of South Carolina's senators were Democrats with influential committee positions. Senator Ellison Smith was the chairman of the Agriculture and Forestry

³ The author compiled and validated a dataset that includes all major surface combatants acquired by the U.S. Navy from 1930–1940, as well as the locations and ownership status of all active naval shipyards during this period. The original data source for the shipbuilding information is <http://shipbuildinghistory.com/navalships.htm>. The data was validated using primary sources from the FDR Library. For more detailed information on data sources and methods, see the ReadMe file in the linked GitHub repository.



Committee and was a committed pro-Navy member of Congress. He had pushed for PWA funding for the construction of additional shipways in Charleston over both Navy and Budget Bureau objections (Levine, 1988, p. 375). Senator James Byrnes was the chairman of the naval subcommittee of the Appropriations Committee, which was hugely influential over the Navy's regular budget. Byrnes was also a close congressional ally of Vinson (West, 1980, p. 496). As a result of the senators' influence, NIRA funding was allocated to be spent at the Charleston yard (Levine, 1988, p. 376). At the time, Charleston Navy Yard was unable to build ships larger than destroyers, even with the improvements Senator Smith forced through the PWA (Carroll, 2023). As a result, to satisfy its political supporters, the Navy ordered the construction of a gunboat, a type of ship it had generally turned away from since the turn of the 20th century and which would be of little use in a Pacific war (Caiella, 2020). From 1933 to 1937, the Navy would allocate contracts for six destroyers and additional small craft to be constructed at the yard (Carroll, 2023).

Congressmen were attentive to the minute differences in funding bills which could determine whether contracts went to the shipyards in their districts or not. In addition to the above examples of congressmen supporting the government-owned yards in their districts, congressmen also fought to promote local private shipyards, occasionally at the expense of government yards. In January 1934, during the HNAC hearing on the Vinson-Trammell Act, Rep. John McGrath (D-CA) expressed his displeasure that private shipyards near his district, especially the Hunter Point plant of Bethlehem Shipbuilding Corporation, had not received NIRA naval contracts. "Why should the two yards in San Francisco be left idle?" he repeatedly asked the testifying Navy officials (*Hearings on H.R. 6604*, 1934, p. 184). Vinson tried to placate McGrath by reminding him that the Navy had allocated several ships to Mare Island Naval Shipyard, which was also in San Francisco (*Hearings on H.R. 6604*, 1934, p. 184). McGrath was not swayed. He represented California's 8th district, which comprised the counties to the south of San Francisco. Mare Island was in Vallejo, north of San Francisco, out of his district and not within commutable distance.⁴ The attention paid by congressmen to naval shipbuilding policy could be refined down to a matter of mere miles, and it paid off.



⁴ Bethlehem's San Francisco plant was not actually located in Rep. McGrath's 8th district, but rather the nearby 5th district. Given its proximity to the 8th district, workers from Rep. McGrath's district would have been able to easily commute to Bethlehem San Francisco. On the other hand, Mare Island Naval Shipyard was in the 3rd district, on the opposite side of the bay from the 8th district and out of the typical commuting distance of a worker at the time. This paper has assessed the influence of shipyards by examining commuting radii, rather than purely along district lines, because work patterns do not neatly align with district borders. Congressmen at the time also thought about political influence in terms of their constituents' jobs, not district lines. Rep. William P. Connery Jr. (D-MA), responding to a comment that he supported public shipyards because he had one in his district, said "I have many constituents who work in the Charlestown Navy Yard at Boston. The Charlestown Navy Yard is in the district of my friend and colleague, Mr. Douglass" (78 Cong. Rec. 1626, 1934).

Figure 1. Shipyards Building U.S. Naval Vessels in California, 1930–1939⁵

In the same HNAC hearing, Vinson would later say “I think, Mr. McGrath, we can trust the Navy Department to try to allocate whatever building is done in a fair and in a liberal manner” (*Hearings on H.R. 6604*, 1934, p. 184). Given McGrath’s prominent role on HNAC, and Vinson’s prodding, it is perhaps unsurprising that Bethlehem San Francisco received contracts for two destroyers, DD-400 *McCall* and DD-401 *Maury*, in 1936—the next possible appropriations cycle (Carroll, 2023). This is all the more remarkable given that Navy Secretary Claude Swanson had argued in early 1934 that “there are very few private shipbuilding plants on the west coast capable of doing satisfactory work” (Claude Swanson to FDR, 1934, pp. 2–3). Other west coast congressmen tried to direct naval contracts to the private shipyards in their districts by introducing a legislative measure in the spring of 1936 to permit Pacific coast private shipyards to add 6% to their Navy bids to “account for transportation costs”—another blatant attempt at local favoritism (Levine, 1988, p. 395).

Domestic politics impacted the implementation of American geostrategic goals by, at least on the margins, forcing the Navy to purchase ships it did not need in yards it did not want to operate just to keep its political supporters happy. Keeping these yards open and active and distributing production across the country led to inherently higher cost per ship, a fact that the Navy was aware of at the time (Charles Edison to FDR, 1937). However, much as modern defense contracts are spread across the country to ensure congressional buy-in, this cost inefficiency was not necessarily a negative nor was it unintended. Distributing expenditures across a wider area may have sacrificed the benefits of economies of scale, but it also ensured that the political environment was permissive of funding a larger, albeit more expensive, navy. Another key side effect of distributing contracts across more shipyards than would have been optimal for purchasing costs was the preservation of those yards, which could then be mobilized for surging wartime production. Pork-barrel politics in the interwar years were cost inefficient but politically necessary for implementing an American grand strategy that anticipated a two-ocean war.

Private Shipbuilders and the Effects of Lobbying

The shipbuilding industry also played a major role in determining the distribution of naval contracts. The shipbuilding industry’s interest in manipulating contracts was driven by market conditions. Unlike gun and ammunition manufacturers, which sold mostly abroad, shipbuilders were especially reliant on the government as their primary customer (Koistinen, 2015, p. 258). The government had also played a key role in shaping the creation of the shipbuilding industry in the 19th and 20th centuries, and the industry remained overwhelmingly intertwined with the federal government (Pedisich, 2016, p. 4). Shipbuilders therefore leveraged their connections with local politicians to shape legislation and pressured the Navy to adopt favorable regulations.

Private shipbuilders had a vested interest in lobbying for ship construction because of the product-driven nature of the market at the time. Product-driven markets are distinct from sustainment-driven markets, in which industry contractors have lucrative, long-term contracts to support a product once it is sold. While the modern defense industry derives much of its profit from long-run sustainment contracts, and therefore has an incentive to support existing systems with contracts for upgrades and routine maintenance, the interwar naval industry was not able to benefit from sustainment sales (Lofgren, 2020). From 1920 to 1939, the volume of naval repair work across all private yards was a mere \$1,870,000—

⁵ This map was generated by the author using congressional district data from Jeffrey B. Lewis (Lewis et al., 2013).



around 0.3% of the shipyards' total commercial and naval repair work (Smith & Brown, 1948, p. 105). The Washington Naval Treaty created a premium on modernization programs as new battleship construction was impossible. However, the funds allocated to modernization programs were minor. Furthermore, the Navy's own yards took on most of the naval repair and modernization work during the interwar period (Levine, 1988, p. 373). Because of a lack of other forms of military sales, private yards in the interwar years continually lobbied for new ship construction.

Major shipbuilders played an outsized role in this lobbying effort thanks to their dominance of the naval construction market and their powerful industry association. The largest of the contractors were known as the "Big Three" of Fore River, Newport News, and New York Ship. The next largest set of yards were the "Little Three" of Bath Iron Works, Federal Shipbuilding, and United Shipyard (later Bethlehem Staten Island after its acquisition). These six, along with a small handful of other major shipbuilders, were the core members of the National Council of American Shipbuilders (NCAS; Levine, 1988, p. 96). The actions of this industry association, alongside individual lobbying efforts by shipyards, played a major role in shaping naval procurement from 1933–1938. Major shipbuilders worked to get new shipbuilding contracts created and allocated to the private sector. They also made concerted efforts to discourage the Navy from branching out and working with new, upstart shipbuilders (Levine, 1988, p. 96).

Shipyards were supported by local groups at all levels of politics. New York Ship's response to its 1938 financial crisis is a prime example of the multi-pronged lobbying approach taken by private shipyards. Having failed to secure several commercial shipbuilding contracts in 1936 and 1937, New York Ship was in dire financial straits (Heinrich, 2020, p. 44). The firm had not received a major surface combatant order from the Navy since it was assigned the two cruisers CL-43 *Nashville* and CL-46 *Phoenix* in 1933. Construction on these ships lasted from keel laying in 1935 until their launches in 1937 and 1938, respectively (Carroll, 2023). Facing a dearth of orders and with its expensive and well-trained workforce about to be scattered, New York Ship leaned on the entire political and civic establishment of its hometown of Camden, New Jersey. Senator Harry Moore (D-NJ) wrote to FDR stressing that New York Ship employed 5300 workers and was in danger of closing without getting new business from the government (Heinrich, 2020, p. 44). New York Ship also got local groups involved in shipyard politics. The Camden County Chamber of Commerce wrote to FDR blaming New York Ship's troubles on the federal government's alleged hatred of private enterprise. New York Ship even sponsored a petition from Camden school children asking for a Navy contract for the company (Heinrich, 2020, p. 44). Eventually, though not necessarily solely because of this lobbying, New York Ship was allocated the lead ship of the *South Dakota* class of battleships in FY39, which improved its economic prospects before it entered the boom period of World War II (Carroll, 2023).

In addition to relying on favorable political dynamics with local congressmen, the National Council of American Shipbuilders conducted sustained public relations campaigns to make the advantages of shipbuilding clear to those who might not normally understand the benefits it could bring them, like Midwesterners and the general population of workers. The goal of these campaigns, like many modern lobbying efforts, was to shape public and expert opinion to influence policy outcomes in Congress or at regulatory bodies to encourage naval rearmament. NCAS officials gave interviews and advocated for their policy positions in major newspapers like *The New York Times*. On January 19, 1932, *The Times* published an article based on an interview with NCAS president, H. Gerrish Smith, which noted NCAS's endorsement of Vinson's naval appropriations bill ("Steady Aid Urged for Shipbuilders," 1932). A subsequent January 1933 article quoted Smith sounding an alarmist



note about the future of the shipbuilding industry if there were no further government spending. The campaign came as the pressure grew to include naval construction in NIRA, which was being considered at the time (“Increase Unlikely in Shipbuilding,” 1933). After NIRA had been signed into law and funding had started to flow to private yards, Smith underscored the impact of the bill on jobs in *The Times* in August 1933, stating that “\$105,000,000 of the of \$130,000,000 to be received by the private yards would be expended for labor . . . every State in the Union eventually would received [sic] a share of the income” (“Jobs for 30,000 on New War Ships,” 1933).

NCAS also defended the reputation of the private shipbuilders. After the Nye Commission revealed the cartel-like behavior of the Big Three shipbuilders, Smith was cited in a *New York Times* article disputing the accuracy of the Nye Commission’s figures, trying to cast doubt on the anti-Navy politicians in the public sphere and reinforce the perception of private shipbuilders as honest and effective contractors (“Costs Seen Higher in U.S. Shipyards,” 1936). In 1937, NCAS self-published a book, *Commercial Shipyards and the Navy*, that cast doubt on the Nye Committee’s methodology and impartiality and attacked its recommendation of government ownership of all naval construction facilities (Shipbuilders Council of America, 1937, p. 7). Some of NCAS’s claims stretched credulity, especially its assertion that NCAS “has never, in fact, urged upon Congress the construction of a single naval vessel” (Shipbuilders Council of America, 1937, p. 9).

The major shipbuilders also relied on their close relationships with Navy officials to ensure the Department represented their interests in intragovernmental fights over contract terms, regulation, and legislation. The Nye Committee argued that concerns about the welfare of shipbuilding corporations were given undue weight in the Navy Department’s decision-making process for deciding its fleet architecture—in terms of ship count and location of construction (Koistinen, 2015, p. 258). The Committee found that the Big Three’s cartel coordination on the 1928 cruisers had been done with the knowledge and even encouragement of the officials of the Navy Department who were more interested in preserving shipbuilding capacity than keeping costs honest and low (Koistinen, 2015, p. 259). Navy officials also had a revolving-door relationship with figures at the top of the shipbuilding industry. The interwar president of Newport News, Homer L. Ferguson, was a former naval officer (Koistinen, 2015, p. 261).

The Navy Department’s exceptionally cooperative attitude towards the major shipbuilders is clearest in the fight that erupted over labor rights in shipyards. Title I of NIRA allowed the administration to require that federal contractors adhere to labor codes which regulated worker hours and pay. In May 1935, Title I was declared unconstitutional by the Supreme Court (Levine, 1988, p. 434). Labor advocates within the FDR administration, alongside union activists in the shipbuilding industry, pressured the Navy to implement new labor codes in the 1935 contracting cycle (Levine, 1988, p. 437). A subsequent labor bill, the Walsh-Healey Government Contracts Act, passed in June 1936 and permitted the government to mandate that its contractors adopt 40-hour workweeks and pay minimum prevailing wages (Government Contracts Act, 1936). Shipbuilders vehemently opposed such labor codes as they believed they would raise labor costs and introduce regulatory difficulties. NCAS stated that none of its members would submit bids that agreed to new contract terms which demanded a commitment to arbitration for certain labor issues and adherence to future federal labor laws (Levine, 1988, p. 443).

The private shipbuilders tried to subvert labor regulations by appealing to Navy officials. They submitted bids conditioned on their being exempted from the Walsh-Healey Act, or dual bids with prices estimated with and without labor code enforcement. In some cases, they simply notified the Navy that they would not submit any bids at all (Levine, 1988,



p. 455). In *The New York Times*, H. Gerrish Smith attributed the need for dual bids in 1936 to higher labor costs and the costs of new worker regulations ("Navy Opens Bids for 9 New Craft," 1936). For its part, the Navy was not pleased with the labor advocates' meddling and used shipbuilder complaints as a cudgel against labor advocates in the FDR administration. ADM. Land called the Walsh-Healey Act "a labor racket," and ADM. William D. Leahy, an influential naval officer who would eventually replace Standley as CNO, called it "radicalism" (Levine, 1988, p. 459). The Navy's geopolitical focus and industry's profit motive to get as many ships built as quickly as possible conflicted with labor's interest in worker compensation. The Navy Department conducted a long-running campaign against implementing labor regulations in the defense industry. The Navy complained to the Labor Department and other administration officials about the difficulty of contracting to build ships and the resultant decline of defense readiness. The labor conflict was eventually solved by an agreement with the unions (Levine, 1988, p. 466). The incident showed how successful the shipbuilders could be in lobbying the Navy, as they effectively mobilized one department of the government against another.

The Navy's willingness to cater to the desires of the major shipbuilders arose from the indisputable value these firms provided for national defense. While the major shipbuilders were reliant on the government for much of their business, without these contractors the Navy could not build its warships. The more ships the Navy ordered at any given time, the more that the major contractors could charge because of the Navy's dependence on such a limited number of firms (Koistinen, 2015, p. 259). Shipbuilders had an additional source of leverage when dealing with the federal government in times of relative economic prosperity. Shipyards' appetite for government contracts was inversely related to overall economic conditions. In times of economic upheaval like the Great Depression, businesses sought out government contracts for a source of income. In boom times, however, shipbuilders preferred to supply the needs of the private sector and would avoid taking government contracts due to onerous requirements like labor regulations and profit caps (Levine, 1988, p. 450). The 1935–1936 labor fight coincided with a general economic recovery and resurgent commercial shipbuilding demand. Shipbuilders could afford to submit dual bids rejecting the labor regulations or not bid at all. Shipbuilders claimed that industrial activity had flooded their shops with orders, so they had no capacity for naval shipbuilding (Levine, 1988, p. 451). But the economic mini-boom was over by 1937, and it was followed by a deep recession in the spring—derisively called the "Roosevelt recession" (Kagan, 2023, p. 364). FDR then announced that both planned *North Carolina*-class battleships would be built in government yards, triggering the crisis at New York Ship mentioned above. The Navy would eventually revert to its usual 50-50 arrangement, but private shipbuilders had seen the power of government contracting during an economic downturn when they had limited commercial options (Wilson, 2016, p. 42).

In addition to direct lobbying, and broad public relations efforts, NCAS also sought to shape the opinions of Navy officials by more narrowly targeting the tenor of discourse in tight Navy circles. NCAS leveraged its favorable relations with Navy officials to get into *Proceedings*, where it could influence a readership primarily composed of Navy officers. In 1938, H. Gerrish Smith authored "The Necessity for a Definite Shipping Replacement Program," which argued for a program of continuous replacement of aged commercial shipping vessels. Smith notes the importance of maintaining a nucleus of trained shipbuilding workers and argues that "a shipbuilding boom that would bring into the industry a large number of employees that could not be continuously employed is most undesirable" (Smith, 1938). NCAS advocated for policies that favored existing shipbuilders over newcomers.



NCAS made use of its superior industry knowledge and data to lobby more effectively. NCAS had better information on shipbuilding statistics than any other public group thanks to its data collection from its member shipyards.⁶ NCAS had state-by-state data on the materials, machinery, or services produced by each state that were purchased by the shipbuilding industry. This data covered a wide range of goods from major elements like “machinery” and “structural iron and steel” to items as minute as “gallery and pantry outfit” and “bedding linen and drapes” (Smith & Brown, 1948, p. 106). State-by-state data enabled NCAS to more effectively lobby congressmen by making clear the connections between their state industries—in places as far from the sea as South Dakota, which produced brass, lead, zinc, paint, and interior decorations for ships—and the construction of more naval vessels (Smith & Brown, 1948, p. 106). The Navy Department’s information on the production supporting shipbuilding was far less advanced.

NCAS also made use of its information asymmetry to shape the information space of debates over shipbuilding in Congress. NCAS provided its shipbuilding statistics to the Navy informally and via publication in *Proceedings* and other industry-aligned journals (Smith, 1938). The Nye Committee found that the Navy, in turn, made little to no effort to collect its own information. This lack of interest was especially pronounced regarding the costs and profits of the shipbuilders. Instead of calculating its own profit estimates, the Navy provided NCAS’s figures to Congress. These figures were far from neutral—one set of NCAS statistics estimated private shipyard profits at one third of the level that the Nye Committee found using its own sources (Koistinen, 2015, p. 260). By shaping the information on which shipbuilding debates were based, NCAS was able to subtly advance its members’ pro-construction agenda.

NIRA Funding is Dead, Long Live Congressional Funding

The era of the NIRA navy ended not long after it began. Shifting political winds and adverse Supreme Court decisions after 1936 had dismantled much of the First New Deal and the primacy of the PWA as a source of funding for naval shipbuilding along with it. In the end, the Navy was not terribly sad to see the public works funding vehicle go (Levine, 1988, p. 490). Although initially appreciative of being unshackled from Congress, the Navy soon chafed under its new unfriendly paymasters at the PWA, as well as the continued informal influence from congressmen, and constant pressure from industry. Regular congressional budget appropriations returned to the center stage of naval acquisitions.

Between 1934 and 1938, a basic pattern emerged for the regular budget: the Navy would present its requests for building new ships in keeping with its long-range plan to hit treaty limits by 1942, the Budget Bureau would lop some substantial but survivable amount off the top for the sake of demonstrating FDR’s commitment to fiscal probity, and the appropriations committees would knock off another small amount to show they too were serious about economizing (West, 1980, p. 489). As Vinson had predicted in 1934, once Congress had authorized building up to the treaty limits, the appropriations committees would prove unwilling to rock the institutional boat and would regularly provide most of the needed funding (West, 1980, p. 490). From 1934 to 1938, the Navy’s shipbuilding budget

⁶ The extent of this information asymmetry is clear in *The Shipbuilding Industry of the United States*, a 1948 publication compiling chapters on the history and business dynamics of shipbuilding from prominent figures within the industry. H. Gerrish Smith, who was still of president of what had by then been renamed the Shipbuilders Council of America, wrote a chapter aptly titled “Shipyard Statistics.” While much of NCAS’s data is from government bodies such as the U.S. Maritime Commission, a substantial portion is from their own independent research and surveys of their member firms. NCAS’s data captures production and consumption of naval industries on a state-by-state basis, as opposed to the government data which shows only overall production levels.



requests steadily increased and were—albeit at a slightly reduced level—consistently approved by the appropriations committees.

The speed of U.S. rearmament and exceeding of treaty limits was spurred by the aggressive actions and major naval rearmament programs of Japan, Italy, and Germany. Senior naval officials including ADM. Leahy warned in January 1938 that these nations were “engaged in an extravagant naval building program . . . which must be taken into consideration by American’s sea defense” (*Hearings on H.R. 9218*, 1938, p. 1942). FDR had been growing more concerned himself. On October 5, 1937 he denounced—without naming—the future Axis powers in his so-called “three bandit nations” speech (Kagan, 2023, p. 371). Nevertheless, FDR remained concerned about presenting himself as too aggressive. For example, after Japanese planes attacked the U.S. gunboat *Panay* in China during a broader attack on Chinese Nationalist forces, FDR resisted senior cabinet officials’ calls to respond forcefully (Kagan, 2023, p. 372).

Vinson again took the lead in pushing forward naval shipbuilding. After steering the regular FY 1939 budget through Congress in January 1938 to provide funding for an overall Navy budget of \$553 million, Vinson began to call for “a Navy second to none” (83 Cong. Rec. 780, 1938). The Second Vinson Bill originated in a conference on January 28 with FDR and congressional leaders. FDR went to Congress to ask for a 20% increase in authorized tonnage above the treaty levels authorized by the Vinson-Trammell Act (Heinrich, 2020, p. 46). The U.S. naval program had been unhampered by the treaties since the collapse of the 1935–36 London Naval Conference due to Japanese intransigence (Levine, 1988, p. 364). By 1938, the treaty system was a relic of the past and its limits had been broached by almost all major navies. FDR’s direct involvement was nonetheless a marked change from his distance from the Vinson-Trammell Act of 1934. After FDR’s call to action, Vinson immediately introduced H.R. 9218, the Second Vinson Bill. Vinson bulled through his committee hearings on the bill and brought the bill to the floor with the help of sympathetic House leadership. Despite impassioned speeches against the bill from liberal Democrats and isolationist Republicans, the bill passed 294-100 (Cook, 2004, p. 138).

Much as with the Vinson-Trammell Bill, voting on the Second Vinson Bill reflected the political influence wielded by shipyards. As the first map below shows, supporters of the bill included both Democratic and Republican congressmen. The bill’s Democratic support came from across the country and was in keeping with FDR’s influence over his own party. But the few Democratic naysayers were concentrated in the isolationist and land-locked Midwest. The bill’s Republican supporters were highly concentrated on the coasts. Looking at the second and third maps which focus on the Northeast, it emerges that proximity to a naval shipyard is a reliable indicator of congressmen crossing party lines to support the bill. The Republican congressmen in New Hampshire and Massachusetts who voted in favor of naval spending were almost universally representing districts that were within commuting range of shipyards, while the Republicans opposing the bill were generally outside of shipyard commuting range. While this dynamic has been described before in anecdotal terms by Levine, the below maps show visually and on a national scale the power of naval shipyards to influence their congressional representation’s voting patterns.



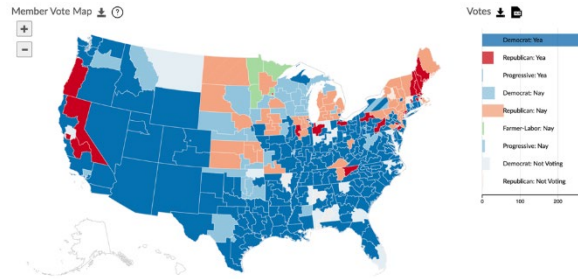


Figure 2. Voting on the Second Vinson Bill (H.R. 9218)⁷

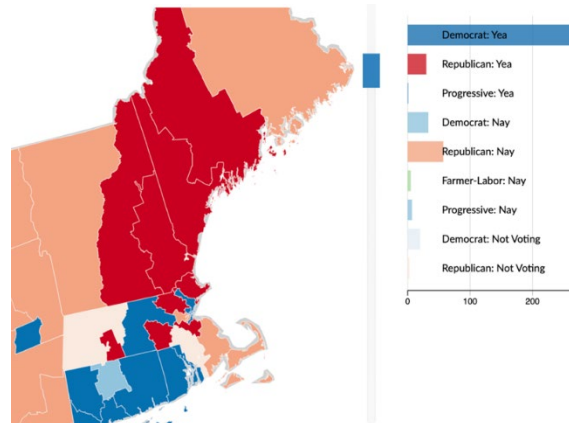


Figure 3. Voting on the H.R. 9218 (Northeast)⁸

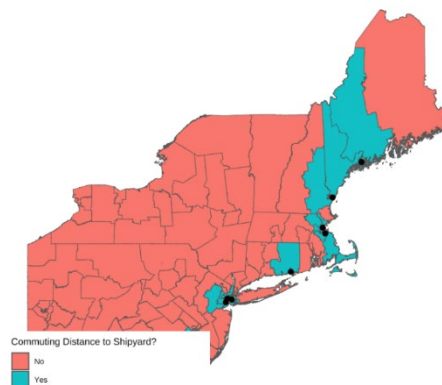


Figure 4. Commuting Distance to Shipyard (Northeast)⁹

The Second Vinson Bill was arguably the final major shipbuilding legislation of the resource-constrained era of the interwar years. The bill authorized 46 ships, 22 auxiliaries, and 950 airplanes. It was the largest U.S. peacetime naval shipbuilding program to date, and the last major surface combatant authorization before the outbreak of World War II in Europe (Cook, 2004, p. 142). While subsequent major shipbuilding bills were signed while

⁷ This map records the House vote on the Second Vinson Bill and was generated by Voteview.com (Lewis, 2016).

⁸ This is a subset of the prior map, focused on the Northeast region (Lewis, 2016).

⁹ This map was generated by the author using congressional district data from Jeffrey B. Lewis (Lewis et al., 2013). The black dots show the locations of the shipyards in the Northeast that built naval vessels from 1930–1939. The map colors blue any congressional district within commuting distance of these shipyards.

the United States itself was at peace, these were signed after the resource constraints that typify the 1933–1938 era had ended. By November 1938, polls showed that 88% of Americans thought the United States needed a larger navy and 53% said they would support raising taxes to pay for a larger military (Cook, 2004, p. 142). The 1938 midterm elections further strengthened congressional support for an interventionist foreign policy that included major military spending (Kagan, 2023, p. 395). The era of resource constraints and political squabbling over limited shipbuilding funds was over, replaced by whole-of-nation efforts to prepare for wartime. The foundation for these preparations was laid by the political compromises forged by the Navy, Congress, and industry from 1933 to 1938.

Conclusion

The conventional view of history portrays President Roosevelt as a great leader guiding the United States through one of the most turbulent times in its history. This perception has in turn influenced how historians have written about naval shipbuilding policy. However, studying the politics of shipbuilding provides evidence that this leader-driven portrayal of policy formation is incomplete. Self-interested domestic actors like congressmen and industry executives profoundly shaped U.S. interwar naval shipbuilding. In this messy, contentious, and occasionally even corrupt process of backroom wheeling and dealing they distorted the composition of the U.S. fleet and manipulated where Navy ships were produced. All of this pushed the Navy away from what could be thought of as the “military ideal” policy that the Navy might have preferred.

This is the frustration and promise of democratic politics. The Navy welcomed and worked with these special interests via the loose Navy-Congress-industry alliance because these domestic actors provided key information and support which enabled a sustainable naval strategy. Grand strategy is the adaptation of inherently limited means to accomplish potentially unlimited ends (Gaddis, 2018, p. 21). The Navy accommodated these domestic influences to forge a realistic, if not theoretically ideal, strategic position. Naval shipbuilding in the interwar years is a story of disparate actors making rational choices, using all available information, to build toward their ambitious goal of creating a navy second to none. In the end, the self-interested behavior of these players—naval officers, congressmen, and business executives—worked together to produce something greater than the sum of its parts. By tying geostrategy to parochial interests, they were able to build political support in Congress and across the country for massively expanding the Navy. Thanks to these efforts, the United States entered World War II with the nucleus of what would become a world-beating navy.

The story of interwar shipbuilding remains relevant today. The United States is again facing an increasingly dangerous geopolitical climate, with rival naval powers like China challenging its control of the seas. In the past few decades, the United States has lost much of its remaining commercial and military shipbuilding capacity. The timeless dynamics of shipbuilding politics, as illuminated by the interwar years, can guide decisionmakers in thinking about whole-of-economy maritime mobilization in the event of great power conflict. Currently, policymakers are considering radical solutions such as off-shoring naval production to low-production-cost allies like South Korea and Japan. Naval advocates during the interwar period struggled to build a domestic political environment favorable to shipbuilding by spreading its economic and political benefits across the country. Modern efforts to consolidate shipbuilding capabilities have had the opposite effect by eroding the geographic reach of shipbuilding’s remaining political base. Offshoring naval production would accelerate this loss of political buy-in as shipyards in yet more districts lose their production contracts and become defunct. Shipbuilding can build its own political



momentum—or it can fall apart when this momentum is squandered or given away. The world has changed since 1933, but it is worth remembering the lessons of the past.

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PANEL 5. INTEGRATING CYBERSECURITY AND MANAGING RISK

Wednesday, May 8, 2024	
12:45 p.m. – 2:00 p.m.	<p>Chair: Gaurang R. Dävé, Cyber Technology Officer, Marine Corps Systems Command</p> <p><i>Improve Acquisition Cybersecurity Risk Using the Acquisition Security Framework and Software Bills of Materials Risk Framework</i> Michael Bandor, Software Engineering Institute</p> <p><i>Vulnerabilities and Social Engineering in Acquisition Scenarios</i> Zachary Levenson, MITRE</p> <p><i>The Value of an Agile Approach to Independent Verification and Validation (IV&V) for Acquisition</i> Justin Smith - Software Engineering Institute</p>

Gaurang R. Dävé—serves as acting Dept of Navy Deputy Senior Information Security Officer (Marine Corps) He is responsible for ensuring Federal, DoD, and DON Cybersecurity requirements are addressed during the lifecycle of systems Corps. In this role, he coordinates with DON SISO and DON CIO Staff for uniform and consistent application of Cybersecurity policies, processes, responsibilities, and procedures throughout the DON.

Mr. Dävé previously served as acting Deputy to the Commander Marine Corps Systems Command, Systems Engineering and Acquisition Logistics and the Chief Engineer, MCSC. His responsibilities included: responsible for directing enterprise-level systems engineering in support of command product lines and lifecycles to ensure MCSC provides end-to-end integrated, interoperable and certified warfighting capabilities.

Mr. Dävé serves as Cyber Technology Officer for the Marine Corps Systems Command (MCSC). In this role, he serves as the principal cyber advisor and technical expert to the Commander, Executive Director and Chief Engineer, MCSC; and Program Executive Office Land Systems (PEO-LS) and subordinate activities, for Cyberspace, Cybersecurity, and information technology (IT).

Prior to joining MCSC, Mr. Dävé served as Senior Cyber Technical Advisor and Cybersecurity Program Director for Naval Surface Warfare Center (NSWC) Dahlgren. In this capacity, Mr. Dävé led the Navy's combat systems cybersecurity portfolio across the Warfare Systems Program Office. Mr. Dävé provided technical leadership, guidance, and program management leadership. Prior to that, Mr. Dävé served as Cybersecurity Risk Posture lead for the Office of the Chief of Naval Operations, OPNAV N2N6 Cybersecurity Division at the Pentagon. His contributions included synchronizing cyber strategy, standards and requirements, evaluating and prioritizing investments, providing oversight, and resource sponsorship.

Mr. Dävé began his career as a software engineer and served in technical, program management, and supervisory positions across the joint services. Mr. Dävé led the Chemical, Biological, Radiological (CBR) Analysis, Testing, and Systems Engineering Branch at NSWC, Dahlgren Division. Under his leadership, the branch provided SME in CBR modeling & simulation, threat analysis, and led several ACAT-3 efforts. Mr. Dävé served as CBR Thrust Area Manager for Major Defense Acquisition Program at Joint Science & Technology Office led by US Army. Prior to joining government service, Mr. Dävé worked in private industry at International Business Machines (IBM).



As a Security Software Engineer, Mr. Dävé led several software security program development efforts designed to protect the company's network.

Mr. Dävé holds Bachelor of Science degrees in Computer Science and Biochemical Pharmacology from State University of New York at Buffalo. Master of Science degree in Systems Engineering with focus in Operational Research from George Mason University. Graduate degree in Cyber Engineering from University of Maryland. He is DAWIA Level III certified in Systems Engineering.



Improve Acquisition Cybersecurity Risk Using the Acquisition Security Framework and Software Bills of Materials Risk Framework

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Charles M. Wallen—has been a thought leader in operations and risk management for over 25 years. He has provided consulting to public and private organizations, led industry-wide risk initiatives, and managed global operations risk management and governance programs for financial services organizations. Today, Wallen works closely with the CERT Division of the Software Engineering Institute on initiatives to strengthen the resilience of critical infrastructure, to improve software assurance, and to enhance and/or refine techniques for managing supply chain risk. [cmwallen@sei.cmu.edu]

Christopher Alberts—is a principal cybersecurity analyst in the CERT Division of the Software Engineering Institute where he leads applied research and development projects in software assurance and cybersecurity. His research interests include risk analysis, measurement and analysis, modeling and simulation, and assessment. His research has been adopted by a variety of government and industry organizations, both nationally and internationally. He has coauthored two books and published over 50 technical reports and articles. Alberts has BS and ME degrees in engineering from Carnegie Mellon University. [cja@cert.org]

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Abstract

Increasingly, complex, software-intensive systems rely on software from third parties. However, recent events, such as MoveIT, SolarWinds®, and Log4j™ (Liu, 2021), demonstrate the profound cybersecurity consequences of lax third-party component management. Too often, these components are unknown, and suppliers are only beginning to be incentivized to consider the risk their products pose. For their part, acquirers remain primarily focused on cost and schedule. To help manage these challenges, and to deliver a secure-by-design outcome, the Carnegie Mellon University Software Engineering Institute (SEI) developed the Acquisition Security Framework (ASF). The ASF describes practices needed across the supply chain to reduce risk gaps.

In a derivative effort, the SEI also developed the Software Bills of Materials (SBOM) Framework, a set of SBOM practices and process for managing risk. Building and using SBOM requires heightened collaboration between suppliers and acquirers. Achieving effective SBOM results requires planning, tooling, trained staff, measurement, and monitoring, because technology and its use is always changing. Information available from an SBOM can offer insights into the challenges faced by the groups engaged in managing a



system. This paper describes both frameworks and the opportunities for improving acquisition cybersecurity risk provided by each.

Introduction

Software supply chain risk has increased exponentially since 2009 when the Heartland Payments System breach (King, 2009) made the issue newsworthy. The perpetrators reaped 100 million debit and credit card numbers. At the time, this was the largest data breach in recorded history, but it would not remain so. Recent events in 2020 and 2021, such as SolarWinds and Log4j, a popular logging package for Java (Liu, 2021), show that the scale of disruption from a third-party software supplier can be massive as organizations grow their dependence on software-reliant technology.

The reuse of software has enabled faster fielding of systems because common components can be sourced externally, but all software comes with vulnerabilities, and attackers have expanded their capabilities to exploit them in products that have broad use. Virtually all products or services that an organization acquires are supported by, or integrated with, information technology that includes third-party software and hardware components and services. Each component represents a potential source of cybersecurity risk. For many organizations, information about the acquisition of products or services, practices, and decision points critical to monitoring and managing their supply chain risks and operational implementation is scattered. Security and supplier risk management typically lie outside of the engineering efforts that manage system and program risk management. However, dependency on systems, networks, and the multitude of suppliers necessary to support that environment is unprecedented. Managing the risk of those dependencies and environments has become a primary personal, business, and governmental imperative. Unfortunately, many organizations have resisted changing their approach to managing risk to systems, suppliers, and software. Instead, they have continued to rely on checklists, adding more regulation, and using software development and operational methods that do not effectively address the risk challenges.

Short-term budget and schedule demands become key drivers that can distract from more efficient, effective, secure, and resilient approaches to managing technology and systems. However, resilience and security are elusive goals that require new methods, risk-driven organizational cultures, and strong leadership to achieve. But what do we mean by terms like resilience and security? The terms security and resilience, while sometimes used interchangeably, offer different emphases and perspectives on managing cyber risk. Both perspectives are important, and rather than attempting to parse the differences, this paper uses both terms and recognizes their interdependence. The National Institute of Standards and Technology (NIST), has established the following definitions (National Institute of Standards and Technology, 2021):

Cybersecurity—Prevention of damage to, protection of, and restoration of computers, electronic communications systems, electronic communications services, wire communication, and electronic communication, including information contained therein, to ensure its availability, integrity, authentication, confidentiality, and nonrepudiation.

Cyber Resilience—The ability to anticipate, withstand, recover from, and adapt to adverse conditions, stresses, attacks, or compromises on systems that use or are enabled by cyber resources. Cyber resiliency responds to any known or unknown changes to the environment through holistic implementation of risk management, contingency, and continuity planning.



Many Software Engineering Institute (SEI) solutions share a common theme: using technology to enable mission success. This theme has driven the development of several innovative SEI solutions, such as the Capability Maturity Model Integration (CMMI); the Operationally Critical Threat, Asset, and Vulnerability Evaluation (OCTAVE); and the CERT Resiliency Management Model (CERT-RMM). These solutions resulted in highly influential bodies of knowledge that have informed the subsequent development of many methods, tools, and techniques, including the Acquisition Security Framework (ASF). However, the ASF's research influences are not limited to CMMI, OCTAVE, and CERT-RMM. As illustrated in Figure 1, the ASF has been influenced by a rich SEI research lineage that includes software engineering management, operational risk and resilience, and cybersecurity engineering.

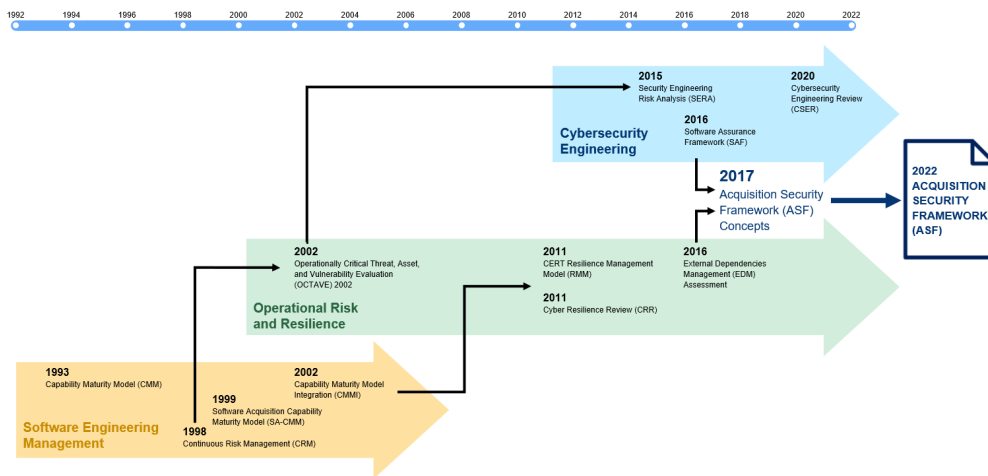


Figure 1: Research Lineage of the ASF

To facilitate the management of software and third-party challenges, and to deliver a Secure by Design outcome, the SEI has developed an ASF that describes the practices needed across the supply chain to reduce risk gaps. To help address software risk, the ASF and the methods it leverages were utilized to build a Software Bills of Materials (SBOMs) framework. SBOMs have come to the forefront of efforts to strengthen software risk management and transparency that can help manage suppliers and software components that are a common aspect of today's application development process.

Based on our broad experience helping organizations address engineering, security, and supplier risks, the SEI team assembled the following six key principles for use in developing and applying a framework to remedy the gaps described above:

- **Risk Based**—A risk-based management approach improves decision-making, enables effective identification and management of security/resilience risks, and facilitates prioritization of security/resilience activities and resources based on mission impact.
- **Lifecycle Focused**—Security/resilience practices must be integrated consistently into each lifecycle phase, from initial concept through system disposal.
- **Process Oriented**—Higher degrees of process management translate to more stable environments that produce consistent results over time.
- **Collaboration Focused**—Teamwork and timely communication across teams and organizations facilitate effective security/resilience management.



- **Context Sensitive**—Implementation of security/resilience practices must consider the organizational context in which these practices are being applied, including program and organizational requirements, operational mission, supplier network, and lifecycle phase.
- **Software Focused**—Systems are increasingly software intensive and complex, requiring an integrated acquisition, engineering, development, and operational focus to manage security/resilience risks.

The ASF supports improved decision-making to effectively address threats and vulnerabilities in a timely manner using risk considerations to prioritize security/resilience activities and resources based on mission impact. This approach recognizes the importance of proactively managing risks by investing in security/resilience activities that target risk levels acceptable to the program or system.

The ASF establishes a systematic, integrated process of engineering, developing, implementing, operating, and retiring information systems and programs. This approach emphasizes the importance of a collaborative approach to managing programs, teams, and systems that recognizes the importance of building software-reliant systems that consistently address security/resilience risks in the face of change and evolving threat environments.

The ASF emphasizes management of activities and practices that target the achievement of programmatic goals. Process improvement is a key aspect of the ASF. It promotes ongoing refinements to existing activities and practices. Process management treats change as continuous and expected, requiring ongoing effort to ensure that processes remain effective at adapting to evolving program and system objectives.

The ASF establishes active linkages among teams, systems, and processes across participating organizations. Integration facilitates collaboration and communication directed toward a common set of goals. This integrated approach leads to increased efficiency, improved productivity, and more effective risk management.

ASF goals and practices provide an actionable, context-sensitive roadmap for managing security/resilience across the systems lifecycle and supply chain. These goals provide a conceptual foundation that can be tailored to an organization's specific context and mission. In addition, the ASF's principles and underlying philosophy can be applied to other types of security/resilience problems, such as integrating an SBOM into an acquisition program's security/resilience risk management practices.

Software is a growing component of modern business and mission-critical systems. As a result, software assurance is becoming increasingly important to programs across all sectors. A key aspect of software assurance is keeping security and resilience risks within acceptable tolerances across the systems lifecycle. The ASF leverages acquisition, engineering, and assurance disciplines to build security/resilience into software and systems across the lifecycle.

Acquisition Security Framework

The SEI team applied the principles and concepts described above to create the ASF. ASF is a framework of leading practices and processes for managing the security/resilience of applications and systems of systems. The ASF facilitates an integrated approach to cyber risk management across a system's lifecycle and supply chains. The motivation for developing the ASF came from a need for innovative methods to manage third-party/acquisition risk, the growing role of software in systems, the lack of integration



among support teams, and the complexity of systems. Key to meeting these challenges is taking a multidisciplinary approach to managing cyber risk over a system's lifecycle, and the ASF incorporates this necessity.

Many security/resilience solutions focus on a few aspects of engineering, such as security/resilience requirements specification, secure coding practices, or supply chain risk management. In contrast, the ASF leverages a proven set of integrated program management, engineering, and supplier management practices and processes that span the systems lifecycle. ASF practices promote proactive dialogue across all program and supplier teams, helping integrate communication channels and facilitate information sharing. As a result, the ASF enables programs to acquire, develop, and operate complex systems that function at a lower level of risk in an increasingly contested, challenging, and interconnected cyber environment.

The ASF is designed to help a program coordinate the management of engineering and supply chain risks across system components, including hardware, network interfaces, software interfaces, and mission capabilities. The ASF includes 51 goals and 334 practices spread across the following six practice areas:

1. Program Management
2. Engineering Lifecycle
3. Supplier Dependency Management
4. Support
5. Assessment and Compliance
6. Process Management

Within each practice area, critical domains are identified, and questions relevant to the analysis of goals for each domain are provided. ASF goals and practices provide a roadmap for managing security and resilience across a system's lifecycle and supply chain. The response to each question gives an organization or program insight into how well each practice is addressed and where there may be potential concerns. The ASF defines engineering-driven, risk-based practices and processes for building, deploying, and operating secure and resilient systems. The following sections describe each of the six practice areas. Details about the domains, goals, and practices for each practice area are available in the SEI technical note *Acquisition Security Framework (ASF): Managing Systems Cybersecurity Risk* (Alberts et al., 2022).

Program Management

From a traditional perspective, program management is focused on controlling cost, schedule, and performance. In the ASF, the Program Management practice area defines a set of practices for ensuring that security/resilience are addressed from the earliest stages of an acquisition and throughout the systems lifecycle. Including security/resilience considerations during a program's early planning and management activities provides a foundation for coordinated and integrated management of security/resilience across all program teams. The Program Management practice area also identifies security/resilience practices for requirements and risk management that are coordinated across the program and lifecycle.

Engineering Lifecycle

The term *engineering lifecycle* describes the range of management and technical activities needed to build and operate a system, from initial concept through development, production, deployment, and support. In the ASF, the Engineering Lifecycle practice area defines a set of practices for integrating security/resilience into a program's systems



engineering and software engineering activities. In addition to addressing the technical aspects of security/resilience engineering, the Engineering Lifecycle practice area also ensures that the program's engineering activities are planned and managed, including those performed by third-party contractors. Finally, Engineering Lifecycle practices ensure that engineering processes, software, and tools (i.e., the engineering infrastructure) are secure and resilient, reducing the risk of attackers being able to disrupt program and system information and assets.

Supplier Dependency Management

A broad network of contracted and non-contracted suppliers enables a program access to specialized skills, components, and infrastructure in a cost-effective manner. At the same time, these supplier relationships create dependency risks that must be managed in the context of the program's overall risk management strategy. Suppliers of products and services that are governed by contractual agreements require careful management and monitoring. Some suppliers, such as infrastructure providers and government service providers, do not typically rely on contracts to codify relationships, leading to dependency risks that are frequently overlooked. While non-contracted suppliers are often less of a concern, programs must manage security/resilience risks resulting from these dependencies as well. In the ASF, the Supplier Dependency Management practice area provides leading practices for managing dependencies that should be considered when building secure/resilient systems.

Support

As it works toward its acquisition and development mission, a program requires support from a variety of organizational departments, groups, and teams. Organizational support activities provide a broad range of services, including security management, facility management, access management, measurement and analytics, and training. The Support practice area outlines leading practices that facilitate integrated support for acquiring, developing, and managing secure/resilient systems across their lifecycle.

Independent Assessment and Compliance

An independent assessment is an activity in which individuals who are not directly connected with a program or system evaluate some or all aspects of that environment and report the results to designated stakeholders. Compliance is the act of conforming to the requirements outlined in the set of laws, regulations, policies, and standards that a program or system must meet. In the ASF, the Independent Assessment and Compliance practice area defines activities for reviewing a program or system to determine whether it meets security/resilience requirements, including customer, product, and product component requirements, and whether it fulfills its intended use when placed in its target environment.

Process Management

Process management comprises practices that facilitate the predictable and efficient delivery of program activities, putting the program in a position to achieve its security and resilience objectives. Process management practices help clarify and align an organization's strategies, policies, procedures, standards, and approach. A key premise of process management is that organizational outcomes are highly influenced by the quality of its processes. Increased use of consistent process management translates to more stable environments that produce predictable results over time and help enable mission success at lower risk. In addition, process management is based on the principle that change is continuous. Managing change in a program or system environment requires continual management and improvement of processes, helping to ensure that those processes continue to meet their objectives. A key challenge to every acquisition program is



implementing an appropriate level of process management that reflects its environment, mission, and objectives. The ASF leverages process management to help ensure that cyber investments are implemented and managed effectively across the program and its suppliers. In the ASF, the Process Management practice area defines activities for managing and improving the processes used to acquire, develop, and operate software-reliant systems.

Leveraging ASF to Address SBOM Challenges

Teams of business and technology experts must collaborate and develop new techniques for identifying potential risks and proactively managing (i.e., tracking, analyzing, and mitigating) risks. SBOMs can help facilitate the building of those new techniques and foster the necessary collaboration. The U.S. Department of Commerce (DOC) defines an SBOM as follows (Department of Commerce [DOC], 2021):

An SBOM is a formal record containing the details and supply chain relationships of various components used in building software. In addition to establishing these minimum elements, this report defines the scope of how to think about minimum elements, describes SBOM use cases for greater transparency in the software supply chain, and lays out options for future evolution.

SBOMs have come to the forefront of efforts to strengthen cybersecurity risk management tools, which was a highlight of Executive Order (EO) 14028, *Improving the Nation's Cybersecurity*, issued on May 12, 2021 (The White House, 2021). EO 14028 requires U.S. government agencies to enhance software supply chain security and integrity, with a priority on addressing critical software.¹ A key aspect of enhancing software supply chain security and integrity is transparency. Implementing SBOMs for critical software will help establish transparency in the software supply chain. Therefore, EO 14028 calls for standards, procedures, and criteria for providing SBOMs for products directly or publishing them on a public website.

Our survey of SBOM publications and guidance revealed a strong emphasis on defining the content and format of SBOMs. Establishing a standard for SBOM content is an important aspect of the problem; however, organizations also need guidance on how to plan for, develop, deploy, and use SBOMs. As a result, our team at the SEI focused its research activities on the SBOM lifecycle.² SBOMs must support more, including (1) proactively considering how to best manage risks posed by third parties, and (2) developing effective mitigations as new or emerging threats and vulnerabilities emerge. There are too many moving parts and risks in today's software-driven technology environments to simply rely on ad hoc or poorly organized SBOM practices and processes.

Developing more comprehensive and collaborative SBOM practice frameworks will offer techniques for effectively establishing and managing proactive software information and risk management programs. Using SBOMs can also provide software developers, integrators, and risk managers with a unique opportunity to collect information that they can

¹ *Critical software* is defined as software that performs functions critical to achieving trust, such as affording or requiring elevated system privileges or direct access to networking and computing resources.

² ASF was developed using multiple influential bodies of knowledge that have informed the subsequent development of tools and techniques that have been further refined through extensive use across a range of sectors and industries. The organizational outcomes that result from the ASF approach are characterized by efficient and predictable environments and more manageable delivery and risk outcomes. The SBOM lifecycle refers to the set of activities required to plan for, develop, and use an SBOM.



analyze, monitor, and act on to manage software components, suppliers/dependencies, provenance, vulnerabilities, and more—the possibilities are extensive.

Building the SBOM Framework

We started developing the SBOM Framework by reviewing published use cases. Based on this review, we developed core SBOM practices, which primarily focused on developing SBOMs (i.e., building and construction practices) and using them to manage known security vulnerabilities and associated risks (i.e., operational use practices).³ We then expanded on this initial set of practices by considering a lifecycle perspective. Here, we identified practices for specifying requirements, developing plans, and allocating resources needed to build and use SBOMs. Finally, we identified practices for activities that enable and support operational use of SBOM data. These practices include management and support practices, third-party practices, and infrastructure practices. The result is an SBOM Framework comprising the following six goals:⁴

1. Requirements
2. Planning
3. Build/Construct
4. Deploy/Use
5. Manage/Support
6. Infrastructure

The framework currently includes 44 practices distributed across the six goals. It provides a starting point for integrating SBOMs with a program's security risk management practices. As we collect lessons learned from piloting the framework and gathering feedback from the community, we will update the framework's goals and practices as appropriate.

Leveraging SBOM practices

SBOMs have been primarily designed to help organizations build more structure into the management of software risks. That management must include not only identifying, but effectively mitigating, security and resilience risks in systems. Clearly, much more can be done to facilitate a broader benefit of using SBOMs. Data from SBOMs, while a key factor in managing risk, have many other possible uses and innovations.

Achieving effective SBOM results requires planning, tooling (because the scale is too great), training staff to do the job, measuring, and monitoring. Information that can be gathered from an SBOM can offer insights into the challenges faced by the groups engaged in managing a system. Figure 2 depicts some of the support teams that could use and benefit from SBOM information and processes to improve software and systems. The SBOM Framework largely focuses on the risks posed by software components and the suppliers who develop and/or manage that software. There are many other potential uses of, and innovation opportunities for, SBOM use, particularly given the vast data that SBOMs can provide.

³ An SBOM has multiple operational uses, including managing known security vulnerabilities, software versions and licenses, code reuse, and software end-of-life issues. The SBOM Framework focuses on managing security vulnerabilities and risks.

⁴ There is not a separate goal for third-party practices in the SBOM Framework. Third-party practices are included in Goal 1 (Requirements) and Goal 5 (Manage/Support).



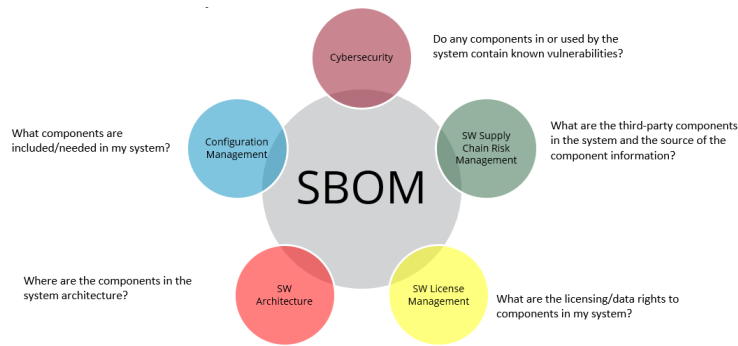


Figure 2: SBOM Relationships With Other Areas

The SBOM Framework addresses the establishment of processes to manage multiple SBOMs and the vast data that they can provide; however, those processes will likely require further tuning as pilot-related activities provide input about improvements and tooling. Data about software risks and vulnerabilities are rich and extensive. Unfortunately, the risk information that SBOMs contain only adds to what is already an overwhelming conglomeration of content and potential information. Organizing and prioritizing that information is a challenge, and we expect that the SBOM Framework can help direct its users' efforts to establish the most effective approach for them. Key to that approach will be the collaborative use of methods and tools by multiple teams involved in software and systems management.

SBOM data analysis can be leveraged to visualize difficult or, in some cases, unseen relationships and dependencies. These relationships and dependencies can be invaluable to teams who manage software in ever more complex technical environments. That benefit was described in *The Minimum Elements for a Software Bill of Materials (SBOM)* (DOC, 2021):

An SBOM should contain all primary (top level) components, with all their transitive dependencies listed. At a minimum, all top-level dependencies must be listed with enough detail to seek out the transitive dependencies recursively.

Going further into the graph will provide more information. As organizations begin SBOM, depth beyond the primary components may not be easily available due to existing requirements with subcomponent suppliers. Eventual adoption of SBOM processes will enable access to additional depth through deeper levels of transparency at the subcomponent level.

Conclusion and Next Steps

There is a saying attributed to Benjamin Franklin: "Change is the only constant in life. One's ability to adapt to those changes will determine your success in life." As technology and risks continue to evolve, we must adapt our approaches to meet these new challenges across their lifecycles. The ASF was built using research and leading practice methods developed by the SEI over the last 30-plus years. The ASF concepts, principles, and leading practices provide a roadmap for managing the highly dynamic technology and threat environments we must address today. ASF accomplishes that objective by recognizing that acquisition and suppliers are the lifeblood that supports businesses getting things done. Collaborating with suppliers and other partners is essential to efficiency and the effective management of operational risk and resilience.



We have applied ASF concepts and principles to build a software-oriented framework for considering security/resilience. That ASF derivation is an SBOM Framework that can be used to build processes and leading practice environments that can address acquisition and software supply chain risk. The SBOM Framework provides a lifecycle programmatic approach to building and managing SBOMs and software risk. The framework was designed to support continuous process and practice improvement, along with measurement and monitoring of the threat environment, to drive effective security/resilience results. An SBOM program can also be leveraged to manage software for multiple cybersecurity data needs and related collaboration among technology support areas.

It is imperative that we move beyond the current compliance-driven mindset and institute a culture of risk management, with responsible information sharing and collaboration among all participants in acquisition and development, across the lifecycle. The ASF and SBOM initiatives explicitly recognize the value of leading practices, process management, and optimization of cyber risk investments, as well as the importance of establishing cyber capabilities that can adapt to change. We have successfully piloted ASF and the SBOM Framework derivative in selected environments and would welcome the opportunity to assist with further pilots to confirm accuracy and completeness. Use the frameworks to improve practices in your organization, and let us know if you see opportunities for enhancing them.

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Vulnerabilities and Social Engineering in Acquisition Scenarios

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Abstract

As our adversaries look to weaken the United States, a constant barrage of social engineering attacks are hitting both the Defense Industrial Base and the Government at record numbers. Constantly, our adversaries are looking for weaknesses within our acquisition system to collect information, conduct fraud, or steal U.S. Government funded intellectual property. The report entitled "Vulnerabilities and Social Engineering in Acquisition Scenarios" is a follow-up effort to the paper presented by MITRE at the NPS Acquisition



Research Symposium in May 2023, “Social Engineering Impacts on Government Acquisition.” We have developed hypothetical scenarios based on open-source reporting where our government acquisition community is uniquely vulnerable and susceptible to attacks. Each scenario aligns to a different part of the acquisition lifecycle and addresses various social engineering attack and compromise types. These scenarios highlight different government agencies and various acquisition positions (e.g., contracting officer, program staff, technical members of source selection panels, contracting specialists, etc.) to demonstrate how different mission sets and roles can all be affected by acquisition exploitation. We discuss the impact of each vulnerability attack, whether that be economic espionage or exposure of CUI. Finally, each scenario includes recommendations that can be used to help mitigate the risk, decrease the attack surface, or repel a future attack.

Introduction

The Federal acquisition workforce is becoming increasingly vulnerable to intelligence collection and exploitation attacks, to include social engineering attacks, information exploitation, and malign influence. The nature of acquisition procedures encourages the open sharing of data across internal and external stakeholders. The nature of acquisition is to encourage participation and competition from all U.S. businesses, no matter the socio-economic status, current relationship with the Government, or location. This puts the acquisition workforce in a uniquely vulnerable position when conducting routine acquisition activities such as market research, which requires receiving and disseminating email attachments (MITRE ATT&CK, n.d.-d) from unknown companies. When combined with heavy workloads and manual processes, both of which increase the potential for human errors, it creates an environment where acquisition staff present themselves as targets ripe for attackers to exploit.

The Federal acquisition process introduces a myriad of potential attack opportunities for U.S. adversaries to exploit in their efforts to infiltrate U.S. critical supply chains in their pursuit of global economic superiority. Acquisition is a complicated process occurring largely on unclassified networks with many different stakeholders playing key roles throughout the lifecycle. This, in combination with the fact that acquisitions coalesce and share massive amounts of data in order to comply with the “Competition in Contracting Act,” creates a unique and currently under-addressed situation in which acquisition staff across industry and government have become rich targets for exploitation. There is growing evidence demonstrating the extent that our adversaries are exploiting the U.S. Government (USG) and its Industrial Base in any way possible, while awareness of the issue lags far behind. Most USG agencies do not have acquisition policies and processes to adequately address this threat.

In an effort to demonstrate areas where the government acquisition community is uniquely vulnerable, the following hypothetical scenarios were developed to help show potential types of attacks, potential impacts of attacks, and recommendations to assist in mitigating or repelling such attacks. Each scenario aligns to a different part of the acquisition lifecycle and addresses various social engineering attack and compromise types. These scenarios highlight diverse government agencies and many acquisition positions (e.g., contracting officer, program staff, technical members of source selection panels, contracting specialists, etc.) to demonstrate how the mission sets and roles can all be affected by acquisition exploitation.

The intent of these scenarios is to increase awareness of potential issues within the acquisition community and help acquisition professionals recognize when they are potential targets. With awareness will come increased security practices and processes that will help



to limit the effects and vectors for potential acquisition exploitation and social engineering attacks against the government acquisition community.

Definitions

Artificial Intelligence (AI): The practice of programming and utilizing machines to mimic human intelligence to perform tasks (McKinsey & Company, 2023).

Machine Learning: The act of developing artificial intelligence through models that can “learn” from data patterns without human direction. Machine learning is a type of artificial intelligence (McKinsey & Company, 2023).

Operational Technology (OT): Programmable systems or devices that detect or cause a direct physical change in a system or environment. Examples include industrial control systems, building management systems, fire control systems, and physical access control mechanisms (Editor, n.d.). OT systems are often not designed to be internet connected and run on proprietary software. OT differs from IT because IT systems are designed to be networked and typically run commercially available operating systems like iOS and Windows, which are more secure as they are broadly monitored and continuously updated.

Social Engineering: The act of deceiving an individual into revealing sensitive information, obtaining unauthorized access, or committing fraud by associating with the individual to gain confidence and trust (National Institute of Standards and Technology, 2023).

Attack/Compromise Type

AI Bias: The fact that any outputs, judgements, or answers provided by AI are inherently based on the data that the AI engine was taught, learned, and trained on. AI technology is 100% reliant on source data such as news articles, magazines, scholarly journals, books, and many other types of media to leverage as “knowledge.” Furthermore, humans decide which type of data that is ingested by the model. Therefore, AI may give answers that unfairly discriminate against, or in favor of, particular individuals or groups if the sources that underpin the AI technology contained bias (Team, n.d.).

Client/Vendor Impersonation Fraud: This technique involves a social engineer posing as a client or vendor in order to gain sensitive information through a conduit of trust; phishing and other techniques can be used to collect information to build a more sophisticated cover-for-action and cover-for-status.

Cold Calling/Vishing: This technique involves a simple act of gathering information by making unsolicited phone calls, sending voice messages, and leaving voicemails as a means to make contact. These acts are conducted in ways that initially seem to amount to insignificant interactions, but small pieces of information about a person gathered separately over time are often combined to form a valuable profile to be used by attackers.

Elicitation: This technique involves a subtle approach that is used to gather information from users through basic social interactions and research into a user’s online and social media presence.

Framing: This technique is used to frame a situation by asking leading questions or phrasing statements in such a way that they focus on the target’s unique biological and cultural influences to create a level of comfort and familiarity. That familiarity is then leveraged to manipulate targets into sharing sensitive information or enabling access to systems.



Phishing: This technique is one of the most popular social engineering attack types, which are email and text message campaigns aimed at creating a sense of urgency, curiosity, or fear in victims. It then prods them into revealing sensitive information, clicking on links to malicious websites, or opening attachments that contain malware (MITRE ATT&CK, 2020).

Pretexting: This technique is a premeditated attack in which a person constructs an elaborate story to place a user in a tense and urgent situation in which they might disclose information they normally would not disclose.

Spear Phishing: This technique is a type of phishing attack that targets specific individuals or organizations, typically through malicious emails. The goal of spear phishing is to steal sensitive information such as login credentials or infect the targets' device with malware. Spear phishers carefully research their targets, so the attack appears to be from trusted senders in the targets' life (CrowdStrike, 2023).

Scenario 1: "Open Source" Acquisition Data Collection

Acquisition Phase(s): Market Research, Solicitation

Attack/Compromise Type: Framing, Pretexting, Cold Calling/Vishing, Vendor Impersonation

Scenario: A foreign agent, posing as a business development manager for a small business, creates accounts on sites like SAM.gov and gains access to Requests for Proposals (RFP) and Requests for Information (RFI) from USG Agency solicitations that mention Operational Technology (OT) engineering (e.g., traffic lights, water plant control systems, railway control systems, etc.). The agent canvases the POCs listed in the RFPs and RFIs to gain access to additional solicitations – under the guise of obtaining business opportunities for their fictional company (MITRE ATT&CK, n.d.-f).

By compiling several solicitations and RFIs, the foreign agent begins to piece together critical information (MITRE ATT&CK, n.d.-c) on USG capabilities, to include:

- The offices and departments working OT based projects
- The scope and size of OT needs the USG Agency has (e.g., number of full-time equivalents [FTEs] requested/relative budgets of specific offices, etc.)
- The technical focus areas where the USG Agency needs assistance (e.g., agency problems identified in the Statement of Work [SOW] may outline where the USG staffing or technical capability is currently lacking)

Potential impact: By compiling many pieces of seemingly inconsequential unclassified information in acquisition documentation, a foreign agent could compile a profile of USG Agency focus areas in the OT space. The level of detail of the agent's report would directly correlate to the detail in acquisition documents, which is often extensive, to allow companies to accurately bid on projects.

The nature of the USG Agency's mission – protecting U.S. infrastructure – combined with the OT-focused acquisition documents, would allow the foreign agent to deduce potentially harmful vulnerabilities and allow the foreign actor's government to invest/focus on areas where the United States is most exposed. By nature, OT has direct physical impacts on systems or environments and, if exploited, could pose real-world harm.

Recommendation: Agencies should move towards publicizing acquisition information in tightly controlled portals that are actively administered and monitored. For agencies without separate networks for sensitive (i.e., Personal Identifiable Information [PII]/Protected Health Information [PHI]) or classified information, a request should be made to receive the RFI



from the Contracting Officer (CO). This will still meet fair competition requirements without publicly releasing acquisition information, and all Federal/State/Local governments should follow similar models to reduce their exposure to these “open source” type attacks.

Scenario 2: AI-Enhanced Market Research

Acquisition Phase: Market Research

Attack/Compromise Type: AI Bias

Scenario: In an era marked by technological advancement, a USG Agency has embraced the integration of Artificial Intelligence (AI) into their acquisition processes, particularly in the pre-award market research phase. Leveraging AI can augment and expedite the work of the Acquisition Team. The USG Agency collects and analyzes vast amounts of data from various sources, including industry reports, supplier databases, and other market analysis platforms. This AI-driven approach allows them to identify potential vendors, trends, the current state of technology, potential solutions, acquisition approaches, and cost-saving opportunities with unprecedented speed and accuracy.

In the pursuit of acquiring next-generation Humvees, the USG Agency has embraced AI-driven market research to identify potential suppliers with a proven track record of durability and ruggedization. The CO relies on AI-based analysis to sift through vast amounts of data, aiming to identify companies known for their exceptional capabilities and innovative solutions in these areas. However, a devious plot unfolds when U.S. Automaker #1, a contender for the contract, decides to tarnish the digital reputation of its closest competitor, U.S. Automaker #2. U.S. Automaker #1 launches a comprehensive campaign to inject negative bias (MITRE ATLAS, n.d.-a) into the AI models and data sources that provide information, evidence, and support to the USG Agency’s market research and overall acquisition decision-making process.

U.S. Automaker #1 initiates a covert digital marketing campaign aimed at discrediting U.S. Automaker #2. They flood the internet with poorly reviewed blog posts, YouTube videos, Facebook reviews, Instagram posts, and other content that portrays U.S. Automaker #2’s Humvees as unreliable and unsafe. These misleading narratives aim to manipulate public perception. They also finance biased research studies carefully designed to highlight flaws in U.S. Automaker #2’s Humvees. These studies are strategically published in reputable journals and magazines, lending an air of credibility to the misinformation. The disinformation creates a snowball effect of negative publicity, studies, and social media posts.

Ultimately, this leads to a severe decline in U.S. Automaker #2’s Humvee sales, severely impacting their reputation. Meanwhile, the AI algorithms processing market data “ingest” these indicators of low quality and durability, further exacerbating the bias against U.S. Automaker #2 in the USG Agency’s AI-driven market analysis.

Potential Impacts: By manipulating the USG’s AI-driven market research, companies can influence the acquisition process and gain a competitive edge, resulting in awards to vendors who may not have the best interests of national security at heart and/or may not be the “best” vendor that provides the “best” solution for the USG Agency. This could lead to the acquisition of subpar or potentially even compromised technology and reduce the Defense Industrial Base, jeopardizing this or other mission-critical operations.

This scenario can also be flipped, and instead of injecting negative bias towards a competitor, a company can inject positive bias, artificially inflating their own reputation, products, and solutions to gain a competitive edge over other vendors.



Recommendations: To safeguard against these vulnerabilities in AI-enhanced market research, government agencies should consider implementing enhanced authentication. They should implement stringent authentication and verification processes for access to AI-driven market research platforms and ensure that only authorized personnel and vetted firms can contribute to the AI data pool. Agencies should continuously audit AI algorithms for anomalies and should institute rigorous data protection measures to prevent unauthorized access and maintain human oversight in the AI-driven process to critically evaluate recommendations and trends generated by the AI. Humans can provide context and judgment that AI may lack; therefore, a close collaboration between the Acquisition and Technical teams is imperative to ensure market analysis aligns with actual technical requirements. Finally, agencies should continuously educate the Acquisition Team on the risks of AI as a whole and train them to identify potential threats and signs of bias injection.

Agencies should monitor digital platforms for suspicious campaigns and disinformation activities and continuously collaborate with cybersecurity experts to detect and mitigate these threats. These recommendations can allow agencies to tap into the power of AI while mitigating the risks of compromise and exploitation by nefarious actors.

Scenario 3: Market Research Information Gathering

Acquisition Phase(s): Market Research, Solicitation

Attack/Compromise Type: Client/Vendor Impersonation Fraud

Scenario: A malicious actor identifies the government program manager (PM), teammates, and the likely acquisition timeline for a major enterprise acquisition for the USG Agency during an Industry Day that was published on SAM.gov (MITRE ATT&CK, n.d.-f). The contract specialist (CS) publishes his USG email address on SAM.gov to coordinate attendance. The USG Agency is utilizing a full and open competition for this solicitation, so there are several companies inquiring who are unfamiliar to the CS. Further, the CS is extremely busy with preparing the solicitation package and coordinating the Industry Day. In conjunction with the Industry Day, the USG Agency posts an RFI to give Vendors the opportunity to provide feedback on the materials to be presented during the Industry Day.

Unfortunately, and unbeknownst to the CS, the malicious actor submits an email response to the RFI with a PDF attachment that contained malware (MITRE ATT&CK, n.d.-d). With all the active distractions happening at once, the malicious email did not get the security scrutiny that it should have by the CS. Without knowing, the CS has unknowingly forwarded a malicious attachment to the entire technical program team, which later results in a backdoor providing unauthorized access into the USG Agency network.

Potential impact: With the program hierarchy information gleaned from the Industry Day and the backdoor access provided by the malicious attachment, the agent proceeds to systematically comb through USG Agency systems and databases, downloading and exfiltrating gigabytes of valuable health records, personnel files, and military duty summaries for thousands of patients.

From these sensitive records, the malicious actor is able to piece together sensitive operational details of several military operations – based on the patients' skill identification codes, educational histories, and their combat injuries. The actor is able to use all of this information to piece together how many different units assemble their teams and operate in combat.

In addition, the actor is able to report back to their home country with large amounts of PII on patients who operated in the actor's home country or in operations where the home



country was a target. They are able to build a roster of U.S. personnel to target in future retribution operations.

Recommendation: Agencies should move towards publicizing acquisition information in tightly controlled portals that are actively administered and monitored. Vendors should be required to register for the portal and undergo a verification process before gaining access. Each RFI/RFP published should also be limited based on 'need-to-know.' Companies should be required to prove via North American Industry Classification System (NAICS) codes or prior experience that they have expertise that is applicable to the RFI/RFP before gaining access. All of these measures still allow for fair competition while also verifying Vendors and reducing the risk of malicious actors accessing sensitive information.

Scenario 4: International Traffic in Arms Regulations (ITAR)/Controlled Unclassified Information (CUI)

Acquisition Phase(s): Solicitation, Contract Management

Attack/Compromise Type: Cold calling/Vishing (Donahue, n.d.), Client/Vendor Impersonation Fraud

Scenario: ITAR is a regulation established to restrict and control the export of defense and military related technologies to safeguard U.S. national security and foreign policy objectives. This regulation is in place so that when the need arises to share technical data outside of the United States with its partners, it is approved for sharing by the USG to export the material or information to a foreign person who has the appropriate need-to-know (Article – DDTC Public Portal, 2016). Acquisition and solicitation documents may contain sensitive information that should only be shared with approved ITAR partners.

An RFP is published containing information about new technology regarding equipment being developed by the USG Agency. A CS involved in the creation of the RFP is contacted by someone claiming to be from one of the bidding companies, when in actuality, this person is an imposter attempting to access sensitive contract information. The imposter requests to view the full solicitation/RFP package and the details on the new USG Agency technology and equipment. The RFP materials are marked as ITAR/CUI sensitive, and the unknown entity claims to be a representative from a company with prior ITAR approval. ITAR approvals for companies must be renewed every 12 months. The CS, who is unfamiliar with ITAR regulations, is overtasked during the RFP/solicitation phase of the acquisition. The imposter posing as a representative from the company states that the company is approved for ITAR sharing, but the CS fails to notice that the approval in question expired the prior month. The CS then grants the request and sends the RFP containing the sensitive data to the foreign entity, thereby sharing information in a way that does not comply with ITAR regulations.

Potential impact: The RFP contains information on how to develop USG Agency owned property, which is exposed to a non-U.S. entity. This data is exported in violation of state department and export rules, which creates the potential for the adversary to duplicate/steal the technology, or even for them to find access points into the equipment to possibly disrupt future missions.

The request to share information with external entities can arise during the contract management phase as well, after the contract has been awarded. Contract professionals must be aware of ITAR regulations in order to answer these requests throughout the entire acquisition lifecycle.



Recommendation: ITAR is not a topic that comes up often during the acquisition process. Agencies should strive to increase awareness of ITAR regulations and policies, as some contracting and acquisition professionals may not be familiar with them or the process for sharing information with entities and partners external to the United States. Further, agencies should consider adding a step into the solicitation process to double check the recency of ITAR approval for all bidding companies.

Scenario 5: Economic Espionage

Acquisition Phase(s): Solicitation

Attack/Compromise Type: Framing, Pretexting (Donahue, n.d.), Cold Calling/Vishing (Donahue, n.d.), Client/Vendor Impersonation Fraud

Scenario: A foreign agent, posing as a lead researcher in a company that develops vaccines, tricks a CS into sharing Government Furnished Information (GFI) associated with a vaccine development solicitation that is currently “on the street.” The GFI contains key information gleaned from years of intensive research and millions of dollars spent, thereby enabling Intellectual Property Theft for the purpose of boosting a Nation State’s economic interests.

With the advent of hybrid work models, the foreign agent is able to target hundreds of CSs across the country supporting vaccine-adjacent programs. Using common business platforms, the agent is able to reach many more targets with minimal time and effort invested.

Potential impact: Gaining access to key research findings allows the foreign agent to convey valuable insights back to their government to be exploited. The foreign government is able to forego investing years of time and money into developing their own vaccine and use state-owned companies to begin producing the U.S. vaccine ahead of other manufacturers.

While the vaccine is successful in saving many lives, the foreign government also sells it to several other countries, reaping massive profits across the world. The U.S. companies who invested in the vaccine miss out on millions of vaccine sales and are unable to recoup their research and development costs. This leaves them less financially able to continue research and development on future vaccine initiatives. Future diseases end up taking longer to thwart, as the leading vaccine company from the foreign country has no research/development capabilities.

Recommendation: Agencies should move towards keeping active control of critical data, even if it is not classified or national security related. Maintaining lists of trusted entities, whom GFI or other critical information can be released to, would be highly recommended. Companies participating in solicitations would provide POC lists to the CO, and all government personnel should refer to the list before the release of *any* information, especially critical GFI or background data.

For an even more robust response, the government should consider creating dedicated IT systems for contractors to view and consume critical GFI or other agency-owned information without being able to export or remove the information from those systems. Vendors could then build proposals with knowledge of the critical information, but the official records/databases/documents would remain close hold. Software development sometimes occurs in this manner. The government provides an entire IT system for developing code, that is entirely hosted and controlled by the government, then the contractor performs their



work on the government systems, not a contractor system, thereby ensuring the government retains control of critical data and interfaces.

Scenario 6: AI-Enhanced Source Selections

Acquisition Phase: Source Selection

Attack/Compromise Type: AI Bias

Scenario: A USG Agency is in the process of procuring an advanced border surveillance system to enhance national security. To expedite vendor selection, the USG Agency has incorporated AI into the evaluation process, allowing AI algorithms to analyze and rank potential vendors based on predetermined evaluation criteria such as cost, technical expertise, and past performance. However, this innovative approach inadvertently leads to AI-induced bias in the vendor selection process, with potentially far-reaching consequences.

In an effort to streamline the vendor selection process, the USG leverages AI to assist in the evaluation of proposals submitted by potential contractors. The AI system processes vast amounts of data, including both sections L and M, past performance records, technical capabilities, and cost estimates to assess each vendor's suitability for the project. This approach has the potential to enhance efficiency and objectivity in the evaluation process.

Unbeknownst to the agency, there is a flaw in the AI's training data (MITRE ATLAS, n.d.-b). The flaw concerns the past performance data for the vendors. Though the system should be considering past performance data from the past 5 years, the AI engine's training model only contained data for 2 of the last 5 years because it hadn't been updated since 2021. This effectively disregards several years of data that could impact the overall assessment of a vendor and their ability to successfully deliver on the contract requirements.

This systematic flaw introduces unintended bias into the system. The inaccurate historical information that was used to train the AI model creates an inadvertently lower score assigned to proposals submitted by small businesses, even though they possess competitive technical capabilities and cost-effective solutions. This bias results in the unintentional exclusion of highly qualified small-business vendors from the shortlist of potential contractors. These vendors, despite meeting all the specified criteria, consistently receive lower rankings due to the biased AI evaluation.

Potential Impacts: This AI-induced bias leads to the unjust exclusion of qualified vendors, potentially limiting the government's access to innovative and cost-effective solutions. Furthermore, it erodes trust in the fairness of the acquisition process, raising concerns about bias in AI-driven decision-making within the USG Agency. Also, it could impact the solution that is acquired and the overall mission of the Agency.

Recommendations: The USG should ensure that the AI's training data is comprehensive, diverse, and free from historical biases. They should employ continuous monitoring and validation of the training data as this could help mitigate the risk of bias. Also, the USG Agency should maintain a human oversight mechanism in the evaluation process. Expert evaluators should review AI-generated recommendations, correcting any instances of bias and ensuring that decisions align with the Agency policies.

Scenario 7: Technical Exchange Panel (TEP)

Acquisition Phase(s): Source Selection

Attack/Compromise Type: Elicitation, Spear Phishing (MITRE ATT&CK, n.d.-d)



Scenario: During an Industry Day for an upcoming solicitation, a foreign actor (agent) identifies the program lead and teammates and the likely timeline for a major USG acquisition. The agent then turns to social media to develop an initial profile of each of the team members, including personal email accounts (MITRE ATT&CK, n.d.-b). The social media research leads the agent to see that the program lead's daughter is part of a travel softball team and there are many photos on Facebook. The agent then poses as a photographer from a local newspaper and crafts an email to the program lead's personal email including a link to additional photos from a recent game. The program lead clicks on the link using his personal phone, not realizing the link contains malware that allows the agent to exploit a software vulnerability and install a backdoor on the program lead's iPhone. This allows the agent to bypass authentication and control the phone remotely.

For the next few weeks, the agent uses the microphone on the iPhone to listen in (MITRE ATT&CK, n.d.-a) on virtual technical exchange panel (TEP) deliberations on technical merit, risks, and impact, discussions of the elements and realism of the business proposals, and the trade-offs between technical merit, risk, and price. All information that can be used by the agent to collect mission critical information.

Potential impact: By listening in on the USG TEP consensus session, the competitor/foreign agent gains more nuanced information to add to what is publicly available. There are numerous applications in obtaining this inside information. This ranges from simply gaining an unfair competitive advantage in accessing a proposal or leakage of intellectual property (IP) and its value as perceived by the government to an industry competitor conducting full-scale IP theft. Full scale IP theft could boost a nation-state's economic interests by allowing it to avoid research and development investments.

Recommendations: Agencies should resist prevailing post-COVID practices of remote consensus sessions and prohibit phones. Additionally, the USG should add social engineering training to procurement integrity training and conduct the training at key phases of the acquisition schedule. Finally, it is recommended that they ensure all key stakeholders both in industry and government practice cyber hygiene and proper mitigations are put in place at home, outside, and in the office to resist simple cyber-attacks that can compromise information.

Scenario 8: Consensus

Acquisition Phase(s): Source Selection

Attack/Compromise Type: Elicitation

Scenario: A large oil company located in the Middle East finds a government solicitation on SAM.gov (MITRE ATT&CK, n.d.-f) for overseas fuel replenishments. This oil company is nation-state backed by a kingdom that is looking to improve their diplomatic relations with the United States. The goal of this contract is to provide the USG ships oil for them to transport to refuel the ships at sea. This is a major contract valued in the billions. The large oil company attends an industry day and identifies the acquisition and technical teams. This is an important acquisition for both the Agency and the oil company, both because of its size and because it is advertised as a departure from acquisition strategies of the past to increase competition.

The business development (BD) team of this oil company implements a multi-prong information gathering campaign to enhance its chances of winning. First, the company leverages social media to find onsite contractor employees who are badged by the Agency and have access to all of the buildings (MITRE ATT&CK, n.d.-b). They ask the contractor staff to simply pay attention to the team's meetings and locations. Next, the BD team begins



to frequent local restaurant happy hours near the program lead's office building and notices that on Thursday nights, the team seems to gather at the local hotel bar (National Cyber Security Centre, n.d.). The BD team connects the gatherings to the team's all-day Thursday meetings and, over the course of a few weeks, picks up enough bits and pieces of conversation to figure out that the decision is coming down to two bidders: the incumbent and themselves. The large oil company responds to the Agency's request for Final Proposal Revisions (FPR) and decides to offset the incumbent's perceived natural advantage by eavesdropping on the team's final meeting using the location and scheduling information provided by its BD team's scouting.

The conference room's large windows and video-conferencing configuration make it a natural candidate for drone surveillance (Arthur, 2013). The BD team, who could score big bonuses and praise for their company and home country, deploys a commercial drone fixed with a camera and microphone to listen in on and observe the FPR discussion. Realizing that it is about to come in second, the BD team uses the competitive information gained to submit a last-minute "administrative correction" to its FPR pricing. Unaware of the illicit surveillance, the Agency awards the overseas fuel replenishment services contract to the state-backed oil company as the best value.

Potential impact: By monitoring the acquisition team's movements and eavesdropping on publicly held conversations loosened by the alcohol consumed in after-work gatherings, the BD team gained situational awareness it was able to leverage to gain unfair competitive advantage in the FPR determination. If this becomes known, the Agency will be subject to public embarrassment and increased scrutiny. This has happened with large telecommunication contracts in Denmark when Huawei, a Chinese government-owned telecommunication corporation, utilized drones to spy on deliberations to win a contract (Bloomberg, 2023).

Recommendations: Agencies conducting source selections should use operational and physical security practices to ensure the integrity of the source selection remains. Additional training related to this should be included in the "just in time" training that many agencies conduct prior to source selection with the entire team.

Scenario 9: Supply Chain Risk Management (SCRM)

Acquisition Phase(s): Purchasing and Supply Chain Management

Attack/Compromise Type: Spear Phishing (Mitre, 2020)

Scenario: A foreign illegal drug cartel discovers that a company based within their country is serving as a trusted subcontractor to a USG Agency. The cartel, already adept at manipulation, compromises the trusted supplier's property management system by targeting low-level logistics clerks with spear phishing attacks that contain information about their neighborhoods.

One clerk is fooled by the spear phishing because of the specific details contained in the social media messages and clicks a spoofed link that installs rudimentary keylogging software on their work computer. Once installed, this software reports everything the clerk does back to the cartel.

The cartel uses information gathered to discover an order being processed for surveillance camera upgrades, the specifications of the ruggedized, high-resolution cameras and ordering Agency indicate they are clearly destined to monitor the border. The cartel uses its vast network and financial resources to acquire five cameras and hire software engineers to



modify their firmware (MITRE ATT&CK, n.d.-e) to include “backdoors” that allow the cartel to remotely monitor and control the cameras.

Potential impact: As surveillance of the logistics clerk continues, the cartel is able to see when orders are coming in and shipments are going out. The cartel slips the counterfeit cameras into shipments going to the Prime contractor for installation. The cameras are inspected by the Prime, as well as the government, but the cameras look and operate in accordance with all of the quality assurance standards. The cartel ends up with several areas along the southern border where they can view and control the cameras doing daily surveillance.

Recommendation: Agencies with critical missions or sensitive projects should be evaluating and tracking supply chains using robust Supply Chain Risk Management (SCRM) practices. This should include requiring a detailed Bill of Materials (BOM) and Software Bill of Materials (SBOM). While these documents/files can be manipulated as well, continuously monitoring and verifying the information gives the government a view into the complex supply chains that underpin critical projects and discrepancies or vulnerabilities that have the greatest likelihood of discovery.

In this instance, an SBOM would reveal the trusted subcontractor’s operation within cartel territory, and government risk managers would report this as a vulnerability to the program, knowing cartels would have a vested interest in manipulating the cameras destined for the southern border. The components from that subcontractor could be more strictly inspected, or the Vendor replaced entirely – to mitigate the risk.

Scenario 10: Banking Changes for Invoice

Acquisition Phase(s): Contract Management, Post-Award, Invoicing

Attack/Compromise Type: Spearfishing and Vendor Impersonation Fraud

Scenario: A malicious criminal seeking to score a large amount of money searches on LinkedIn for acquisition staff working in the USG Overseas Contracting Division. Gathering information from previous DoS solicitations, the actor is able to decipher the emailing convention for the USG acquisition workforce. The malicious actor poses as an industry contract administrator, emailing the USG CO in the Overseas Contracting Department stating that their banking information has changed and requesting to change it. Previous email from the industry contract administrator has come from joe.smith@industry.com. The email the CO receives this time is from joe.smith@industry.com, and they overlook the extra period at the end. The CO then sends a form to certify the change that contains their previous bank information, revealing the accurate bank information. When the CO receives an email back from the fake vendor, the payment information is updated. This new, trusted email, though it is fake, can be used to extract information such as an additional copy of the contract to include technical information, deliverables, and the Statement of Work. Once the payments are processed, the fraudulent actor is now receiving the payments, likely in very large sums. It will potentially take a few months for a business to realize that they are not receiving proper disbursements. Furthermore, the CO is likely to record that they are getting paid into the new account, which will then alert both parties that they have been a victim of fraud.

This is more likely to happen to a USG CO due to the huge variety of worldwide vendors located within and outside of the United States who support the overseas contracting division. A multitude of international vendors with different currencies and foreign languages can make for an ideal target for vendor fraud. The CO is likely to overlook subtle spelling or grammatical errors due to English not being a first language for foreign vendors.



Potential impact: A loss of federal dollars to vendor impersonation fraud will require a federal criminal and internal investigation, mitigation of data loss (e.g., bank information, any technical data, proprietary information, etc.), and significant time to recover and retrain staff. The recovery of stolen money from a bank account, the payment to the correct bank account, and the security repercussions that will be detailed in future past performance evaluations in a source selection may impact the company's financial situation and reputation.

Recommendation: Agencies that work with foreign vendors should exercise extreme caution relating to information changes and requests for documentation. Furthermore, instead of replying to new email threads, acquisition professionals should utilize previous conversations or start new ones with known email addresses. For banking changes, a formal process with confirmation by phone from vendor and a second email from a supervisor to confirm all details from industry vendor should be considered.

Recommendation

To address the unique challenges acquisition professionals face, the preceding scenarios explore common areas of improvement that can be implemented to mitigate counterintelligence risks.

To address the challenges, we aggregated all the recommendations and determined that a great deal of these risks associated with the acquisition can be mitigated at the Acquisition Strategy Phase. With this in mind, we recommend the development and implementation of an Acquisition Strategy Counterintelligence Risk Assessment (ASCRA) during the Acquisition Strategy approval process. The goal of the ASCRA is to evaluate the overall risk of conducting a specific government acquisition in hopes of implementing mitigations early and to ensure security of the acquisition. The ASCRA would also help shape the RFP and the resulting requirements conveyed to the vendors, subcontractors, and the entire supply chain associated with each procurement. Currently, the Acquisition Strategy risk assessment conducted by nearly all Federal agencies is solely focused on the cost, schedule, and performance risks of the product or service being acquired. The repeatable ASCRA model could have broad implications across the USG and US Industrial Base, as there are currently no standardized processes for assessing the counterintelligence risk of simply conducting the acquisition. This would benefit the USG by better protecting acquisitions and benefit Industry by standardizing requirements and policies to adopt to the evolving threats rather than the current decentralized approach of acquisition operational security.

Conclusion

Acquisition vulnerabilities impact the whole of government as they create unique access points and target areas for U.S. adversaries to attack. American principles of fair opportunity and free markets require the sharing of information but also create many opportunities for foreign actors to exploit our economy. Acquisitions can unwittingly provide deep insights into the USG's most sensitive and closely guarded projects. The scenarios presented above represent possible attack vectors and are meant to be a tool to increase the acquisition community's awareness of this advancing challenge.

The proposed recommendations implementing an ASCRA in the acquisition strategy development process will enable Agencies to have a process, standard lexicon, and pre-vetted and tailorable set of mitigation strategies for any vulnerabilities that may arise during the acquisition process. Adding ASCRAs to standard Agency acquisition processes has the



potential to drastically reduce the amount of U.S. resources lost every year due to adversary exfiltration and improve the overall protection of mission critical information.

Appendix A: Acronyms

AI	Artificial Intelligence
ASCRA	Acquisition Strategy Counterintelligence Risk Assessment
BD	Business Development
BOM	Bill of Materials
CO	Contracting Officer
CS	Contract Specialist
CUI	Controlled Unclassified System
FPR	Final Proposal Revisions
FTE	Full Time Equivalent
GFI	Government Furnished Information
IP	Intellectual Property
ITAR	International Traffic in Arms Regulations
NAICS	North American Industry Classification System
OT	Operational Technology
PHI	Protected Health Information
PII	Personal Identifiable Information
PM	Program Manager
RFI	Request for Information
RFP	Request for Proposal
SBOM	Software Bill of Materials
SCRM	Supply Chain Risk Management
SOW	Statement of Work
TEP	Technical Exchange Panel
USG	U.S. Government

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The Value of an Agile Approach to Independent Verification and Validation (IV&V) for Acquisition

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Abstract

IV&V is common in both the public and private sector and can range from a risk mitigation strategy to a requirement levied by a safety board or law. IV&V is performed by a team of analysts independent from the development team. The end goal of a second set of eyes on the system under development is to ensure the system satisfies its mission objectives and add assurance of mission success. This paper focuses on addressing the challenges that come with providing software IV&V for cyber-physical systems being developed for the federal government using an agile implementation. Another focus area this paper will address is how an Agile IV&V approach not only allows the IV&V team to be more in phase with the software development activity, providing more focused and timely assurance, and it reinforces the focus on rapid incremental delivery of working products by the enterprise. Observations from Agile IV&V implementations in the federal government and the DoD will be provided, demonstrating the value this Agile IV&V approach provides the program office and a reason to view IV&V as more of an informative partner rather than a burden on the program or as a necessary requirement of the acquisition process. This paper will also highlight how program offices can leverage the beneficial perspective of IV&V to influence the future in a proactive and timely manner rather than correct the past.

Key words: Agile Software Development, Independent Verification and Validation, Risk Mitigation, Technical Debt

Background

Software is often one of the most important pieces of the complex cyber-physical systems that the world is constantly designing and building. This paper will highlight the importance of software assurance on those systems and help the decision makers understand the ever-changing risks associated with software development.

Independent verification and validation (IV&V) is a form of software risk mitigation which has been around for decades in both the public and private sector. Projects in these sectors could either choose to perform IV&V of their software through their own volition or be told that IV&V will be performed on the project to satisfy a law or safety requirement. IV&V will provide valuable insight into the quality of the software and even insight into the development process, depending on what the program is looking for in their relationship with IV&V. No matter the reason for why IV&V is being performed, this paper aims to help the reader get the most out of the information that the IV&V team is providing throughout the interaction with the project or program.

IV&V has been rather commonplace in the federal government for several decades. Most of the instances in the Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) are instituted from a safety perspective, usually mandatory by statutes dictating the use of IV&V either internally to the agency, or externally from a commercial provider. This “forced relationship” between IV&V and the developer usually



sets the tone for how the experience will go. It doesn't mean that there is no strain on the relationship between IV&V and the developer if the program office voluntarily has chosen to do IV&V; it just provides an additional excuse for the relationship to sour if the developer can lean on the fact that they "were forced to participate" with IV&V.

This is where the role of the acquisition organization, the program office, can help set the tone for how the developer will interact with the IV&V agent. IV&V has an incredible role in acquisitions. The IV&V team will be able to provide the program office an unbiased view of what is happening at the software level. This insight the IV&V team provides will highlight where the software is doing what it is supposed to be doing well and identify issues that may be preventing it from doing so. IV&V can highlight risks in the development process or in the software itself and whether the software is satisfying the requirements the program office set in place. All this work boils down to one thing, information for the decision makers along the way to help them make the best decisions possible regarding resources and technical outcomes to make the development a success that will safely execute what it was designed to do.

One major change that has occurred impacting program offices as well as IV&V providers is the way software is developed. In the past decade, Agile software development has moved to become more of the norm when it comes to software development in the DoD and other federal agencies. As this approach to software development has been maturing within the federal space, many of the players involved with acquisition have had to tailor some of their own practices to allow the rules and regulations of federal acquisition to mesh with the iterative approach of Agile development. This is no different for IV&V; the work this team must perform has become slightly more complicated due to an Agile approach to software development.

It is up to the program office, teams that support the program office, and IV&V to understand how the developer is utilizing Agile in their development methodology and figure out the best way to integrate into that flow without more disruption than is required. There are many pros and cons when it comes to Agile software development in the public space, but there are a few positives that should be focused on from an acquisition standpoint.

If you reference the Manifesto for Agile software development (agilemanifesto.org), it highlights the values and principles that most Agile software development teams are trying to adhere to. There are a few themes of these values and principles that, from an acquisition perspective, should make the program office very happy. Those are enhanced collaboration, transparency and visibility in the work, working software delivered to the customer quicker, and flexibility. The Agile Manifesto is very focused on customer satisfaction, and that is great news from a program office's perspective.

One of the greatest strengths of an Agile development approach is the iterative nature, that provides numerous touch points with the developer, and opportunities to course correct along the way. This is very different to traditional waterfall development methodologies, where requirements and designs can be set in stone years before the project is complete. While it is true that the stone that those requirements and designs are etched in can be changed for a price, it is still an undue burden to the program office that they would like to avoid.

Challenge for IV&V

The challenges arise with the cadence at which the software is being developed and the IV&V team's ability to match that pace given the rigor that they are expected to provide when analyzing the software. A traditional IV&V effort would be able to review requirements,



design, code, and test, and have naturally occurring checkpoints with the program office and developer to deliver findings.

Teams performing IV&V for a developer using an Agile approach likely have had to make some sort of adjustment compared to a more traditional waterfall development methodology. A waterfall methodology is a methodology described by Winton Royce in 1970 in which steps occur sequentially, one after the next, and when this is depicted visually, looks like a waterfall. In a waterfall methodology, the requirements would be written and then approved in some sort of review. After the requirements are approved, the developer would move to do the design of the system, which would also be approved in a formal review. After the design is complete and approved, code will be written to satisfy the design and ultimately tested as well. This methodology was the paradigm for several decades and is still prevalent in the federal government today.

From an IV&V perspective, it was relatively straightforward for the IV&V team to begin involvement on a project using a waterfall approach. Depending on what level of coverage the program wanted, IV&V could be added early in the requirements phase or brought in when the software was delivered, and the program was doing testing. No matter when IV&V began their work, the goal of adding assurance for the software was achieved. If IV&V was a requirement for that project, that requirement was satisfied. Yes, it makes sense to have IV&V involved as early as possible so that the team can build up their system understanding, and integrate their findings into the development, but sometimes that level of coverage isn't in the budget and IV&V can only be brought on for code reviews.

The iterative approach of an Agile development is very different for an IV&V team that isn't used to the speed at which the development can move through the traditional phases of development. Continually iterating on the requirements, the design, and the code. IV&V teams are used to having everything they need to perform the analysis they want to do and a date to deliver the findings by that typically coincides with a milestone review. This model for IV&V struggles to be successful unless the team is educated in Agile principles and understands how to best integrate with the program and developer while still maintaining independence, as will be documented later in the paper.

A program office who is going to perform IV&V utilizing an Agile development approach should look at it from the lens of getting to have more insight into the development as it is happening. This should come with more collaboration along the way, and opportunity, as the customer can share thoughts on where the development is headed. This collaboration may not always be easy given traditional relationships between program offices and their developers, but IV&V teams are in a unique position to help bridge any potential gaps that may be in place.

It does matter what level of independence the IV&V team has when it comes to execution and not impacting the work that the team is doing, but perhaps not so much from an insight perspective where the team is delivering insights to the program officer quicker. The Institute of Electrical and Electronics Engineers (IEEE; 2017) Standard for System, Software, and Hardware Verification and Validation (IEEE 1012-2016) does a great job highlighting the different levels of independence. These levels are so important to recognize and to understand by all parties involved when defining the scope and execution of the work. It matters if a program office wants to have a say in what is in scope for the IV&V team and what is not in scope. It matters where the funding comes from for the IV&V activities. It matters if the IV&V team shares developers with the team that did the development work. All these things impact that level of independence the team does or doesn't have. This paper wants to focus on the integration of the information the IV&V team is providing to not only



the developer, but also the program office. Using an IV&V provider that integrates into the agile development cadence is great for the developer, being able to add issues and risks into their backlog and weigh them with the business value of the other things they wanted to accomplish that increment. Allowing the developer to factor in the issues found prior to doing a thorough review when the software is delivered is reducing the amount of technical debt overall that the program will face. That same constant insight from an independent source to the program office is also extremely valuable. The early warning signs can help direct questions to the developer. The analysis done by the IV&V team can serve as the evidence needed to help decision makers with what they want to address and what they are comfortable accepting as risk.

This approach to IV&V could be different than what your program office is used to. The more traditional IV&V approach would have the IV&V team present findings at various milestone reviews, and decisions from the program could be handed to the developer to either fix the issues or accept the risk moving forward. The issue is that these milestone reviews could be years apart, an eternity in the scope of an Agile developed program. Adopting an Agile mindset and implementing Agile principles can build ceremonies and a cadence with a much greater frequency, shortening that timeline to months or weeks depending on your program's preferences. It also can help get inside the developer's OODA loop (Observe, Orient, Decide, and Act). Timing is very crucial for a program utilizing an Agile approach, so if you as the program office can help them out with your timing, it would be very beneficial for all.

Adopting Agile Values and Principles

The first thing the IV&V team needs to do to become Agile is to understand their process. This may seem straightforward, but many teams do not truly understand their IV&V process. The team sets out to simply just do IV&V. IV&V analysts are creatures of habit, and they fall into methods and techniques that are comfortable to them, where they have high confidence in their work. There is nothing wrong with that, but how does an IV&V analyst doing IV&V fit into the team's overall process. When does the analysis begin, when does it end, what is the analyst looking for, what will they do if they find what they are looking for, and so on. Thinking through this process is very important to understand what the team is doing when and for what reason. After the process is understood, it can more easily be determined where Agile principles make the most sense.

Once the process is understood better, the team can begin exploring better ways to get in phase with the developer. This is the overall goal of going Agile in the first place, for the team to be flexible and reactive in nature to things they may find along the way, enhancing their ability to communicate it to the developer and stakeholders as quickly and efficiently as possible.

The next step recommended to IV&V teams adopting Agile principles is to understand what work the IV&V team needs to perform to assure the software to the desired level of detail. This step tries to answer the questions posed earlier about when analysis begins and ends and what the analyst is looking for. This will likely involve some level of internal planning for the IV&V team to understand the entire scope of the task as well as to begin to develop a backlog of work that needs to be accomplished. This backlog, just like a developer backlog, will need to be groomed and prioritized based on the rationale set forth by the IV&V team. With an Agile project, the days of being able to get a code release and have 6 months to review it prior to a major milestone review while the developer and program office are doing their own testing are gone. As described above, the iterative nature of an Agile approach makes this approach a flawed one. So going into this level of planning and strategically deciding on what makes the most sense to work on when is critical.



Planning is foundational to a team utilizing Agile. It is an action that helps them stay grounded in what they are doing to achieve the vision and the goals of the development lifecycle. One of the key ceremonies that is observed by development teams, especially those at scale, is an increment planning meeting. These planning meetings are great opportunities to gain insight into the work the developer is planning to do. From an IV&V perspective, there should be a concentrated effort to attend these planning meetings to understand where the developer is prioritizing their efforts for the next 10 to 12 weeks. From a program office perspective, if there isn't already representation present at these planning meetings, it should be strongly considered for the strong insights they can provide.

Once the IV&V team has insight into what the developer plans to do at any given increment, they can use this information to prioritize the IV&V backlog, choosing the highest priority and relevant work, ultimately having greater impact and adding the most value as it pertains to the timing aspect of issue delivery. The program office will play a big role in this, but the IV&V team should try to get all issues identified and delivered for the given work they have chosen to do during an increment into the planning cadence of the developer. Whatever issue adjudication process is implemented by the program office should establish target due dates for IV&V issues. These due dates should provide enough time ahead of the next increment planning so that if accepted by the program office, the issues can be added to the developer's backlog and be prioritized with all the other work they would like to accomplish that increment. Doing this allows you as a program to get inside the developer's OODA loop. This will go a long way in strengthening the relationship between all parties involved. It helps the developer understand what the program office values and can then help the developer establish their business value off that. It will also drive conversations that will allow each side to understand the plan for that increment as well as the issues that the program office wants to see addressed at some point.

Observations

This Agile IV&V approach has been implemented across the federal government and has been used by NASA (Smith et al., 2019), and currently within the DoD. There are several observations through various implementations that should be pointed out and can help with the success of an Agile IV&V approach for any program. These observations also serve as warning signs for potential trouble spots normally revealed while performing IV&V for an Agile project.

The first set of observations revolves around relationships across the project. The levels of independence discussed earlier as defined by IEEE 1012 is something that needs to be clearly understood by all parties involved. It is very easy for program offices or leaders within the acquisition community to try and dictate where the IV&V team's effort should be focused based on the information shared. It is the good and the bad that comes with the IV&V team performing in phase analysis. If a more traditional IV&V was done after a milestone or at final software delivery, the conversation is more focused on what issues should be fixed. When the IV&V team is providing in phase analysis and communicating issues up through the program office to allow for adjudication, it is a very different approach and very easy to fall into the temptation of trying to drive the IV&V team to look in certain areas. If the team has the three levels of independence, this violates that independence in the managerial area. Now, if it were discussed ahead of time before the IV&V began their work that the program office would have the ability to steer or recommend where the IV&V team would focus their efforts based on findings, that that is a different story, but everyone is on the same page and understands that from the beginning.

Another observation is the "us vs. them" mentality that can develop in any IV&V relationship. It is very easy to forget that everyone is on the same team and ultimately wants



the same outcome of mission success. Given that this approach calls for increased communication and integration of findings into the developer's backlog, there seem to be more opportunities for this mentality to arise. The program office will receive issues and risks that need to be communicated to the developer on a much more frequent basis, and given the early lifecycle integration, it can be easy to develop a pessimistic attitude towards the developer. This is where the insight and understanding of the developer's approach and plan can help tremendously in trusting that plan. There will be times where the developer chooses not to incorporate the IV&V findings into a specific increment's plan, and that is okay. The issue still needs to be captured in the backlog or an issue tracker for future reference, but if other things are higher priority than planning increment, that is an acceptable approach. The trap that teams can fall into in this dynamic is the developer is doing that intentionally, they are ignoring IV&V, or the program office. That is likely not the case; it is more of a matter of vision and knowing when it makes the most sense to implement fixes in their development process.

Ultimately having an IV&V team getting involved in software assurance is an exercise of trust. The relationship between IV&V, the program office, and the developer should be collaborative in nature. The IV&V team will know their lane and understand the boundaries that should not be crossed to maintain independence. It is up to everyone involved to make sure that the IV&V involvement does not lead to an adversarial relationship. It is very easy in development environments for IV&V to take the "blame" for slowing things down. IV&V will find issues that will create technical debt; they will identify systemic risks that no one else could possibly have seen. At the end of the day, it is highly likely that IV&V will create some very difficult decisions on what findings must be addressed and what risk will ultimately be accepted, which can lead to a delicate balance of the perception of IV&V. There is a great paper by James Dabney and James Arthur (1998) highlighting the professional challenges to IV&V which reiterates some of the observations mentioned related to the parties trusting and cooperating with each other as well as some other potential pit-falls that could occur when using IV&V.

Another delicate balance is the importance of sticking to the facts that are produced by the evidence that the IV&V provides. This is important for all parties involved, going back to the earlier mention of the shared vision of providing the best software product possible. Based on the evidence the IV&V team provides, if one becomes too emotional regarding the findings, it could lead down a trap that the developer wasn't performing up to their maximum potential. This is just emotion leading people down an unproductive path. The facts help ground everyone in the reality of what has been found. If the issues that are found are in fact warranted, then the teams will need to work together to figure out how to move forward. The decision with what to do with the issues will likely come down to risk tolerance, but finding these issues earlier in the lifecycle is such a better outcome than finding them later or, worse yet, in operation.

Conclusion

In conclusion, there are many approaches IV&V can take for projects implementing Agile software development. There are many approaches for the program office to have insight into how the development of the software is progressing. This paper highlights the value in transparency and communication. Between the program office and the IV&V provider, as well as communication with the developer. What has been described is an approach that is tailorable to fit various settings in acquisition, and applications of IV&V. In the spirit of Agile, this approach to IV&V focuses on continuous improvement. How can the team, and team in these cases is everyone involved with the project, continually learn from each other to improve the overall development of whatever they are trying to do.



The key concepts that should be considered are consistent communication with the IV&V team and being an active attendee, and participant if able, during the developer's increment planning, getting inside their OODA loop. These concepts paired with insight into the backlog of IV&V work through the consistent communication will help the program office be much more in phase with the developer. Depending on the level of independence, the program office may or may not have influence of the priorities of that backlog, but either way, they will have a clearer picture and the supporting detail of the work being performed by the IV&V team.

Ultimately, program offices acquiring a software product from a developer will have to make a final call on acceptance of that software. If IV&V is involved in some fashion, issues with that software will likely be uncovered along the way. It will be up to the program office leadership to decide what to do with that information, no one else. The IV&V team will have opinions on the findings, the developer will have opinions on the findings, and there will likely be cost and schedule impacts to the decisions that the leadership team must make regarding the findings. At the end of the day, though, hopefully the use of an IV&V team in an agile approach has informed the decision makers enough along the way that they feel confident enough leveraging the beneficial perspective of IV&V to influence the future in a proactive and timely manner rather than correct the past.

Hopefully, this paper has shown the value when it comes to performing IV&V in phase for an Agile project. These concepts do not have to be limited to IV&V, though; the same principles and approaches can be valuable to the internal verification and validation (V&V) team or even operational testing. All these teams contribute to the overall risk-mitigation of the software development for the program and can benefit from some of the concepts discussed in this paper. There is so much value in the increased communication across the program and the developer that it is worth looking at ways to implement different Agile ceremonies. If a program is struggling with technical debt, and consistently being surprised by issues coming up and impacting cost and schedule, Agile and lean concepts should strongly be considered by the program office to help get in sync with the developer.

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PANEL 6. STRENGTHENING SUPPLY CHAINS AND LOGISTICS

Wednesday, May 8, 2024	
12:45 p.m. – 2:00 p.m	<p>Chair: David H. Lewis, VADM, USN, (Ret), Senior Vice President, Maritime, Leidos</p> <p><i>Hypersonics Supply Chains: Securing the Path to the Future</i> Rebecca Wostenberg, NDIA Emerging Technologies Institute</p> <p><i>Fuel Logistics Platform Requirements to Support Naval Surface Combatants and Expeditionary Marine Forces in INDOPACOM AOR</i> Geraldo Ferrer, Naval Postgraduate School</p> <p><i>National Security & Technology - How the Semiconductor shortage revolutionized U.S. Manufacturing Policy</i> Martin Barlow, Aero Space Corp</p>

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Lewis graduated from the University of Nebraska in 1979 and was commissioned through the Naval Reserve Officers Training Corps program. He also holds a Master of Science in Computer Science from the Naval Postgraduate School.



Hypersonics Supply Chains: Securing the Path to the Future

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Abstract

Over the past few years, the United States Department of Defense (DoD) has undertaken an ambitious effort to develop and deploy hypersonic technology in support of a variety of national security missions. Hypersonic weapons are maneuverable, fly at least five times the speed of sound, or Mach 5, within the Earth's atmosphere, and can deliver long-range lethal effects on short time scales. Despite this recent effort, the DoD has often wavered in its commitment to fielding hypersonic systems at scale. Some years, it has been a clear priority while other times, the commitment has been ambiguous. As such, the current supply chains, including the manufacturing base, supply of critical materials, testing infrastructure, and workforce are incapable of supporting DoD's ambitious plans. To rectify critical hypersonics supply chains vulnerabilities, a holistic and coordinated approach among government, industry, and academia is essential. This integration will facilitate the cost-effective and reliable production of operational hypersonic systems. If action is taken now, the DoD's hypersonics aspirations are within reach. The most important step the DoD can take to secure hypersonics supply chains for the future is to provide a consistent demand signal to industry.

Critical Raw Materials and Goods

Assessment of the Sector

The availability of critical raw materials and goods plays a vital role in U.S. defense supply chains, especially in the production of hypersonic systems. Current hypersonics supply chains face a plethora of vulnerabilities, including foreign dependency for sourcing. Although additional vulnerabilities may exist, this section will highlight those most pressing as well as



provide recommended solutions to establish healthy and resilient hypersonics supply chains for the future.

High Temperature Materials

High temperature materials have numerous applications in hypersonic systems including heat shields, thermal protection systems, rocket engine components, scramjet engine components, nozzles, and especially leading edges. The materials used for various high-temperature components include:

Carbon Fiber

Carbon fiber's physical and mechanical properties make it a preferred choice in the aerospace and defense industry. It is lightweight, durable, corrosion-resistant, chemical-resistant, and temperature-resistant. Carbon fiber is a key component of high temperature materials including carbon-carbon composites, silicon carbide, silicon carbon fiber, phenolic-impregnated carbon ablator (PICA), and ceramic matrix composites. Approximately 90% of all carbon fibers are manufactured using a polyacrylonitrile (PAN) process while the remaining 10% use a rayon or petroleum pitch process (*How is Carbon Fiber Made?*, 2022). The United States and Japan are the top two carbon fiber producers (Sloan, 2020). With significant production occurring domestically and in an allied country, the carbon fiber supply chain is relatively healthy and secure. However, potential market shifts may introduce risk in the future (Sloan, 2020). According to a recent Market Research report, "The global carbon fiber market was valued at USD \$6.5 billion in 2022 and is projected to reach \$21.7 billion by 2032" (*Carbon Fiber Market*, 2023). While there are numerous industries that rely on carbon fiber, "aerospace and defense accounted for 44.2% in terms of value in the carbon fiber market in 2022" (*Carbon Fiber Market*, 2023). The wind energy industry accounts for the second largest share at 14.7% of share in terms of value (*Carbon Fiber Market*, 2023). As countries impose strict environmental policies, the demand for carbon fiber (especially in the wind energy industry) will likely increase. According to recent estimates, with rapidly increasing demand, the carbon fiber market could see a potential shortfall of 55,250 metric tons by 2026 (Sloan, 2021). Shortages in carbon fiber have existed in the past and suppliers have added additional capacity (*Carbon Fiber Market*, 2023). However, it can take a minimum of two years to construct and commission a new carbon fiber line (Sloan, 2021). With an increased emphasis by the government worldwide on alternative sources of energy, including wind, this could negatively impact the availability of carbon fiber, in the short-term, for aerospace and defense uses, including hypersonics (Sloan, 2021). At the same time though, in the long-term, growth of carbon fiber supply could benefit hypersonics supply chains. However, only time will tell if the carbon fiber industry can grow quickly and sufficiently to support all end uses including hypersonics.

Carbon-Carbon and Ceramic Matrix Composites

Carbon-carbon and ceramic matrix composites are lightweight, strong, and stiff materials that remain durable even at very high temperatures (*Hypersonic Composites Resist Extreme Heat and Stress*, 2007). Carbon-carbon is the only option for coatings for the higher speed hypersonic systems. Because these composites have only niche applications and DoD demand is low, the supply base is relatively small, and most coatings are made by hand. According to industry participants in the working groups, there are only three suppliers for the carbon-carbon composites used in hypersonic vehicle coatings. The lack of a consistent market has led to a very fragile supply chain. Given these risks, some defense prime contractors are acquiring high temperature material manufacturers in order to guarantee availability (Mason, 2022). The DoD has taken notice of the fragile supply chain and is funding the University of Buffalo through LIFT, a DoD Manufacturing Institute to research alternate materials (Brothers, 2022). In December 2022, the DoD also awarded \$22.9 million for expanded domestic production of high- and ultra-high temperature composites (Martinez & Bistarkey, 2022). These are both steps in the right



direction but will likely take a significant amount of time to yield results. In the near-term, the current size of the supply base is a significant barrier to scaling hypersonic systems.

Tantalum

While tantalum has many other applications, it is an important component in tantalum carbide, an ultra-high temperature ceramic, with significant applications in hypersonic systems, given its high melting point (3880 degrees C; Canan, 2007). Tantalum powder also offers a highly corrosion-resistant, strong, and pure material. Its unique properties enable industry to 3D print components for aerospace and defense applications. Finally, tantalum is also used in manufacturing micro-electronics which are found in hypersonic systems. There are three import streams of tantalum to the United States: 1) ores and concentrates, 2) metal and powder, 3) waste and scrap (Friedline, 2023). From 2018-2021, the U.S. imported most of its tantalum ores and concentrates from Australia (43%) and Rwanda (21%), (Friedline, 2023) metal and powder from China (42%) and Germany (23%), and waste and scrap from Indonesia (23%) and China (17%; Friedline, 2023). Tantalum metal and powder are the product of processing ores and concentrates, which are then used to make alloys designed for different purposes. While tantalum is included in the National Defense Stockpile, thus providing limited insurance against supply issues in case of unexpected, increased demand, there is significant concern surrounding the percentage of U.S. tantalum metal and powder, and waste and scrap that originate from China. It is not clear from open-source information if tantalum for hypersonic uses is imported as ores and concentrates, metal and powder, or waste and scrap. Therefore, it is unclear how much risk is introduced into the supply chain due to reliance on China. If the majority of tantalum for hypersonic systems is imported as ores and concentrates, this supply chain is relatively secure and stable with reliance on a close U.S. ally. However, if the necessary tantalum quantities are imported as metal and powder or waste and scrap, Chinese production introduces significant risk into this aspect of the supply chain.

Rare Earth Elements

The supply of rare earth elements (REE), consisting of the 15 lanthanides on the periodic table plus scandium and yttrium, has been the subject of much discussion in the public forum over the past decade for applications that go far beyond hypersonics (*What are rare earth elements, and why are they important?*, 2023). Although several rare earth elements have hypersonic applications, one of the most important is yttrium, a key component of ceramic applications including high temperature refractories for continuous-casting nozzles (Gambogi, 2020). According to U.S. Geological Survey data, Chinese exports of refined rare-earth metals account for 74% of U.S. rare-earth imports from 2018–2021 (U.S. Geological Survey, 2023). China not only mines the rare earth elements, but also controls more than 85% the world's processing capacity (International Energy Agency, 2021a). The only current domestic rare earths mining alternative to China is California's Mountain Pass mine, operated by MP Materials. In 2020, MP Materials extracted 38,503 tons of material, (MP Materials, 2021) compared to Chinese extraction reported at 140,000 tons in 2020 (Daly, 2021). However, MP Materials' raw material is sent to a subsidiary of the China-based firm, Shenghe Resources Holding Co. Ltd., for processing (United States Securities and Exchange Commission, 2022; Easley, 2023) In 2021, Mountain Pass Mine in California received \$10 million in funding from the Department of Defense to "help it build a \$200 million refinement facility for light rare earths" (Magnuson, 2021). With help from the DoD funding, processing for some light rare earths will be onshored, thus eliminating some reliance on China. At the same time, Round Top Mine in Texas, operated by USA Rare Earth, has similar goals to mine and process rare earths domestically. In 2020, USA Rare Earth opened a pilot processing facility in Wheat Ridge, CO with the goal of being "the first processing facility outside of China with the ability to separate the full range of rare earths" (Svaldi, 2020). While these recent developments are encouraging,



mining and processing take time to reach full capacity. As such, the United States will continue to be reliant on China for REE mining and processing, thus posing a direct vulnerability to numerous defense and non-defense applications, including hypersonics.

Other Raw Materials and Goods

Ammonium Perchlorate

Until recently, the DoD relied on a single source for ammonium perchlorate (AP), a key component of hypersonic systems. AP is a principal raw material used in solid rocket propellants, and until recently, was sourced only from American Pacific (AMPAC). AMPAC was the only DoD-approved, North American supplier of the material since the company merged with Pacific Engineering and Production Company of Nevada in the 1980s (Judson, 2017). The U.S. government actually assisted in consolidating the businesses following an industrial accident, the largest non-nuclear explosion in U.S. history at an AMPAC facility in 1988 (Judson, 2017). Advocates for the merger claimed it would drive down the cost of ammonium perchlorate due to economies of scale (Judson, 2017). However, the second-order effects were significant vulnerabilities in the supply chain for solid rocket propellants with a single point of failure, higher prices due to lack of competition, and therefore a vulnerability for hypersonic systems. However, starting in 2016, Northrop Grumman (NG) stood up AP production for internal evaluation, increasing to full design production by 2019/2020.¹⁴ NG's decision to begin producing AP at its location in Promontory, UT, was based on a desire to create competition in response to rising prices. NG is now a qualified supplier of AP to the U.S. government for multiple programs including hypersonic-related programs. Only time will tell if two AP suppliers for hypersonic purposes is sufficient. However, a second entrant into the market reduces the risks associated with a single supplier and will likely reduce costs, due to competition.

Summary

Critical raw materials and goods in hypersonics supply chains face several challenges, including foreign source reliance and shortages due to the pandemic and other factors. While some pose significant vulnerabilities in the hypersonics supply chains, like rare earth elements, others, like plastics, face short-term challenges that may be righted by economic forces over time. In some cases where there is a challenge for future supply, industry and the DoD have begun to look for alternatives but these efforts need to be expanded and fully resourced. Of the materials discussed in this chapter, high-temperature materials and the raw materials necessary for them are the most critical. The following recommendations should be implemented to ensure secure hypersonics supply chains in the future.

Recommendations

- Working together, Congress and the Department of Defense should reinforce the National Defense Stockpile of strategic minerals.
- The DoD should provide a clear demand signal to private industry to increase investment in additional carbon fiber suppliers.

¹⁴ All Northrop Grumman information was gathered via e-mails with the company.

Manufacturing Base and Workforce

Assessment of the Sector

The U.S. manufacturing base and workforce is essential to the defense industrial base's ability to develop and deliver hypersonic capabilities at scale. While not traditionally considered part of a supply chain, testing infrastructure is a key component of delivering hypersonic systems and therefore was also considered by the working groups. During the ETI-led working groups, participants assessed the health of the current manufacturing base and workforce by addressing key issues, areas of success, and opportunities for improvement through policy changes. Overall, the existing hypersonic manufacturing base and testing infrastructure is insufficient to meet the needs of the future. At the same time, the accompanying hypersonic workforce has waned over the years and cannot meet the current, much less, future demands. Over the past few years, some positive steps have been taken, however, it is not enough.

Manufacturing Base

Insufficient Manufacturing Base Due To Inconsistent Demand Signal

Throughout the hypersonic working group discussions, a common theme from industry and academia was a lack of consistent government demand signal when it comes to hypersonics. As such, the existing manufacturing base is small and suited only to manufacturing small numbers of hypersonic systems with long lead times. In recent years, DoD leadership has attempted to send a clearer demand signal for hypersonic systems by stating the need for "hundreds in a short period of time" and according to one official, potentially even thousands or tens of thousands (Freedberg, 2020). This, in theory, would be a tremendous leap from the current demand for a handful of prototypes, if supported by budget requests and appropriations. The current manufacturing base cannot produce hypersonic systems at that scale due to several issues that will be addressed in this section. Solutions are also presented but must be implemented quickly to create secure, resilient supply chains to supply hypersonic systems at scale.

Limited Suppliers

According to several working group participants, the hypersonic manufacturing base relies on a relatively limited supply base. As noted in the Critical Raw Materials and Goods section, many materials used in hypersonic systems are highly specialized and do not have extensive commercial applications, which limits the number of companies participating in the market. For example, there are only two U.S. suppliers of rocket motors used in missile propulsion systems: Aerojet Rocketdyne and Orbital ATK. Orbital ATK was acquired by Northrop Grumman in 2018, while Aerojet Rocketdyne is set to be acquired by L3 Harris Technologies in 2023, pending government approval (L3Harris Technologies, 2022). As prime defense contractors depend on propulsion system components for hypersonic vehicles, reliance on only two entities may be driving costs up (due to a lack of competition) and creating a potential point of failure in the supply chain. Hypersonic systems are only a small percentage of the rocket motor market, with the space industry making up the majority. As the proliferation of space continues to take off, this will put increased demand on an already limited supply, potentially channeling finite resources away from hyper-sonics development. According to one industry participant, limited supplier issues also exist with hypersonic structural components like Titanium-Zirconium-Molybdenum (TZM) bolts that are used to provide strength at elevated temperatures, as well as protective items such as thermal blankets that shield the vehicle from excessive heat. Because the commercial market is almost nonexistent for these materials, the industrial base remains small, and the market remains fragile due to inconsistent demand. Finally, due to the limited number of second- and third-tier suppliers for critical hypersonics components, prime defense contractors often share vendors. For example, Lockheed Martin



and Raytheon are both reliant on the same suppliers for radar equipment, propulsion systems, satellite electronics, and semiconductor chips. This creates a potential vulnerability in supplier overlap and limited suppliers. As discussed in the Critical Raw Materials and Goods section, there is a limited supply base for high temperature materials. This need, in particular, has been recognized and Purdue University's Hypersonics Advanced Manufacturing Technology Center (HAMTC) is currently heading an effort with several leading defense contractors to produce high-temperature materials necessary for hypersonic flight. Research in advanced manufacturing capabilities will play a vital role in the study of these materials, but the effort cannot stop there. Both industry and government need to consider more investment in these alternative production techniques for improving the technological capability needed for tomorrow's hypersonic systems.

Advanced Manufacturing

Advanced manufacturing, and in particular additive manufacturing (AM), has the potential to enable industry to cost-effectively increase production. According to the Deputy Director of the Office of the Secretary of Defense's Manufacturing Technology Program, "The science has proven it's possible, but the practice is not widespread enough" (Albon, 2022). The hypersonic industry has already seen significant improvements in weapon design and cost reduction, through AM. According to two industry participants, AM has resulted in 20 times the reduction in the number of components required when compared to the X-51. This progress is paramount to the scaling of hypersonic weapons, as decreasing the number of parts also reduces the number of potential failure points. According to the same industry participants, the subsequent effect is an 8-fold decrease in cost accompanied by the part reduction and a 4.5-fold reduction in lead time for components.

As a general practice, AM is not a blanket application. However, some hypersonic systems require intricate geometric specifications that traditional manufacturing processes are unable to meet or are too expensive to produce at scale. This has led the DoD to request prototype solutions for its Growing Additive Manufacturing Maturity for Airbreathing Hypersonics (GAMMA-H) challenge (OSD Manufacturing Technology Program, 2022). The objective is for AM companies to address propulsion and high temperature requirements for systems traveling at Mach 5 or higher.

These benefits not only improve the performance of the weapon, but also drive the justification for companies to invest in AM. While AM will disproportionately affect air-breathing systems, there are multiple areas of hypersonic weapon design that lend themselves best to new manufacturing techniques. These include liquid rocket motors that use a fuel-cooled design. AM can improve both the thermal performance of the engine as well as the overall performance. Ultimately, reducing the cost of the engine and advancing its performance is critical for scaling up production. Design flexibility is also suitable for highly complex components, such as heat exchangers, optimized topologies, or complex cooling channels. Finally, AM could be used for wiring, antennae, and circuit boards to reduce weight, according to an industry participant.

Overall, AM reduces the number of components and people involved in the manufacturing process and eliminates tooling. For design complexity, AM achieves a performance that cannot be accomplished with conventional techniques. Advanced manufacturing also includes new technologies, such as big data collection, simulation software, and machine learning, which monitor AM processes by predicting stress and part distortion. The convergence of modern technologies advances hypersonic technology by removing welding, unnecessary machine operations, and joints. However, when considering where AM techniques can be applied, it should be noted that the materials needed ought to exist in sufficient quantities either through domestic or allied sources. Nevertheless, this improvement in



manufacturing methods can substantially improve lead time and cost overall for hypersonic systems.

Unit Cost

Because hypersonics supply chains are still fairly nascent, the cost per unit—particularly for early prototypes and low-rate production systems—has been relatively high, though estimates are all preliminary and include different assumptions. Since specialty materials are not widely available, nor produced at scale, this drives the cost up overall. A constant message heard from senior DoD and Congressional leadership is the need to reduce the cost per unit for hypersonic systems. As Under Secretary of Defense for Research and Engineering Heidi Shyu explained, “We need to figure out how to drive towards more affordable hypersonics. And that’s a piece I would like to help industry focus on: how can we develop affordable hypersonics materials and manufacturing processes to drive the cost down?” (Harper, 2021).

It is important to note that system affordability is not quantifiable per se, since it depends on a complex set of prioritization decisions within the Pentagon, White House, Congress, and industry. However, there are several different factors, regarding the capability of hypersonic systems, that can and should be taken into consideration. First, for hypersonic cruise missiles, a comparison could be made to the cost of conventional cruise missiles which typically cost approximately \$1 million per unit (Cohn et al., 2019). However, a hypersonic cruise missile brings far more capability than a conventional cruise missile, namely, speed and maneuverability, which makes defending against the missiles far more challenging. This increased capability will likely increase development, production, and sustainment costs. It is estimated that air-breathing systems—based on DARPA’s HAWC program—will cost approximately \$2 million per missile. This is a significant drop from the current cost of “tens of millions per unit” currently associated with hypersonic cruise missiles (Stone, 2021). On the other hand, the Navy’s CPS program and the Army’s LHRW provide a very different capability and thus are estimated to cost \$50 million (*The U.S. Army’s Long-Range Hypersonic Weapon [LRHW]*, 2023). These estimates are all very preliminary, include different assumptions, are based on limited data and analysis, and are sometimes biased by industry and service parochialism. It is important to note that some reduction in cost will occur through economies of scale as the Department purchases a larger number of hypersonic systems. However, in order to bring the cost in line with the above estimates in the future, significant changes will have to occur in the hypersonics manufacturing base overall.

Long Lead Times

Due to the lack of demand for large quantities of hypersonic weapons and a low supply of components, lead times have grown exponentially. This issue was raised by multiple working group participants regarding several different components. The current long lead times, in turn, prevent the hypersonic industry from moving quickly. Because the United States is still in the prototype phase of fielding hypersonic systems, there is little economic incentive for multiple hypersonic component suppliers to enter the market and, therefore, reduce lead time. Overall, the longer lead time does not only apply only to hypersonics, but across the defense manufacturing ecosystem. Competition for components goes beyond military applications, as the defense industry must compete for resources with non-defense commercial companies, creating strains on the supply chains of products and components even where the DoD is the sole customer. As discussed elsewhere in the report, this is especially true for components that overlap with commercial aerospace and space applications. Given the tremendous recent growth in the space industry, this competition for components and resources will likely continue. However, in the long-term, this overlap could benefit hypersonics by growing the supply base to meet increasing demand.



Testing Infrastructure

Testing infrastructure, while not traditionally considered as a component of supply chains, plays a crucial role in moving hypersonic systems from the early developmental phase to a fully fielded system. Therefore, it was deemed within the purview of this study. A constant theme throughout the working groups was the insufficiency of current national hypersonics testing infrastructure. While a full, detailed analysis of testing infrastructure could be the subject of an entire study, and has been on several occasions, this report will only touch on a few key issues.¹⁵

There are two broad categories of test facilities needed for the maturation of hypersonic technologies—ground and flight. The first category includes hypersonic wind tunnels (HWTs), that are generally less expensive to operate and allow for easier collection of data compared to actual flight. HWTs simulate air flow and ultra-high temperatures that hypersonic vehicles need to withstand in-flight. The second category is an open-air range, which enables actual flight of a hypersonic prototype or testbed. Open-air ranges provide the space for putting a hypersonic missile on the vehicle's surface itself, enabling testers to better mimic the conditions of the atmosphere. Both facilities simulate the unique conditions experienced in hypersonic flight (e.g., speed, pressure, and heating) and are instrumental for hypersonic development.

Among the biggest constraints to the development of hypersonic technology is the inadequate testing infrastructure in the United States. According to a study conducted by the Institute for Defense Analyses (IDA), the United States had only 48 specialized hypersonic test facilities and mobile assets in 2014 (*The U.S. Army's Long-Range Hypersonic Weapon [LRHW]*, 2023). The facilities are a mix of government, academic, and business entities, including: 10 DoD hypersonic ground test facilities, 11 DoD open-air ranges, 11 DoD mobile assets, 9 NASA facilities, 2 Department of Energy (DoE) facilities, and 5 industry or academic facilities" (*Hypersonic Weapons: Background and Issues for Congress*, 2023). While this study was completed almost 10 years ago, only a few minor changes have occurred since. Two encouraging developments (that will be discussed in more detail below) are that a few universities have begun building additional testing facilities and the DoD has very slowly begun to explore limited changes to increase testing infrastructure. It is challenging to quantify exactly how many more facilities are needed. However, additional capacity is required for several different reasons raised by working group participants.

First, hypersonic systems must compete for test time slots with current high-priority programs, such as missile defense and nuclear deterrence. While DoD leadership has emphasized the importance of hypersonic systems, these other programs have been prioritized in scheduling tests. This is partly due to a lack of a hypersonics program of record and due to the other programs being prioritized by the DoD. The ensuing limited range access for hypersonic flight testing creates inefficiencies. As hypersonic tests are pushed from the schedule to make room for established programs of record, this causes cascading delays to technological development as programs wait months to reschedule (Albon & Gould, 2022). Consistent access to these facilities for ground testing is particularly vital to determine which materials are needed for hypersonic development. One workshop participant noted that optical window materials, for example, have been an ongoing concern for industry, in part because of limited testing capacity. Experiments testing optical window materials in hypersonic flow are necessary to address challenges related to efficient cooling at high speeds and the ensuing high temperatures (Mi et al., 2023). Studies dating back to the 1980s and current SBIR/STTR contracts attempt to provide solutions to address this challenge (Tropf et al., 2023). However,

¹⁵ For examples, see "Advanced Hypersonics Test Facilities" edited by Frank Lu and Dan Marren or "Study on the Ability of the U.S. Test and Evaluation Infrastructure to Effectively and Efficiently Mature Hypersonic Technologies for Defense Systems Development: Summary Analysis and Assessment, Institute for Defense Analyses, September 2014."



the longevity of the issue reflects the poor quality of testing, which hinders industry's ability to collect the appropriate amount of data to adequately pull meaningful results.

A second issue is the age of existing testing infrastructure. Most testing facilities were built decades ago and personnel at the facilities are not accustomed to working at the tempo that is now necessary to keep up with all programs. With this high operational tempo, fatigue sets in and machines break. When one machine goes offline, there is not enough redundancy built in and testing is temporarily halted. Older testing infrastructure also lacks efficient data acquisition. If data acquisition was modernized at testing facilities, this could reduce the number of tests necessary since each test could yield significantly more data.

Current modes of testing also tend to be extremely expensive and difficult to coordinate. For example, the Navy's CPS system has required a "string of pearls" of ship-borne assets across the ocean in order to collect data (U.S. Department of Defense, Office of Operational Test & Evaluation, 2023). However, the Test Resource Management Center (TRMC) is attempting to address this through the SkyRange program, which uses twenty RQ-4B Global Hawks as hypersonic test support (Hoeven, 2022). The goal of the SkyRange program is to increase hypersonic testing, meeting the Department's test cadence of "50 plus tests a year" (Albon, 2022). TRMC and the Office of the Principal Director for Hypersonics are also working with the Space Development Agency, Space Force, and Army to study how satellites could be used to support hypersonic testing (Albon, 2022). TRMC is also leading the development of the Multi-Service Advanced Capability Hypersonics Test Bed (MACH-TB) program, which aims to validate and field hypersonic systems at a higher frequency through a new testing facility (DoD, 2022). Each of these programs are a step in the right direction but only time will tell if they are successful.

Finally, even once the current first-generation hypersonic systems have reached sustainment, modernized, expanded testing facilities will still be needed for the future. A higher tempo of regular S&T flight testing will be necessary to solve key S&T or physics questions for future generation hypersonic systems. Furthermore, as systems are continuously updated with more modern software, materials, and microelectronics, significant continuous testing of the system and subsystems will be required.

Overall, the current U.S. testing infrastructure is insufficient to meet the demands laid out by the Defense Department itself for hypersonic development over the coming years. Even if the rest of the hypersonics manufacturing base were scaled up, aging testing infrastructure would significantly hinder production. Therefore, modernizing and expanding testing infrastructure to support hypersonic programs is a necessary link of a secure, resilient supply chain.

Workforce

Lack of Hypersonic Talent

The hypersonics industry—defined by a workforce lacking substantial experience working on large-scale hypersonic projects—faces an uphill battle in developing a stable supply of hypersonic professionals due to the volatile history of the technology's development. Unfortunately, it is difficult to estimate exactly how large the existing hypersonics workforce is in order to then determine what type of growth is necessary over the coming years. However, a few conclusions can be drawn from the insights of the working groups, subsequent interviews with experts in the field, and internal research. At the same time, trends from the larger aerospace industry workforce likely impact the hypersonics workforce as well and should be considered. As such, this section will summarize the key insights and concerns from the working groups, inter-views with experts, and internal research in the larger context of the aerospace industry workforce, and attempt to provide actionable recommendations to address them.



Overall, the aerospace industry faces many of the same issues facing other sectors in the post-Covid era (Aerospace Industries Association, 2022). The industry has seen rising employee turnover with 69% of respondents to a 2022 Aerospace Industries Association survey stating that turnover increased in the last 12 months (Aerospace Industries Association, 2022). At the same time, there are reports of an industry-wide shortage of talent, especially for workers with engineering skills and strong digital capabilities, despite increasing demand due to the rebound of air travel from the pandemic, the need for advanced defense capabilities due to rising geopolitical tensions, and a renewed vision and prioritization of space travel and deep space exploration (Aerospace Industries Association, 2022). The hypersonics workforce, as a subset of the larger aerospace industry workforce, likely faces similar challenges that are compounded by additional concerns raised by the working groups. According to one working group participant, the current hypersonic-specific expertise is unbalanced and misaligned to current needs. There is a plethora of early and mid-career aerothermal expertise, but a dearth of expertise in other needed areas such as hypersonic controls, system design, and high temperature materials. At the same time, the current hypersonics workforce lacks experience working on large-scale prototypes and system integration challenges as systems scale up from R&D to production.

The hypersonic workforce can be divided into five general groups, along the lines of five different aspects of the technology (United States Air Force Scientific Advisory Board, 2000):

1. Hypersonic-specific technology experts. Certain requisite expertise is applicable only to hypersonic vehicles and their flight regime. Development of the necessary knowledge and expertise in these technology areas requires specific study and experience accrued over a period of years.
2. Workforce that can adapt existing technologies to the specific applications of hypersonics. Other technologies used in vehicle design must be adapted to the severe hypersonic environment. It is likely that technologies from other flight regimes can be adapted to the hypersonic environment. Under some circumstances this can be better and more cost-effective than creating new and unique disciplines.
3. Workforce that combines structures, aerodynamics, engines, communications, sensors, controls, etc., into an integrated operational system. The lack of personnel experienced in vehicle integration and overall hypersonics systems engineering is perhaps the most important issue facing the hypersonic workforce today.
4. Project management for hypersonic vehicle development. The integrated design, building, and testing of a hypersonic vehicle requires project managers with unique expertise. This expertise is largely due to special aspects of components used in the hypersonic environment and the blending and integration of those components into a vehicle.
5. Craftsmen and supporting staff, including machinists, technicians, and other skilled experts. The craftsmen include individuals responsible for activities like installing wind tunnel models, installing instrumentation, precision machining, and systems and infrastructure maintenance and repair. On the supporting side are those who are not subject matter experts, but instead can support engineering activities and rationalize the overarching policy, management, market dynamics, and other business factors that will shape and control program activities.

According to the working groups and interviews with experts, each of these hypersonics workforce sectors faces its own challenges and issues. First, the workforce overall is dominated by late-career professionals and thus a portion is close to retirement. Among the aerospace and defense talent, 28% of the workforce is aged 55 and older, and 42% of the overall workforce has less than five years of tenure at their current company (Aerospace Industries Association,



2022). The working group participants described a similar hypersonics workforce. This is likely due to a heavy emphasis by the U.S. government on hypersonic systems several decades ago. This emphasis led to an increased number of professionals entering the hypersonics workforce. However, that emphasis has ebbed and flowed over the years, and with the uncertainty, fewer professionals have entered the workforce. Another important insight from the working groups pertained to the level of education necessary to work in hypersonics. While certain jobs may require a doctoral level of education, for much of the hypersonic workforce a bachelor's, master's, or even a high school diploma is sufficient. In addition to an aging hypersonics workforce and the necessity for professionals with varying levels of education, several other factors were highlighted by the working groups and experts as impacting the workforce.

Clearance Process Stymies Development of Needed Workforce

Though not specific to hypersonics, the clearance process keeps the industry from moving quickly. Participants in the working groups highlighted that this issue affects nearly all sectors of the workforce and at all levels. One particular issue raised in the working groups is the challenge of clearing students so they can work on relevant research while still in school and be ready to join the workforce immediately upon graduation. Similar issues plague mid-and-senior level talent as well. With clearance processing timelines of 12–18 months, valuable time is wasted. This is an issue that goes far beyond hypersonics, but if hypersonic systems are truly a priority for the DoD and there is a need to move quickly, this talent supply chain issue must be addressed.

Summary

Both the current hypersonics manufacturing base and the hypersonics workforce are insufficient to support hypersonics production in the future. While multiple issues plague both sectors, a lack of consistent demand signal from the Department of Defense has exacerbated the problem. Without a guaranteed return on investment, companies will not invest time, money, and resources into scaling up production. At the same time, individuals may not enter the hypersonics workforce if the viability of programs, and therefore positions, is in question. The first step in scaling up the hypersonics industrial base must be a consistent demand signal from the government. Several other steps must also be taken in order to secure hypersonics supply chains for the future.

Recommendations

- The Department of Defense should provide a consistent and clear demand signal to industry by treating certain hypersonic programs as traditional Programs of Record and utilizing multi-year contracts to send an extended demand signal.
- Additional testing infrastructure should be funded jointly by the DoD and industry at appropriate academic institutions to help replace aging testing infrastructure.
- The DoD should increase the hypersonics flight test schedule.
- The DoD should encourage venture capital to invest in areas where the hypersonics supply chains and growth of the space industry overlap.
- Academia should be leveraged, via the University Consortium for Applied Hypersonics (UCAH), to educate mid-level hypersonic talent.



Supply Chain Security and Vulnerabilities

Assessment of the Sector

Hypersonics supply chains, like other emerging technology supply chains, face a range of threats related to cybersecurity, counterintelligence, and intellectual property theft. While hypersonic-specific examples can be challenging to find in open-source information, some significant conclusions can be drawn from an analysis of recent and historical examples from related industries, in addition to issues raised by the working group participants.

Cybersecurity Risks

Cybersecurity threats to hypersonics supply chains begin at the very lowest tier: mining and production of critical raw materials. As mining operations become more automated, the attack surface area increases (Huq, 2016). Over the years, mining operations have been subject to attacks from numerous fronts, including nation-state actors, with the same techniques used in other sectors such as phishing, vulnerability exploitation, watering hole attacks, and infected equipment (Huq, 2016). The goals of such attacks can range widely from commercial espionage to information operations. For example, from 2006 to 2014, aluminum maker Alcoa Inc. and metal supplier Allegheny Technologies Inc. (ATI) were subject to attacks allegedly originating from the Chinese People's Liberation Army (PLA; Huq, 2016; Mufson, 2014). While exact details are unclear, the hack seemed focused on gaining internal messages related to a February 2008 partnership with a Chinese state-owned company to acquire a substantial stake in a foreign mining company (Huq, 2016; Mufson, 2014). ATI also entered a joint venture with a Chinese state-owned company in 2012 (Strohm et al., 2014). During the attack, the hackers allegedly gained access to network credentials for virtually every employee at a company with approximately 9,500 full-time employees in the aerospace, defense and "specialty materials solutions" sectors (Kravets, 2014).

More recently, an American cybersecurity firm reported on efforts by the People's Republic of China (PRC) related to a "subset of information operations activity . . . across social media that targeted the Australian rare earths mining company, Lynas Rare Earths Ltd." (Mandiant Threat Intelligence, 2022). The activity was one small part of a larger influence campaign, called DRAGONBRIDGE, intended to promote "various narratives in support of the political interests of the PRC" (Mandiant Threat Intelligence, 2022). Not long after, additional attacks took place against the Canadian rare earths miner, Appia, and the American rare earths supplier, USA Rare Earths, in response to reports that Appia had discovered "a new rare earths bearing zone in Northern Saskatchewan" and USA Rare Earths announcing "plans for a rare earths processing facility" (Mandiant Threat Intelligence, 2022). It is likely that the Chinese Communist Party (CCP) saw these commercial entities challenging their dominance in rare earth mining and processing as a threat and thus attempted to undermine the credibility of those commercial entities (Mandiant Threat Intelligence, 2022).

Moving up through the supply chain, hypersonic system manufacturers may face similar cyber threats. According to reporting by the Cybersecurity and Infrastructure Security Agency (CISA), Russian state-sponsored cyber actors have targeted small and large U.S. cleared defense contractors (CDCs) and subcontractors "with varying levels of cybersecurity protocols and resources" (Cybersecurity & Infrastructure Security Agency, 2022). While the exact companies are not named, CISA reports that the CDCs are supporting contracts for the DoD on "command, control, communications, and combat systems . . . weapons and missile development; vehicle aircraft design; and software development, data analytics, computers, and logistics" (Cybersecurity & Infrastructure Security Agency, 2022). Given the breadth of systems targeted, and the fact that Russia has had a robust hypersonics program over the years, it is possible that CDCs working on hypersonics systems are among those targeted.



During the working groups, industry members raised several similar cybersecurity concerns that they, or their suppliers, face on a regular basis. First, the smaller, low-tier suppliers lack the necessary resources for robust cybersecurity measures. The business case is almost non-existent for these small companies to invest in the necessary infrastructure for cybersecurity measures unless they can make a profit in five years—a challenge when the customer is the DoD. Another cyber vulnerability raised by working group participants was the issue of software supply chain attacks. A few suppliers use foreign-made software, which may leave them vulnerable to attacks. According to the CSIS Significant Incident Reports, numerous Chinese hackers have also engaged in cyberattacks against U.S. aerospace companies over the years, including using a malware known as “Sykipot” to target U.S. defense aerospace companies (*Survey of Chinese Espionage in the United States Since 2000*, 2023).

Universities and National Labs conducting hypersonics research and testing have also faced cyberattacks over the years. In 2018, the Australian National University (ANU), which conducts hypersonics research, was allegedly breached by Chinese hackers (Borys, 2018). Exact details are unclear, but according to Australian Strategic Policy Institute’s executive director Peter Jennings, the goal of the attack was to access and extract intellectual property from the institution (Borys, 2018). Oak Ridge National Lab, which has conducted significant research pertaining to modeling the flow of objects in hypersonic flights as well as research aimed at understanding combustion at hypersonic speeds, was subject to a sophisticated cyberattack in 2011 (Liebowitz, 2011). Although full details on the attack are unclear, the lab was forced to shut down its e-mail systems and internet access for all employees when they discovered they were a victim of an advanced persistent threat to steal technical data (*Survey of Chinese Espionage in the United States Since 2000*, 2023). Again, it is unclear if these attacks directly targeted hypersonics research and data, but these examples still show significant cyber vulnerabilities within organizations at various levels of hypersonics supply chains.

Counterintelligence and Economic Espionage Risks

While many current counterintelligence threats to hypersonics supply chains may be classified or not available in the public domain, it is possible to evaluate potential threats based on the reported actions of adversaries and similar historical examples.

China’s technology transfer efforts have become well-known over the past several years. President Xi Jinping has emphasized that in order for China to “grow strong, prosperous and rejuvenated,” (Murphy et al., 2021) it must “become the world’s main center of science and the high ground of innovation” (Murphy et al., 2021). Hypersonics is just one example where China has used both legal and illegal means to field a technology before the United States (Cadell & Nakashima, 2022). Research and development of hypersonic systems in the United States began as early as the 1960s, while Chinese work did not begin in earnest until the mid-2000s (Wood & Cliff, 2020). Given a nearly 40-year difference, how is it that the United States has yet to field a single hypersonic weapon, while China has fielded several and conducted multiple tests on others? While the answer is long and complicated, one factor that potentially accelerated the Chinese programs was the legal, or illegal, acquisition of U.S. research and technology. To be sure, the United States failed to maintain the momentum of its hypersonic programs over the years. If the momentum had been maintained and a clear, consistent focus on fielding hypersonic systems had continued, the United States not only would have outpaced China but many of the existing hypersonics supply chains issues would perhaps not exist. Unfortunately, the reality is that early on, China took note of U.S. hypersonic work, including several open policy documents that explained the value of hypersonic weapons (*America’s Air Force: A Call to the Future*, 2014; Wood & Cliff, 2020). As the United States wavered in its commitment to fielding these weapons, China took advantage of the previous work conducted by the United States and others to expedite their hypersonic programs.



According to a recent report on the issue, China also recruited several former scientists from Los Alamos National Lab to work on their hypersonics programs (Strider, 2022). One example is Chen Shiyi, an expert in fluid dynamics and turbulence, “who has made major contributions to China’s hypersonic missile and aerodynamics programs” (Strider, 2022). After working at Los Alamos National Lab from 1990–2000 and serving as the deputy director of the lab’s Center for Nonlinear Studies, Chen joined Johns Hopkins University in 2001 to serve as chair of the Department of Mechanical Engineering (Strider, 2022). In 2005, Chen returned to the PRC to help establish Peking University’s engineering college and eventually rose to the role of director of PKU’s State Key Laboratory of Turbulence and Complex Systems (LTCS) (Strider, 2022). Allegedly, research that used wind tunnels “built during Chen’s time as PKU engineering dean and LTCS director made ‘important contributions’ that allowed ‘the PRC to surpass the U.S. in airbreathing vehicle research and development’” (Strider, 2022).

Chinese transfer of expertise for hypersonic programs reaches to the semiconductor level. In 2016, Qualcomm, an American semiconductor company, agreed to a joint venture with Huaxintong, a Chinese company, to develop server chips. While the joint venture was closed in 2019, after producing little of value, some expertise “appears to have transferred to other Chinese companies building . . . data center chips” (Miller, 2022). Allegedly, at least one chip design engineer left Huaxintong to work for Phytium, “which the U.S. later alleged had helped the Chinese military design advanced weapons systems like hypersonic missiles” (Miller, 2022). These are just a few examples of how China has legally, and illegally, built up its hypersonic programs with U.S. research and development (Strider, 2022).

Intellectual Property Theft

Another significant vulnerability in hypersonic system supply chains, and all defense supply chains, is intellectual property (IP) theft. Unfortunately, it is difficult to find hypersonic-specific examples of IP theft in open source. However, lessons can be learned by looking at IP theft across the DIB and other related industries. While IP theft can be committed by many different actors, the U.S. Department of Justice has increasingly publicized indictments of Chinese IP theft. In 2014, the FBI indicted five Chinese nationals for stealing trade secrets from American companies (*U.S. Charges Five Chinese Military Hackers for Cyber Espionage Against U.S. Corporations and a Labor Organization for Commercial Advantage*, 2014). While not a hypersonic-specific example, this was the first time the United States ever brought charges against a state actor for this type of hacking (*U.S. Charges Five Chinese Military Hackers for Cyber Espionage Against U.S. Corporations and a Labor Organization for Commercial Advantage*, 2014). Almost a decade later, it is challenging to accurately quantify the damage inflicted on U.S. companies through Chinese theft, however, a few examples can shed light on the issue. In September 2022, an engineer was sentenced to eight months in prison for theft of more than 500 files including trade secrets related to networking chips, that he took prior to resigning from his position at Broadcom (*Former Broadcom Engineer Sentenced to Eight Months in Prison for Theft of Trade Secrets*, 2022). Upon his resignation, he began working for a startup company in the PRC that was “seeking to become a leading chip designer focused on the PRC’s domestic market for networking chips at the time” (*Former Broadcom Engineer Sentenced to Eight Months in Prison for Theft of Trade Secrets*, 2022).

China has also initiated talent programs, including the “Thousand Talents Program” in order to “attract, recruit, and cultivate high-level scientific talent in furtherance of China’s scientific development, economic prosperity, and national security” (*Former West Virginia University Professor Pleads Guilty to Fraud That Enabled Him to Participate in the People’s Republic of China’s “Thousand Talents Plan”*, 2022). One such example was the case of Xiaqing Zheng. While Xiaqing Zheng was an employee of General Electric, he stole valuable intellectual property on advances in gas turbine technologies (Burgess, 2021). Fortunately, GE



stopped the flow of IP when their insider threat program monitoring received an anomaly alert (Burgess, 2021). However, until the alert, GE was ignorant of the fact that he was associated with the Chinese Thousand Talents Program for years (*Hospital Researcher Sentenced to Prison for Conspiring to Steal Trade Secrets, Sell Them in China*, 2021). In 2020, United Microelectronics Corporation (UMC), a Taiwanese semiconductor foundry pled guilty to criminal trade secret theft (U.S. Department of Justice, 2020a). According to the Justice Department, “UMC stole the trade secrets of an American leader in computer memory to enable China to achieve a strategic priority: self-sufficiency in computer memory production without spending its own time or money to earn it” (U.S. Department of Justice, 2020a).

Summary

While hypersonic-specific examples of IP theft, cyberattacks, and CI threats can be difficult to find in open source, several lessons can be learned from similar cases. First, cyberattacks can and do target all levels of the hypersonics supply chains including mining and processing of critical raw materials like REE and aluminum. Similarly, there have been clear examples of the PRC recruiting hypersonics talent from the United States to help build their programs. Finally, IP theft by the PRC has affected many companies and technologies that undergird hypersonics. Overall, there are a number of security vulnerabilities within the hypersonics supply chain that should be addressed by the government and industry.

Recommendations

- The DoD should address major cybersecurity risks at the low-to-mid-tier levels of the hypersonics supply chains by creating a “bug bounty” program for small government contractors working on hypersonics.
- The FBI should work with industry and academic leadership at all tiers of the hypersonics supply chain to increase awareness of counterintelligence threats.
- Industry leadership at all tiers of the hypersonics supply chain should increase awareness of intellectual property theft by foreign adversaries. In addition, industry leadership should take steps to identify and secure cyber vulnerabilities, and screen new and current employees.

International Partnerships and Allied Nearshoring

Assessment of the Sector

The United States places great value on maintaining alliances and partnerships with like-minded nations around the world to safeguard against growing threats. During the ETI-led working groups, participants assessed the challenges to international partnerships, identifying key issues, areas of success, and opportunities for improvements through policy changes. Overall, international partnerships in hypersonics are limited. Given the sensitive nature of hypersonics technology, this is understandable. However, some steps should be taken to strengthen and utilize existing partnerships to better secure hypersonics supply chains.

Current International Partnerships and Agreements on Hypersonics

Multilateral Partnerships

The United States currently has two multilateral partnerships in place on various aspects of hypersonics. First, through the AUKUS partnership, Australia, the United Kingdom, and the United States, agreed to increase trilateral collaboration on several defense capabilities and emerging technologies. Hypersonic and counter-hypersonic capabilities were explicitly named as areas where “AUKUS partners will work together to accelerate development” (The White House, 2022) Second, through the University Consortium for Applied Hypersonics (UCAH), the



United States is working with many international universities from the U.K. and Australia (University Consortium for Applied Hypersonics, 2022). While these partnerships are a good framework at the highest levels, there are significant opportunities that are not being used.

Bilateral Partnerships

The United States has bilateral partnerships with three countries related to hypersonic capabilities: Australia, Norway, and Japan. Beginning in 2007, the United States has collaborated with Australia first on the HIFiRE program and more recently on its successor program, SCIFiRE (*Hypersonic Weapons: Background and Issues for Congress*, 2023). The Hypersonic International Flight Research Experiment (HIFiRE) was a \$54 million flight test program to develop hypersonic technologies, explore scramjet engine technologies, and, more recently, explore the flight dynamics of a Mach 8 hypersonic glide vehicle (*Hypersonic Weapons: Background and Issues for Congress*, 2023). The Southern Cross Integrated Flight Research Experiment (SCIFiRE) program is focused on further developing hypersonic air-breathing technologies with the goal of reaching a point where conducting demonstration tests in the mid-2020s would be possible (*Hypersonic Weapons: Background and Issues for Congress*, 2023). While these partnerships with Australia have been lauded as highly successful, they have faced some of the challenges that international partnerships often encounter. For example, in HIFiRE, some of the rockets needed for the flight tests contained asbestos, a material that could not be legally imported into Australia beyond a certain quantity. A military exemption was made to solve the issue, but that did not come without significant paperwork and associated delay—in this case, nearly two years. Unfortunately, collaboration with Australia has also faced challenges on the U.S. side. According to a working group participant, the program agreements (PAs) established by the U.S. DoD with Australia, were tied so tightly to a specific program, discipline, or application, that they impeded collaboration overall.

In early 2022, the United States announced that it would sign a new agreement with Japan to increase collaboration on the research and development of emerging technologies (Insinna, 2022). Among other technologies, the agreement focuses on advanced space systems and counter-hypersonic technologies (Insinna, 2022). In January 2023, the DoD announced the signing of a “bilateral Memorandum of Understanding for Research, Development, Test and Evaluation Projects” with the Japanese Ministry of Defense to improve defensive capabilities (DoD, 2023). Among other projects, counter-hypersonics was listed as an area for collaboration. While counter-hypersonics is not the focus of this report, this is still an important international partnership worth noting.

Finally, beginning in 2019, the U.S. Department of Defense and Norwegian Ministry of Defense announced a partnership on “the development of an advanced solid fuel ramjet that could find use in supersonic and hypersonic weaponry” (DoD, 2021a). The Tactical High-speed Offensive Ramjet for Extended Range, or THOR-ER, includes the U.S. Navy’s Naval Air Warfare Center Weapons Division, China Lake, and the Norwegian Defence Research Establishment and industry partner Nammo Group (DoD, 2021a). By 2024, the goal was to “not only have a flight demonstration but be able to transition the technology to the warfighter (DoD, 2021a). In 2022, the solid fuel ramjet missile was first flight tested, thus meeting the Phase 1 objective of demonstrating the capabilities of jointly developed propulsion technologies in flight (Saballa, 2022). While this partnership is viewed as valuable both technically and politically, and should therefore continue, the unsecure nature of the Andøya test facility, including its proximity to a peer competitor, poses challenges.

The existing bilateral and multilateral partnerships are a great step in the right direction. However, there are unused opportunities in these existing partnerships to help address current supply chain issues like lack of testing infrastructure, and resource dependency on adversaries.



Allied Nearshoring

As discussed in the Critical Raw Materials and Goods section, the United States is dangerously reliant on foreign adversaries for several critical raw materials relevant to hypersonic systems. While domestic onshoring might guarantee more secure sourcing, sometimes it is not economically feasible. An alternative might be allied nearshoring. Australia and Canada, two strong allies of the United States, could potentially provide economically feasible alternatives for sourcing certain hypersonic materials. With large deposits of cobalt and rare earth elements, both countries provide an important alternative to China (U.S. Geological Survey, 2022a).

Another place where international markets could play an important role in strengthening hypersonics supply chains is expanding the carbon fiber industry. According to a Bureau of Industry and Security (BIS) report, many companies want help from the U.S. government to identify global export opportunities (U.S. Department of Commerce, 2015). As highlighted in the Critical Raw Materials and Goods section, with the tremendous increase in demand for carbon fiber, the supplier base needs to grow and expand.

Hypersonics Challenges of the Current Export Control Regime

A constant theme throughout the working group discussions is the challenge that the current export control regime poses to international collaboration, and especially efforts to strengthen hypersonics supply chains. Export controls in the United States exist to protect American technological advantage and ensure U.S. national security. The International Traffic in Arms Regulations (ITAR) are administered to regulate the export of defense products, including a range of products from munitions to software to technical data and includes many components in the hypersonics supply chains. According to several working group participants, the fear of ITAR violations forces U.S. companies to seek domestic suppliers for the manufacturing of parts rather than pursue the export licenses required for foreign suppliers. These licenses can be especially difficult to obtain for allied nations whose privacy laws protect employees from mandated passport submission. In the U.K., for example, labor laws permit firms to hire across Europe. While U.K. companies may explicitly not recruit from specific countries outside of the E.U., meeting the U.S. requirements for workforce verification poses a challenge. University partners outside of the United States face similar challenges as most programs tend to include disproportionately more foreign nationals. While universities have some procedures in place to safeguard access to protected information, the United States can still choose to deny export licenses if there is any concern of information leakage. While certain levels of export control are important to safeguard U.S. national security, some changes could be adopted to better facilitate international partnership on hypersonics.

Similarly, foreign companies are concerned about potentially losing control of their technology due to legal agreements that give first or sole rights to the U.S. government in government-funded development projects that result in intellectual property. Companies often take a protectionist approach by turning their focus to acquiring patents in order to protect their sensitive information. Finally, in addition to strict U.S. export regulations, the language in some DoD defense acquisition contracts can be uninviting to allied nations. Contracts typically include prohibitions against foreign participation, requiring materials and subcomponents to be sourced domestically—usually without exception. There is often a requirement for programs to be U.S. in origin and performed only by U.S. citizens. Again, in certain situations, prohibition against foreign participation is appropriate for national security reasons. However, the United States should look for opportunities where international cooperation on hypersonics can be strengthened.



Summary

Overall, the U.S. currently has strong international partnerships when it comes to hypersonics. However, there are opportunities to improve upon and expand these partnerships to help strengthen hypersonics supply chains going forward.

Recommendations

- The United States should work with Australia and Canada to increase mining and processing operations for cobalt, rare earth elements, and nickel.
- The U.S. DoD should look for opportunities to increase international partnerships to address insufficient testing infrastructure.
- The U.S. Department of Defense and Australian Ministry of Defence should establish an overarching program agreement to expedite hypersonics collaboration across the board.
- Committee on Foreign Investment in the United States (CFIUS) investigations should be prioritized using a four-tiered system for organizing supply chain risk.

Conclusion

Hypersonics will likely play an increasingly critical role in the future of U.S. defense. Because of the significant advantages that hypersonic systems bring, and because of the relatively advanced state of Russian and Chinese hypersonic programs, these weapons will maintain their place in the spotlight of strategic competition. In recognition of this, it is vital that government, industry, and academia be aware of the many vulnerabilities that exist within the hypersonics supply chains. If left unaddressed, these vulnerabilities could compromise the United States' ability to effectively field hypersonic weapons. The conflict in Ukraine has demonstrated how quickly the demands of war can drain the arms inventories of supposedly well-prepared combatants. The United States must learn from this example and preempt potentially detrimental shortages.

The issues in the U.S. hypersonics supply chains have been building for years. The lack of a clear demand signal has severely impaired the future stability of the supply chain and will continue to jeopardize key national security initiatives until adequately addressed. Ultimately, it will take years of hard work before the system can rebalance and, until then, challenges will still exist. Unfortunately, there are no quick fixes. However, there are many steps government, industry, and academia can take to strengthen hypersonics supply chains for the future.

The DoD must provide a clear and constant demand signal for hypersonic systems. This, by far, is the most important step the government can take to ensure secure, healthy hypersonics supply chains. Furthermore, the DoD should request, and Congress should appropriate, reliable funding for hypersonic systems while also taking action to restore critically depleted stockpiles of strategic materials. The DoD must also pursue expanded cooperation with allies and partners, many of which can help to secure supplies of critical resources and to develop reliable and much-needed testing infrastructure. America's allies and partners are perhaps its greatest asset and one which its competitors almost universally lack. Failing to take advantage of this enormous resource would be an inexcusable blow to U.S. national security objectives.

For industry, there are numerous opportunities for growth and investment. From using additive manufacturing and digital engineering to cut costs, to increasing awareness of counterintelligence threats, to investing in new mines and carbon fiber production facilities, industry can begin today to secure supply chains for tomorrow. Considering these opportunities, industry needs a large, well-equipped workforce to fuel its innovation. Academia is crucial for



educating the hypersonic workforce of the future and can also contribute to expanding testing infrastructure.

Partnerships between government, industry, and academia provide the greatest potential for overcoming the vulnerabilities of the hypersonics supply chain. However, action must be taken today. Each of these changes will take time but are crucial to securing hypersonics supply chains for years to come.

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Fuel Logistics Platform Requirements to Support Naval Surface Combatants and Expeditionary Marine Forces in INDOPACOM AOR

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Abstract

This research sets out to evaluate the existing infrastructure's adequacy and identify potential gaps, specifically focusing on bulk ship-to-shore fuel delivery, a cornerstone for the successful implementation of the Expeditionary Advanced Base Operations (EABO) concept. To achieve these objectives, our research team leveraged the modeling tool Replenishment at Sea Planner, developed at the Naval Postgraduate School. The tool underwent adaptation to simulate a diverse array of operational scenarios, estimating surface combatants' fuel demand to support EABO forces. By addressing critical gaps in the logistical framework, this study ensures the transition to the EABO paradigm is underpinned by an efficient and robust fuel supply chain. This study significantly contributes to enhancing the Navy and Marine Corps' operational readiness and effectiveness in the challenging U.S. Indo-Pacific Command theater.

Introduction

In response to evolving challenges in the Pacific theater, the U.S. Navy and U.S. Marine Corps are undergoing a strategic transformation, shifting towards the Expeditionary Advanced Base Operations (EABO) paradigm. This approach, marked by decentralization and distribution, aims to bolster operational capabilities across the expansive Indo-Pacific Command (INDOPACOM) area. Within this strategic shift lies a crucial concern: ensuring efficient logistical support for naval surface combatants and expeditionary marine forces dispersed across vast island chains. The need to effectively supply fuel and other essentials to these geographically scattered forces raises significant questions about the current state of fuel logistics capabilities.

In the modern landscape of warfare, adversaries wield extended-range weapons coupled with precision munitions, intensifying challenges faced by the U.S. military. The imperative for the Department of Defense (DoD) to organically support its forces abroad becomes even more pronounced, especially considering potential constraints on using foreign ports and contracted sources during conflicts. The 2022 National Defense Strategy (NDS) underscores the necessity for a future force capable of secure and effective logistics and sustainment, even in the face of adversary disruption—a requirement this study endeavors to fulfill (DoD, 2022). Aligned with the 2022 NDS Force Planning Construct, we address the logistical supportability of EABO concept of operations (CONOPS) within the INDOPACOM Area of Responsibility (AOR) in a contested environment.

Objectives

This study undertakes a comprehensive analysis of fuel consumption in EABO configurations and assesses the capability of EABO refueling support by the Combat



Logistics Force (CLF), utilizing Next Generation Logistics Ships (NGLS) in contested environments. The following objectives guide this research:

Identifying Capability Gaps: Determine known and predicted capability gaps for bulk ship-to-shore fuel delivery in the INDOPACOM AOR, which is critical for supporting EABO operations in contested environments.

Impact of Single Fuel Concept: Investigate how switching to a single fuel operating concept, specifically adopting JP-5, affects logistics needs and capabilities, including fuel availability in theater.

Impact of Logistics Support Ships: Evaluate the impact of procuring different or additional logistics support assets on logistics capabilities within the INDOPACOM AOR, specifically focusing on their role in supporting EABO operations.

Approach and Significance

Our approach entails an analysis of in-theater fuel demand, considering the movement of fuel from ports to combatant forces. Through a comprehensive spectrum of demand scenarios, encompassing various operational contexts, the researchers identified existing gaps and gained insights into the challenges delivering fuel with the floating assets under consideration: the NGLS. The study models a future logistics fleet, integrating nominal vessels with diverse capabilities necessary to facilitate fuel movement and delivery to forward-deployed Navy and Marine forces.

The simulations incorporate a standardized fuel demand table for a simulated EABO mission set. The simulations yield data for a contested environment adopting JP-5 as the single fuel. A specific restriction is enforced: the CLF force remains outside the Weapon Engagement Zone (WEZ), limiting fuel delivery inside the WEZ to Medium Landing Ships (LSM) to effectively mitigate mission risks.

This report continues with a background of maritime logistics focused on fuel logistics and on the fuel delivery assets; a discussion of petroleum fuel used in the U.S. Navy, focused on JP-5 as the single fuel for all naval operations; a discussion of the simulation methodology, describing a generalizable EABO network and the characteristics of the fuel delivery assets; a consolidation of the simulations in sustained and surge scenarios, highlighting the different levels of success of each asset configuration;¹ and a summary of the results and recommendations.

Background

The current capacity of the Navy's amphibious fleet, while significant, falls short in meeting the escalating demands in the dynamic operational environment. As the nature of warfare evolves, so must our naval capabilities. By integrating logistics and emphasizing operational effectiveness, the DoD can bolster readiness for future challenges. The solution does not solely lie in heavy-hitting vessels. The Navy must also focus on lighter, more agile ships to complement its capabilities. The absence of a fleet of light amphibious warships within the Navy's portfolio hampers its operational flexibility. Vessels designed to navigate shallower waters could facilitate rapid troop and equipment movement and seamlessly integrate into the Navy's distributed force, providing strategic advantages. In essence, the Navy must expand its fleet, adapt to emerging challenges, and foster innovation to effectively operate in a broader range of environments. To meet these demands, the Navy

¹ These results were previously presented in the MBA thesis by Rodriguez et al. (2023).



must embrace a proactive approach, prepared to face the uncertainties of the future with adaptive strategies and innovative solutions.

Distributed Maritime Operations (DMO)

In 2018, former Chief of Naval Operations (CNO) Admiral John Richardson introduced Distributed Maritime Operations (DMO) in Design for Maintaining Maritime Superiority 2.0 (Design 2.0). DMO is a pivotal naval warfare strategy that involves decentralizing naval forces across vast areas. It capitalizes on the principles of distribution, integration, and maneuvering, enabling naval forces to concentrate combat power at crucial points (Filipoff, 2023). Operating at a theater level, DMO strategically positions distributed and networked assets, allowing for offensive strikes against imminent threats and fortified targets (Clark & Walton, 2019).

At its core, DMO's decentralized nature perplexes adversaries by scattering naval forces, making it challenging to discern priority targets. This approach not only enables preemptive strikes but also imposes significant operational dilemmas on adversaries (Filipoff, 2023).

DMO serves as the guiding principle for EABO, emphasizing the dispersion of forces across extensive areas to enhance resilience and diminish vulnerability. In Design 2.0, ADM Richardson highlighted the necessity of a robust refueling capability, emphasizing the importance of fuel logistics in supporting this decentralized strategy.

Expeditionary Advanced Base Operations

EABO revolutionizes naval strategy through the integration of Fleet Marine Force (FMF) and Navy capabilities to support the warfighter comprehensively (United States Marine Corps [USMC], 2023b). It encompasses skills such as sea denial, sea control, and fleet sustainment in contested environments, countering adversaries' Anti-Access/Area-Denial (A2/AD) strategies by projecting naval forces inland and disrupting their A2/AD capabilities in confined spaces.

EABOs are designed for adaptability, featuring low signature bases, mobility within enemy A2/AD environments, and support for command, control, communications, computing, cyber, intelligence, surveillance, reconnaissance, and targeting (C5ISRT) capabilities. General David Berger emphasized the synergy between anti-submarine warfare (ASW) and EABOs, sustaining or widening the joint force's advantage in ASW and holding enemy submarines at risk (Berger, 2020).

Unlike conventional expeditionary operations, EABO combines various mission capabilities in a distributed, unpredictable manner within the WEZ. As a pivotal DMO component, EABO deploys Marine Littoral Regiments (MLRs) near potential conflict zones, equipped with mobile assets to enhance sea control and denial capabilities. It emphasizes forward presence, rapid response, and power projection across vast maritime theaters. EABO's innovative approach and adaptability redefine expeditionary operations in contested environments.

Fuel Logistics

Efficient maritime logistics are integral to the success of DMO and EABO. Supporting diverse missions across distributed and expeditionary bases demands a robust logistics infrastructure, involving fuel, ammunition, spare parts, and personnel transportation for operational readiness and effectiveness.

Fuel logistics hold a pivotal position within maritime operations. Ensuring a stable and efficient fuel supply chain is essential for sustaining naval forces. This involves



addressing challenges related to fuel storage, transportation, and distribution in diverse and dynamic operational environments. Optimizing fuel logistics is crucial for supporting extended missions, enhancing operational flexibility, and maximizing the Navy's combat effectiveness.

To implement the DMO and EABO concepts in alignment with the NDS, the Navy requires essential resources for refueling, rearming, and repairing naval forces, especially in contested environments. Presently, the Navy operates 31 CLF ships designed for at-sea replenishment, enabling operational reach without port reliance. However, the current hub-and-spoke model is insufficient for widely distributed and contested fleets, revealing vulnerabilities (Minding the Gap, 2021).

Amid rapid transformation and evolving security challenges, combining Navy Logistics Integration (NLI) with maritime logistics becomes pivotal. This integration aligns with the NDS, fostering innovative logistical solutions for widely distributed and contested fleets. This shift is critical, enabling the Navy to adapt, sustain operations, and fulfill its core mission effectively, even amidst evolving threats and complex operational environments.

Consolidation Operations and Lightering

Fuel consolidation (CONSOL) and lightering operations are integral components of maritime logistics, enhancing the efficiency and sustainability of naval operations. CONSOL operations play a vital role in minimizing transit time and extending operational endurance for CLF ships and combatants. Specially equipped large tankers swiftly travel to CLF vessels, allowing multiple refueling sessions before the tankers themselves require refueling. The establishment of specific refueling stations, identified by predetermined coordinates, streamlines the process, enhancing operational flexibility and enabling sustained missions in critical areas (Smith, 2015).

Similarly, lightering operations are crucial for the swift transfer of cargo or fuel between vessels, whether at anchor or while underway. These operations involve meticulous pumping and employ specialized fenders to prevent damage during the transfer process. By enabling the seamless exchange of essential supplies and resources, lightering operations ensure naval forces' readiness. The precision and coordination demonstrated in these operations are essential for maintaining operational efficiency and supporting sustained maritime missions, highlighting their significance in the broader context of maritime logistics.

Single Fuel Concept

The NLI framework unifies procurement, transportation, storage, distribution, maintenance, and disposal, creating an efficient support structure for DMO and EABO. The addition of the Single Fuel Concept (SFC) with Logistics Subsidiarity enhances EABO effectiveness. SFC's simplicity, coupled with resolving logistics issues at the local level, optimizes integration and operational efficiency, ensuring agile and resilient EABOs.

The SFC initiative, developed in response to the complexities of managing multiple fuel types, gained prominence in the late 1980s with the goal of standardizing fuels used by NATO allies. The adoption of JP-8 by the U.S. Army in 1986 and the DoD's mandate in 1989 for JP-8 standardization in land and air operations marked significant milestones in this effort. Despite challenges related to differing fuel types aboard ships and aircraft, historical evaluations highlighted the advantages of a unified fuel supply, including reduced maintenance, infrastructure savings, enhanced flexibility, and improved readiness. Recent assessments have indicated that transitioning naval vessels to JP-5 as the universal fuel for



naval operations could simplify fuel logistics with minimal impact on engines, opening avenues for enhancing efficiency in the maritime domain.

The SFC simplifies logistical processes, reducing the complexity associated with managing multiple fuels and enhancing efficiency. This simplification becomes especially crucial in distributed environments such as those in DMO, where it reduces the logistical footprint, mitigates supply disruption risks, and enhances operational flexibility. Studies assessing the feasibility of transitioning shipboard units to a single fuel type, particularly JP-5, have highlighted numerous benefits, including enhanced naval capability for major contingency operations (Giannini et al., 2002; Guimond, 2007; Jimenez et al., 2020; Witt, 2022).

The convergence of DMO and the SFC represents a strategic and logistical innovation in naval warfare. By aligning the adaptable strategy of DMO with the streamlined efficiency of SFC, a resilient and robust logistical framework is created, ready to confront the challenges of EABO in the modern era. This synergy not only addresses the demands of today's maritime operational environment but also anticipates and overcomes future challenges, ensuring the Navy's readiness and effectiveness in complex and contested maritime scenarios.

Next Generation Logistics Ships

The Next Generation Logistics Ships program exemplifies the Navy's commitment to evolving maritime logistics, addressing the complexities of modern warfare (Eckstein, 2020). Comprising the Navy Light Replenishment Oiler (TAO-L) and the Navy LSM, these vessels play a pivotal role in supporting EABO and DMO, emphasizing flexibility and cost-efficiency. Rooted in Gen Berger's Force Design 2030, the NGLS initiative responds to evolving operational requirements (USMC, 2023a). The medium amphibious ships within the medium CLF family, announced in 2020, are specifically designed for contested environments, counter A2/AD strategies, and emphasize flexibility and rapid relocation (O'Rourke, 2023a).

The core components of the NGLS initiative, TAO-L and LSM, leverage commercial designs, ensuring cost-effectiveness and adaptability. They are described below.

Light Replenishment Oiler and the Platform Supply Vessel

The Light Replenishment Oiler program introduced smaller, maneuverable vessels crucial for at-sea resupply capabilities, especially in confined spaces. These vessels, designed to provide petroleum, oils, and lubricants (POL) support, are equipped with advanced technology, enabling seamless refueling operations in open seas. The TAO-L program is focused on the variant Platform Supply Vessel (PSV), which ensures access to shallower waters and tighter spaces that are vital in contested or congested maritime environments (see Figure 1). Ideally, the PSV has a sustained speed of 15 to 17 knots, a range of about 3,500 nautical miles, a fuel capacity of around 1,575,000 gallons, and a cargo capacity of 800 to 900 short tons, making it capable of delivering approximately 210,000 gallons of fuel in under 2 hours at sea. Moreover, the PSV can deliver 15 loads/hour of ammunition and cargo while refueling, making it a versatile asset within the WEZ (O'Rourke, 2023a).





Figure 1. Platform Supply Vessel (SEACOR, n.d.)

Medium Landing Ship

The LSM is designed to fill the capability gap between multipurpose amphibious warfare class ships and smaller complementary landing craft (see Figure 2). Engineered to embark, transport, land, and reembark small Marine Corps units and their supplies, the LSM possesses the range, endurance, and speed needed to support and conduct DMO and EABO effectively. It has a sustained speed of 14 knots, a travel range of greater than 3,500 nautical miles, a fuel storage capacity of greater than 90,000 gallons, and can transfer fuel at a rate of 3,000 gallons per minute. Additionally, the LSM features a deck cargo area similar in size to the PSV (8,000 to 12,000 sq ft) and includes a ramp and crane to assist in loading and unloading cargo and ammunition. The vessel can conduct up to 11 days of missions without replenishment, ensuring adaptability and agility in the face of emerging threats (O'Rourke, 2023b).

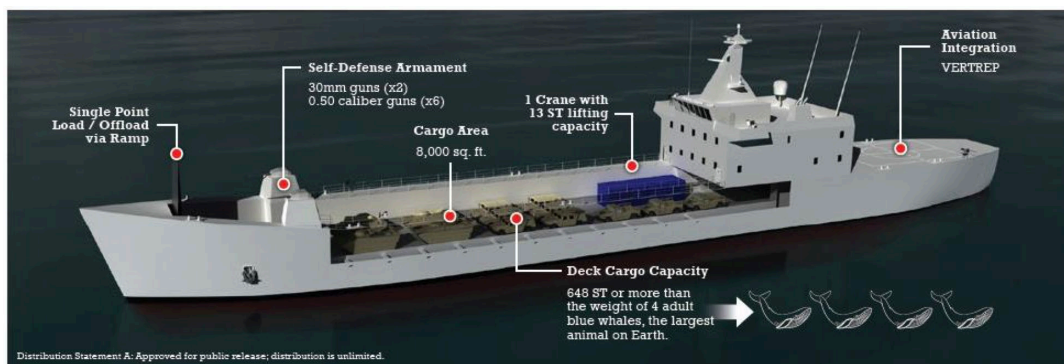


Figure 2. Medium Landing Ship (O'Rourke, 2023b)

Liberty Lifter

Liberty Lifter (LL), an innovative strategic lift concept developed by the Defense Advanced Research Project Agency (DARPA), is a cutting-edge 21st-century aircraft (see Figure 3). It is a long-range, low-cost seaplane capable of performing strategic and tactical lifts (Kent, 2023). The aircraft's key attributes include the ability to perform fast, flexible, and survivable strategic lifts. Primarily designed for EABO, the LL provides a notional range and speed that enable more flexible movement. It is anticipated to enhance DMO by rapidly moving forces with reduced refueling requirements. Additionally, its ability to swiftly reconfigure for various missions and tasks enhances its utility, making it more survivable by minimizing time spent at fixed, targetable locations (Kent, 2023).

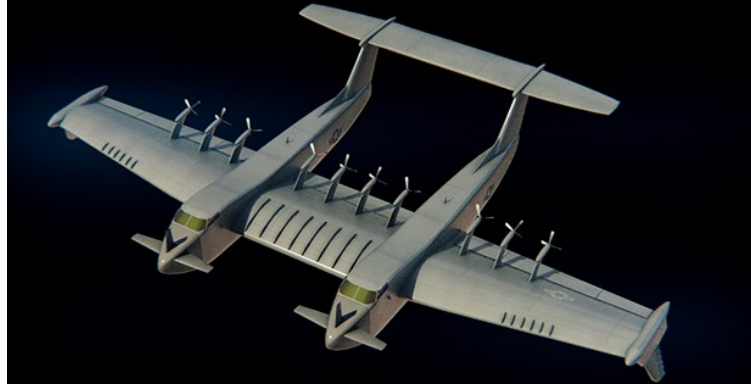


Figure 3. Liberty Lifter Concept Design (Kent, 2023)

The LL program is currently in its initial phase of development, as part of an 18-month collaboration between DARPA and two prime contractors. The primary goals include perfecting the conceptual design, maturing the overall design, and conducting component and subscale testing. The LL team is projected to transition to Phase 2 in mid-2024 and Phase 3 in 2026, with the goal of transitioning to the manufacturing and sustainment phase by the end of 2028.

Once operational, the LL is expected to achieve a sustained speed ranging from 145 to 180 knots, with the range of approximately 8,000 nautical miles (Kent, 2023). The aircraft's estimated carrying capacity is 180,000 lb over 1,440 sq ft, allowing it to accommodate 12 463L air cargo pallets. This translates to the capability of transporting up to 20 U.S. Marine Corps (USMC) *SIXCON* fuel storage tanks, 900 gallons each, providing a total capacity of 18,000 gallons of fuel per load (weighing about 125,000 lb, which is less than the aircraft's carrying capacity). Alternatively, the LL could carry 300 passengers or two USMC Amphibious Combat Vehicles along with their 32 crew members (Kent, 2023).

Highlighting its versatility, the LL concept is intended to take off and land in a sea state of 4, with the capability to conduct on-water operations in sea states up to 5. This unique feature positions the LL as a viable alternative for strategic logistics, enabling effective support for EABO. A preliminary design concept is illustrated in Figure 4, providing a glimpse into the aircraft's potential form and functionality.

In the context of EABO, MLRs reinforce the U.S. Navy's sea-control and sea-denial capabilities in the Western Pacific. These units, deployed in forward locations, enhance fleet and Force Movement Control Center operations, diversifying the Navy's lethal capabilities. Each vessel, PSV and LSM, possesses unique capabilities and limitations, forming the basis for fuel constraints in simulations. Integrating the LL as a fuel delivery asset adds valuable flexibility for planning fuel transfers and operational deployments in contested environments.

Petroleum Fuel in the U.S. Navy

In this section, we discuss the petroleum fuel types used by the U.S. Navy and the concerns that have been raised regarding the adoption of JP-5 as the single fuel for all naval operations.

Types of Fuel Used by the U.S. Navy

The U.S. Navy primarily utilizes three fuel types for its various applications: F-76 (Naval Fuel Distillate or NATO code F-76), JP-5 (Aviation Turbine Fuel JP-5 or NATO code

F-44), and JP-8 (Aviation Turbine Fuel JP-8 or NATO code F-34). They are described below.

F-76

Characteristics: F-76 is a military-grade diesel fuel derived from crude oil, natural gas liquid concentrates, heavy oil, shale oil, and oil sands. It has a high flashpoint of 60°C (140°F), which represents low risk of spontaneous combustion. It contains additives to deactivate metals and to provide lubricity, which is important for engine operations.

Advantages: F-76 is cost-effective, is readily available globally, and is used in conventional U.S. Navy surface ships.

- **Disadvantages:** It may promote microbial growth in fuel tanks, leading to clogged filters. Strict maintenance and surveillance are required. F-76 has a cloud point no higher than -12.22°C (10°F) to prevent equipment damage in cold environments.

JP-5

Characteristics: JP-5 is the standard fuel for all U.S. Navy aircraft. It has a high flashpoint of 60°C (140°F). It contains additives to prevent gum or peroxide formation, inhibit corrosion and icing, dissipate static, and improve lubricity.

Advantages: It is safe for shipboard use, and it has similar performance to JP-8. It can be used in many naval vessel engine fuels.

Disadvantages: Some loss of fuel efficiency compared to JP-8.

JP-8

Characteristics: JP-8 is widely used in the DoD and in military aviation engines. It is similar to commercial aviation's Jet A-1 fuel but with specific additives suitable for military use.

Advantages: It is a low-cost fuel, available worldwide, with minimal differences from Jet A-1, which ensures a stable supply chain and reduced costs for extended fuel logistics support.

Disadvantages: Its low flashpoint of 38°C (100°F) makes it unsafe for shipboard use due to the increased risk of spontaneous combustion.

Naval aircraft are compatible with JP-8, the jet fuel used by the U.S. Air Force and U.S. Army. However, its low flash point makes it unsafe to store in naval vessels. For this reason, our focus is on JP-5. Table 1 compares F-76 and JP-5. All values were sourced from Tosh et al. (1992), except density data, which were derived as the ratio of the respective energy contents.

Table 1. Energy and Density Properties of JP-5 and F-76 (Tosh et al., 1992)

Property	F-76	JP-5	Difference
Specific Gravity	0.844	0.819	-3.0%
Density*	7.005 lb/gal	6.862 lb/gal	-2.0%
Energy content by weight	18,456 BTU/lb	18,356 BTU/lb	-0.54%
Energy content by volume	129,291 BTU/gal	125,965 BTU/gal	-2.6%

It is important to remember that all petroleum fuels have small variations depending on the source of the raw material (petroleum) and on the refinery that produced them. These variations do not impact utilization as long as key parameters stay within acceptable limits established by the respective MIL standards.

Concerns with the Adoption of JP-5 as the Single Fuel

The ongoing debate surrounding the conversion to single-fuel operations in the U.S. Navy has been shaped by eight significant concerns related to the potential adoption of JP-5 as the exclusive fuel. These concerns, ranging from technical challenges to financial implications and geopolitical considerations, contribute to the complexity of the ongoing dialogue surrounding the potential conversion to JP-5 as the single fuel for U.S. Navy operations (Garrett, 1993).

The literature provides extensive analysis addressing several concerns related to the adoption of JP-5 as the exclusive fuel for the U.S. Navy (Giannini et al., 2002; Guimond, 2007; Jimenez et al., 2020). Here is a summary of the findings from the literature:

1) **Physical–Chemical Properties of JP-5:** JP-5's lower lubricity, volumetric energy content, cetane number, and viscosity compared to F-76 have raised concerns about accelerated wear in engines, increased fuel consumption, cold-start problems, power loss, and internal leakage in fuel systems (Giannini et al., 2002; Guimond, 2007). All physical–chemical concerns raised with JP-5 have been studied, as follows:

Impact of lower lubricity: No documented failures of fuel injectors and pumps have been recorded. Studies indicate that if lubricity-related problems should occur, they would be minor and manageable (Guimond, 2007).

Impact of lower volumetric energy content: Theoretical predictions of increased JP-5 consumption do not align with practical experience, and there is no evidence of reduced range or increased consumption when JP-5 is used as bunker fuel. Guimond (2007) recommended a rigorous field test to assess if there is any measurable difference.

Impact of lower cetane number: No reduced acceleration or maximum power issues have been identified in Navy diesel engines when operated on JP-5. However, Guimond (2007) recommended that a minimum cetane level should be required of JP-5 if it were used as a single fuel.

Impact of lower viscosity: While hot starting problems were observed in certain diesel engines due to low viscosity, robust designs were not affected. Other studies found no negative performance consequences in naval diesel engines.

2) **Shipboard Piping Union Alloys Interaction:** Prolonged exposure of JP-5 to cupronickel alloys, present in the fuel lines, could lead to thermal stability issues and potential failure, with no known mitigation systems in place. However, the source of copper

does not affect JP-5 thermal stability significantly. The combined effect of storage in the presence of copper is crucial, regardless of the type of soluble copper or storage conditions (Putnam, 2018).

3) **Impact on Combatant Ship Design:** Transitioning to JP-5, which has lower density (specific gravity) than F-76, may negatively affect the buoyancy and centers of gravity of naval combatant ships. One mitigation strategy suggested is altering engineering manuals to allow ships to carry more ballast water in propulsion fuel tanks to counterbalance the decreased weight of JP-5. However, current U.S. Navy policy prohibits water-ballasting of JP-5 fuel tanks. On the other hand, the difference between the JP-5 and F-76 density is approximately 2%, as shown in Table 1. That would mean a very small fraction of the weight of any weapon system, so it is unlikely that this concern is significant.

4) **Cost Considerations:** This concern has several facets, such as JP-5's perceived higher cost per gallon, increased fuel consumption due to lower energy content, potential rise in contract prices driven by higher demand, and erosion of purchasing power amid military downsizings. Any combination of these challenges could make conversion financially prohibitive. However, the price differential between JP-5 and F-76 has inverted, with JP-5 being less expensive in recent years. The lower energy content, shown in Table 1, does not translate into consumption that is higher than typical variability (Giannini et al., 2002). The most significant cost consideration remains the conversion cost, which can be associated with the time to convert the fleet using existing maintenance schedules (Zheng & Ventura, 2022).

5) **Regional JP-5 Shortages:** The shift to JP-5 may lead to regionalized shortages, considering historical difficulties in meeting peacetime aviation requirements and fewer ports supplying JP-5 compared to F-76. However, studies indicate a sufficient JP-5 fuel supply base available for conversion (Giannini et al., 2002). The adoption of a phased rollout plan could address potential shortages by giving time for the supply chain to adapt to the increased demand.

6) **Refinery Hesitancy:** Refineries have been reluctant to expand JP-5 production due to the short term of the supply contracts and to the uncertainty that they will be renewed in the following year, which hinders their efforts to invest in increased supply. Mitigation strategies could include implementing multiyear or guaranteed renewal contracts with JP-5 refineries to establish longer-term commitments. In addition, as JP-5 gets adopted by an increasing number of floating assets (in addition to aircraft), many refineries will find it an attractive commodity to produce.

7) **Fuel Line and Storage Tank Modifications:** Finalizing fuel consolidation requires cleaning and reconfiguring fuel lines and storage tanks to prevent contamination with residual F-76, ensuring that stored JP-5 meet the stringent requirement for use in aviation. Recent studies have provided estimates for reconfiguring U.S. Navy amphibious assault vessels and DFSP indicating costs and time frames associated with cleaning and repairing F-76 pipelines and fuel tanks (Zheng & Ventura 2022).

8) **Lack of Significant Operational Benefits:** Some opponents of JP-5 have stated that single fuel would offer minimal operational advantages, with claims that significant benefits may not be realized. In addition, Tosh et al. (1992) stated,

The lower energy density of JP-5 translates directly into a 2.6-percent reduction in range, but also means an increase in the amount of fuel purchased. Since combustion efficiency in all systems is generally close to 100 percent at all but idle conditions, little opportunity exists for improvements in



specific fuel consumption to offset the lower heating value of JP-5. In most engines, the fuel controls can be adjusted to regain maximum power, but a larger volume of fuel will still be required. Burning fuels with lower cetane numbers will result in small increases in thermal efficiency in some diesel engines, but generally not enough to offset the lower heating value. Therefore, should a conversion be made to JP-5, potentially an additional 2.6-percent fuel quantity would be needed to support the Navy requirements.

Recent studies have shown the opposite: despite reduced energy content, conversion to JP-5 would result in increased maritime refueling service capacity, improved endurance, and greater operational range for battle groups due to the supply chain phenomenon known as “pooling effect.” It would also reduce the number of tankers and CLF ships needed to sustain major combat operations, leading to substantial logistical benefits. In an analysis of fleet support in the INDOPACOM AOR, Jimenez et al. (2020) stated,

When compared to the dual fuel CONOPS the Navy currently operates under, fewer fleet oilers and tankers would be required to provide the same level of service and logistics refueling capability during high-intensity operations, and task force endurance would be increased.

In addition, in an analysis of fuel consumption during a displacement in the EUCOM AOR, Witt (2022) concluded,

Our analysis showed a consistent reduction in the required number of RASs and CLF trips to port at all JP-5 energy efficiencies in the scenarios evaluated. The added flexibility gained from fewer RASs and CLF trips to port allows for groups of ships to remain at operations and on standby for longer periods of time. Among the benefits of fewer RASs and CLF trips to port is a cost savings to the Navy; water, sewage and power costs are incurred whenever a ship goes to port. These reduced periods in port could help offset the minor cost increase in utilizing JP-5 instead of F-76 to power the ships.

In summary, most concerns associated with JP-5 adoption as the single fuel have been extensively evaluated in previous studies. An important exception is conversion costs, partially addressed by Zheng and Ventura (2022), which still deserves further analysis.

Potential Impact on Intra- and Inter-Governmental Relations

Extensive research was conducted to understand JP-5 adoption as the single fuel, emphasizing potential benefits and strategies to mitigate challenges. There is one more concern that has not been discussed: the impact on governmental relations remains an unexplored aspect of the ongoing dialogue. This impact would likely be multifaceted, influencing various stakeholders and international relationships in different ways. While specific studies on this topic are lacking, we can estimate potential implications based on existing knowledge and general trends. Here are some possible effects:

Intra-Governmental Relations:

Enhanced Collaboration: A unified fuel policy can lead to better collaboration and synchronization among different government agencies and departments. Consistency in defense strategies and joint military operations can be achieved, fostering more effective coordination.

Financial Implications: The transition to JP-5 could impact budget allocations within the DoD. Adjustments might be necessary to accommodate the costs associated with



the transition and the ongoing operations. Proper financial planning and resource allocation would be crucial.

Inter-Governmental Relations:

Strengthened Alliances: If JP-5 aligns with the preferences of U.S. allies, especially within NATO, it could strengthen military alliances. Common fuel standards would simplify joint military exercises, operations, and logistics, enhancing interoperability among allied forces.

Shift in Trade Dynamics: The shift in demand for JP-5 could influence international trade in fuel products. Countries exporting JP-5 might experience increased trade opportunities, while those exporting F-76 could face decreased demand. This change might lead to economic shifts and trade challenges.

Impact on Suppliers: Nations heavily reliant on exporting military-grade fuels, such as F-76, might be economically affected. This could potentially lead to diplomatic challenges and changes in trade dynamics. Geopolitical relationships could be influenced by these economic shifts.

Streamlined Military Operations: A unified fuel standard would streamline military operations during international crises or peacekeeping missions. This consistency could enhance the effectiveness of multinational military efforts, ensuring a smoother collaboration among allied forces.

Reduced Dependence: Standardizing military fuels and diversifying sources, including JP-5, could enhance U.S. energy security. Reducing dependence on specific regions or nations for fuel supply can increase resilience and stability in military operations.

The actual impact of the switch to JP-5 would be complex and contingent on numerous factors. Considerations such as geopolitical context, economic dynamics, technological advancements, and policy agreements would play crucial roles. Detailed studies on intergovernmental relations would be essential to comprehensively assess and navigate the implications of such a significant policy change. However, it is well understood, based on past studies, that significant logistical benefits would be derived from the conversion to JP-5, with minimal impact on ship maintenance and resilience.

Methodology: Modeling, and Simulation

Understanding the complexities of transitioning the U.S. Navy's fuel standardization to JP-5, especially in the contested Western Pacific region within the INDOPACOM AOR, requires a comprehensive analysis involving computer modeling, simulation, and experimentation. This section outlines the systematic approach taken to unravel the interplay of logistical requirements, surface asset configurations, and operational scenarios. Replenishment at Sea Planner (RASP) was employed, alongside theoretical scenarios, to provide insights into the supportability of a distributed MLR operating in contested environments.

Replenishment At Sea Planner Model

RASP is a crucial tool for optimizing the Navy's logistics capabilities by focusing on crafting schedules that minimize travel distances for supply ships during at-sea replenishments. Brown et al. (2013) underscored the significance of planning optimal maritime routes, enabling replenishment while the fleet is in motion, thereby accelerating deployment and generating substantial annual savings.



The evolving landscape of naval warfare, characterized by distributed operations, expeditionary bases, and innovative logistics concepts, demands a meticulous understanding of fuel logistics and supply chains. RASP provides opportunities to optimize naval logistics operations, ensuring a seamless and sustainable fuel supply chain to support the Navy and Marine Corps' missions in contested environments (Stewart, 2013).

Utilizing a transportation linear programming model, RASP generates foundational data that, when integrated with its analytical capabilities, enhance the research process, offering a holistic perspective on naval logistics. RASP addresses the critical question of optimizing refueling schedules, aligning the logistic fleet with established demands from the linear programming model.

RASP's core design focuses on refining the planning and scheduling of replenishment operations at sea, aiming to minimize disruptions to naval operations. In evaluating the optimal combination of LSM and PSV vessels supporting the MLR within the contested WEZ, RASP's linear optimization capabilities were employed to explore various scenarios and initial conditions, emphasizing different levels of surface asset support with a focus on LSMs and PSVs. RASP's schedule optimization played a pivotal role in identifying effective combinations of these assets, shedding light on how adjustments influenced the MLR's operational capabilities.

Fuel Consolidation Stations and Delivery Assets

This study employs advanced features to systematically address the complexities of at-sea replenishment, with a specific focus on enhancing naval operational effectiveness with a generalizable Expeditionary Advanced Base (EAB) configuration. We setup a hypothetical EAB Company+ and four EAB Platoons in the AOR. Company+ features a limited-capacity Forward Arming and Refueling Point (FARP), supporting rotary wing aircraft refueling. The Third Marine Logistics Regiment (3d MLR) spearheads EABO in the second and first INDOPACOM island chains, employing a strategic logistics framework of hubs, spokes, and nodes to extend the range and precision of warfighters, shown in Figure 4.

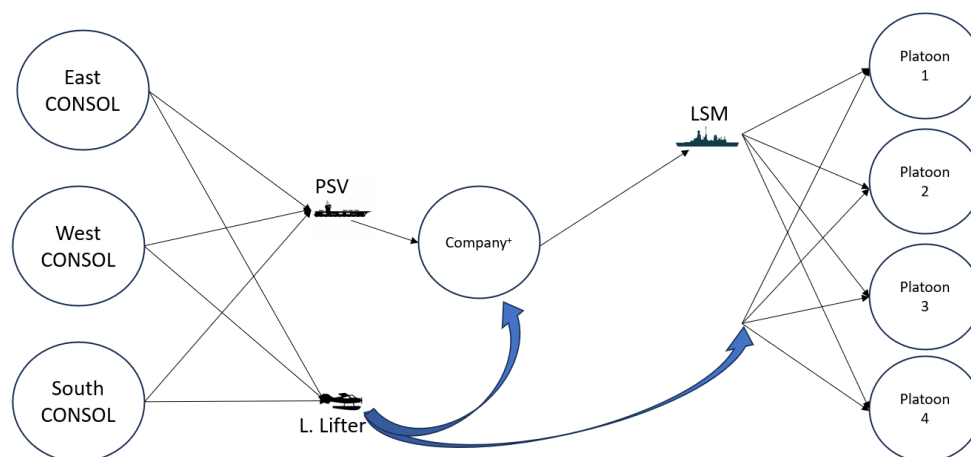


Figure 4. EABO Fuel Distribution Network (Rodriguez et al., 2023)

The simulation assumes that all delivery assets, crucial components in this scenario, exclusively utilize JP-5 as the single fuel. The core hub, functioning as the tactical and logistics command center, is fortified under a theater ballistic missile defense shield. The secondary hub, represented by the EAB Company+, operates at airfields and demands

refined logistics. Meanwhile, the nodes, embodied by EAB Platoons, serve as adaptable pit stops in austere terrains, facilitating swift refueling and rearming for the aircraft fleet.

The focal point of this scenario is on refueling support for the Company+ and designated EAB Platoons. In this context, three hypothetical CONSOL stations—CONSOL East, CONSOL South, and CONSOL West—are strategically positioned outside the WEZ, aligned with the Company+ location. These CONSOL stations are instrumental in providing JP-5 support for all EABOs within the contested AOR. The effective reach of delivery assets to their intended destinations is directly influenced by the distances between these CONSOL stations, details of which are outlined in Table 2.

Table 2. Distance Between Locations in the Simulated EABO Network (Rodriguez et al., 2023)

	W CONSOL	S CONSOL	E CONSOL	EAB Co+	EAB PL 1	EAB PL 2	EAB PL 3	EAB PL 4
W CONSOL	0	2440	3978	1596	2161	2091	1477	1276
S CONSOL	2440	0	2713	2022	1868	1329	1277	2031
E CONSOL	3978	2713	0	2708	2280	2011	2545	3271
EAB Co +	1596	2020	2780	0	665.1	733.6	978	658.2
EAB PL 1	2161	1868	2280	665.1	0	579.4	989.3	1206
EAB PL 2	2091	1329	2011	733.6	579.4	0	658.4	1297
EAB PL 3	1477	1277	2545	978	989.3	658.4	0	1017
EAB PL 4	1276	2013	3271	658.2	1206	1297	1017	0

Fuel Demand, Delivery Assets and Storage Capacity

RASP is a crucial tool for optimizing the Navy's logistics capabilities by focusing on crafting schedules that minimize travel distances for supply ships during at-sea replenishments. Brown et al. (2013) underscored the significance of planning optimal maritime routes, enabling replenishment while the fleet is in motion, thereby accelerating deployment and generating substantial annual savings.

Fuel demand analysis relies on a Mechanized Allowance List (MAL) tailored for Company+ and the EAB Platoons. The assessment considers EAB fuel demand, incorporating equipment-specific fuel consumption, operating hours, and equipment quantity, at an 80% readiness level. Aircraft fuel demand is determined based on fuel consumption, daily flight hours, and aircraft availability at a 70% readiness level. EAB Platoons primarily support organic ground equipment refueling, maintaining minimum fuel for EABO agile base relocation. The assessment considers two burn rate levels, sustained and surge, with detailed daily fuel demand and capacity in Table 3.

Table 3. Consumption and Demand in the Simulated EABO Network (Rodriguez et al., 2023)

	Sustained Operation (gal/day)	Surge Operation (gal/day)	Capacity (gallons)
Company+	52,646	79,357	1,500,000
Platoon 1	1,839	2,539	15,500
Platoon 2	1,839	2,539	15,500
Platoon 3	1,839	2,539	15,500
Platoon 4	1,839	2,539	15,500

Within this operational context, the EAB Company+ relies on two primary delivery assets, the PSV and the LL, stationed at CONSOL Stations. The LSM operates within the WEZ, supporting EAB Platoons and other EAB operations. EAB Platoons receive support through the LSM, while the LLs come into play during extreme situations with insufficient LSM availability. Table 4 details the fuel capacity, speed, and range of these essential delivery assets.

Table 4. Delivery Assets Characteristics (Rodriguez et al., 2023)

	Fuel Capacity (gallons)	Speed (knots)	Range (nm)
Platform Supply Vessel (PSV)	1,575,000	15-17	3,500
Liberty Lifter (LL)	18,000	145-180	4,000-8,000
Medium Landing Ship (LSM)	90,000	14	3,500

Analysis of Simulation Results

This chapter includes the output of several fuel delivery simulations to meet demand from a generalizable EAB configuration. It identifies the utilization of assets and CONSOL stations, using the RASP model to identify the performance of each resource selection. The results presented here focus on CONSOL East scenarios. The primary objective is to optimize the selection and quantity of assets, ultimately proposing an efficient refueling strategy for EABO under both sustained and surge demand scenarios.

The simulation results in this chapter were previously presented in Rodriguez et al. (2023).

RASP Optimization Results

The RASP optimization model was employed to allocate LSMs, PSVs, and LLs in addressing surge and sustained operational demand scenarios. The objective was to identify the optimal asset mix, considering inventory safety levels, delivery route optimization, and cost-efficiency. Efficiency was gauged by minimizing the number of delivery assets required to meet demand while ensuring on-time deliveries above maximum capacity. Optimization runs were conducted for varied combinations of asset types, with sustained demand representing continuous supply needs and surge demand introducing spikes due to heightened operational tempo. The model simulated a 30-day operation, limited to 10-minute simulation runs. Different asset allocations were tested, with PSVs and

LLs departing from each CONSOL station and LSMs from EAB Company+. In the outset, LLs were used only when fuel inventory in EAB Platoons were critically low.

Successful scenarios were achieved for sustained demand but not always for surge scenarios when demand could not be met using a limited number of assets. Because of the surge, we had to explore different settings with a larger number of assets: prepositioning LSMs closer to EAB Platoons and allowing the use of LL support during surge scenarios, which was sufficient to address the deficiencies. This increased model complexity significantly, and RASP could not always reach optimality in the time allocated, leading to suboptimal results. We tried increasing run time in a few scenarios from 10 to 15 minutes with limited impact on the model precision.

Performance Metrics

The optimization process focused on evaluating two key performance metrics:

1. **Fraction of Late Deliveries:** This metric gauges the percentage of deliveries that reached their destinations after their total storage capacity fell below the safety level threshold. The safety level threshold was set at 40% for sustained scenarios and 50% for surge scenarios. It serves as an indicator of the proportion of instances where fuel levels were lower than desired.
2. **Delivery Below Maximum Capacity:** This metric identifies the lowest fuel level, measured as a percentage of storage capacity, that any receiving station reached before experiencing a late delivery. This value represents the lowest percentage that at least one of the receiving stations experienced during an optimization run. Any value below 0% signifies that one or more receiving stations were left with no fuel, which equates to mission failure.

The following sections show how different asset mixes performed according to each metric.

Sustained Scenarios

In this section, all figures are paired showing the scenarios with one PSV on the left side and two PSVs on the right side.

The fuel demand for the EAB Company+ and each EAB Platoon in the sustained scenarios was shown in Table 3. The RASP optimization tool could not find an acceptable solution to yield zero late deliveries with one PSV during the sustained demand scenario when the PSV operated out of the East CONSOL. A single PSV would not be able to complete the round trip on time while keeping the EAB Company+ above the 40% safety threshold (Figure 5).

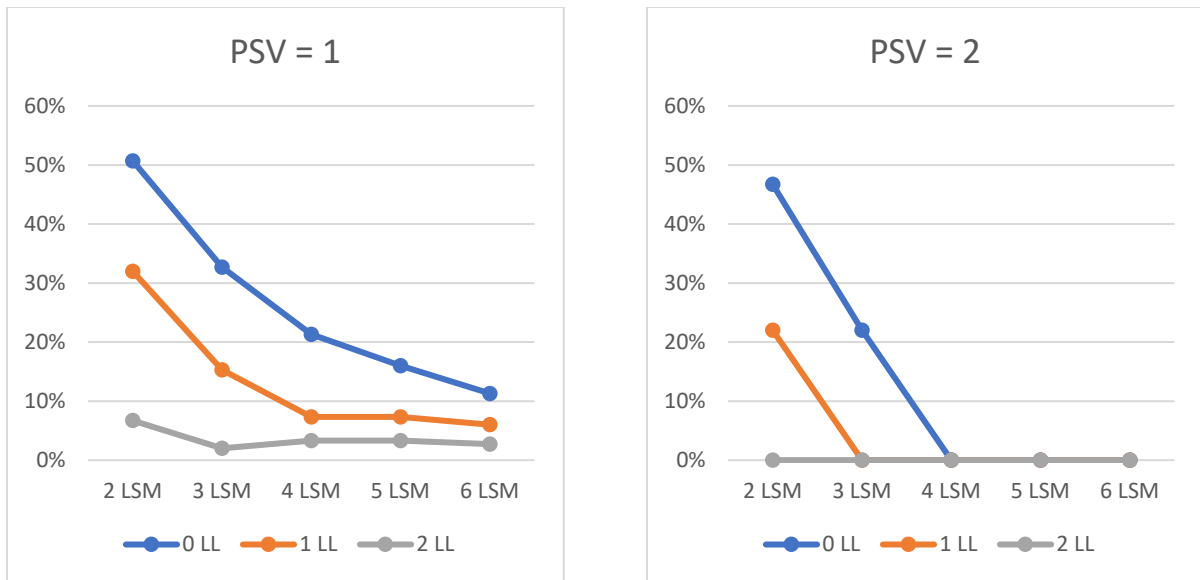


Figure 5. Sustained Demand Average Late Deliveries, East CONSOL

By adding a second PSV during sustained demand, average late deliveries from the East CONSOL yielded similar results as the optimization results from the West and South CONSOLs with a single PSV, illustrating the trade-off between distance and assets: the further the source, the more delivery assets are required to fulfill the mission. These optimization results with two PSVs showed zero late deliveries when the scenario was run with six, five, and four LSMs, regardless of the number of LLs used (Figure 5). Additionally, a combination of two LLs, two PSVs, and two LSMs showed zero late deliveries as well. Scenarios with zero LLs required at least one LSM per EAB Platoon to keep stock levels above safety thresholds.

Overall, the LL traveling speed helped maintain stock levels at EAB Platoons above their safety threshold when three LSMs were not enough to get on-time deliveries to all the EAB Platoons. However, a single LL in combination with two LSMs were not able to maintain stock levels at the EAB Platoons above the 40% safety thresholds.

Average Late Deliveries represents the fraction of instance that at least one receiving station received a delivery after reaching its safety threshold. The Below Maximum Capacity Delivery metric shows how low any one of the receiving stations reached before receiving a late delivery. It represents the lowest level of storage capacity any given station experienced below its safety threshold. This indicates the lowest fuel storage percentage that at least one of the receiving stations experienced during an optimization run. Any value below zero percent indicates that one or more receiving stations were left with no fuel, which equates to mission failure. The lower the number below zero, the greater the cumulative impact on the receiving stations. Any metric with zero value represents that all receiving stations achieved 100% on-time deliveries, or deliveries at or above their specific safety thresholds. The values above zero denote the lowest state of any given station before receiving fuel in reference to their safety threshold.

When supplying from the East CONSOL station, one PSV was not able to keep fuel levels at EAB Company+ above the safety threshold of 40% capacity. None of the data points were at 0%, as shown in Figure 6. All results above 0% represent the lowest any receiving station reached before receiving fuel. All results below the 0% mark represent that

one or more receiving units ran out of fuel for one or more days, resulting in mission failure. The RASP optimization tool could not find a solution to achieve zero below maximum capacity deliveries with one PSV during the sustained demand scenario when the PSV and LLs operated out of the East CONSOL station.

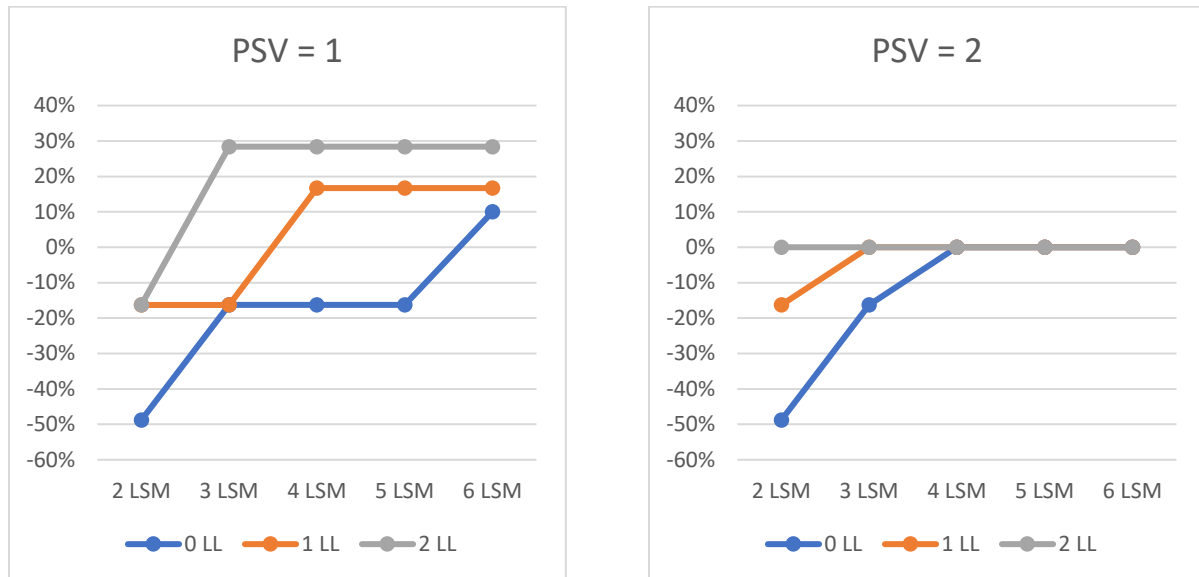


Figure 6. Sustain Demand Deliveries Below Maximum Capacity, East CONSOL (Rodriguez et al., 2023)

An additional run with two PSVs corrected this deficiency as shown in Figure 6. When using two PSVs with six, five, and four LSMs, regardless of the number of LLs, all receiving stations were filled before reaching their safety threshold. Additionally, a combination of two or three LSMs, supported by two LLs and two PSV, also showed zero deliveries below threshold. All other combinations resulted in mission failure. Without the LLs, stations would run out of fuel when using fewer than four LSMs and two PSVs.

Surge Demand Scenarios

During surge demand scenarios, it was not possible to achieve a combination of assets that would result in 0% late deliveries with the same initial conditions of the sustained scenario. Fuel demand in the surge scenario was set 51% higher at the EAB Company+, and 38% higher at each EAB Platoon, compared with sustained demand, as seen in Table 3.

Higher demand and higher safety stock level (raised from 40% to 50% of storage capacity at each location) affected on-time deliveries by forcing an increase in the shipment frequency, stressing the fuel delivery network beyond its capacity. Optimization runs with surge demand yielded zero instances in which any station received fuel below its safety threshold. It was not possible to achieve a combination of assets that would result in 0% late deliveries with the same initial conditions of the sustained scenario. In every simulation, at least one station received fuel below the safety stock threshold. Supplying from the East CONSOL location with one PSV, receiving stations ran out of fuel in 10 out of 15 scenarios, experiencing mission failure.

The Average Late Deliveries Surge Demand optimization with one PSV yielded no results with zero late deliveries, although all results improved whenever LLs were present, as shown in Figure 7.

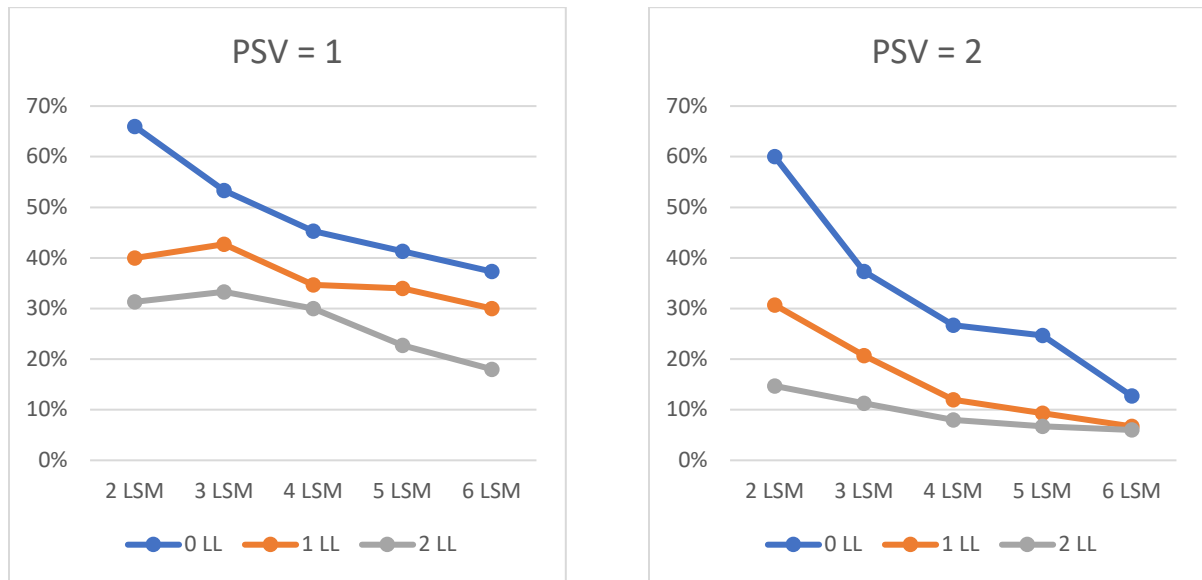


Figure 7. Surge Demand Average Late Deliveries, East CONSOL (Rodriguez et al., 2023)

Unlike in the sustained scenario, adding the second PSV reduced the number of mission failure scenarios, but none achieved 0% below maximum capacity delivery, as shown in Figure 8.

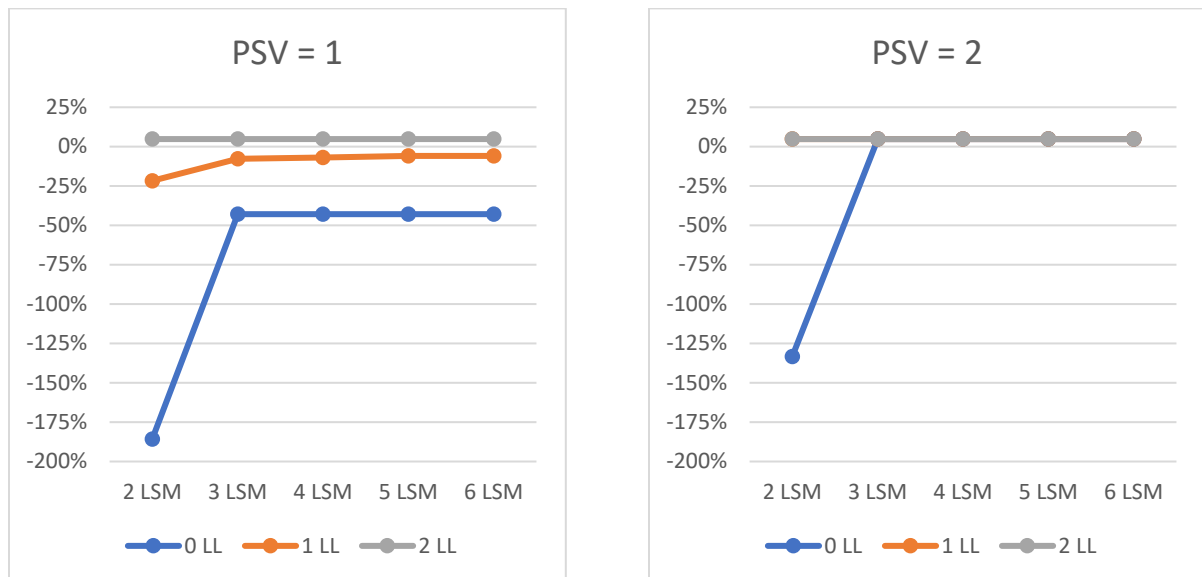


Figure 8. Surge Demand Deliveries Below Maximum Capacity, East CONSOL (Rodriguez et al., 2023)

Surge Scenarios with Prepositioned Assets

To achieve 0% average late deliveries in the surge demand scenario, two LSMs were prepositioned closer to the EAB Platoon locations at the start of the simulations, one to the north and another to the south relative to the EAB Company+. Additionally, LLs were allowed to conduct deliveries within the WEZ, if necessary. Optimization runs for the surge demand scenarios with prepositioned assets were conducted with one and two PSVs. These changes resulted in improved results across all locations. However, as in the sustained demand scenario, the East CONSOL location could not achieve zero late deliveries if only one PSV were available.

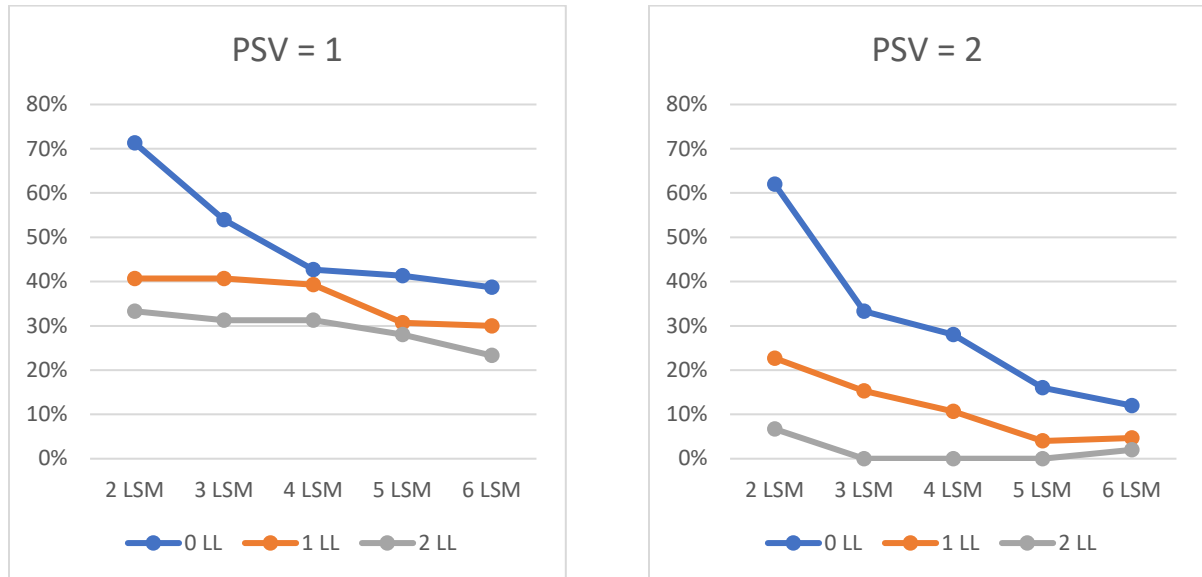


Figure 9. Surge Demand Average Late Deliveries, East CONSOL, With Prepositioned Assets (Rodriguez et al., 2023).

Adding a second PSV to the surge scenario improved the results. Figure 9 shows an anomaly: using two PSVs, three LSMs and two LLs, it is possible to achieve zero late deliveries. However, if the number of LSMs is increased, performance seems to deteriorate. That shouldn't be possible, but the explanation is simple: due to the complexity of the model, the results are less reliable when more assets are available. It would be necessary to increase substantially the time available for each simulation run. We tried increasing the run time from 10 to 15 minutes without significant improvement. Nonetheless, we can be sure that increasing the number of assets will always provide the same performance or better.

To achieve 0% below maximum capacity deliveries in the surge demand scenario, we repeated the procedure by prepositioning two LSMs closer to the EAB Platoon, one to the north and another to the south. We also allowed LLs to deliver fuel inside the WEZ as needed.

As in the sustained demand scenario, the East CONSOL location could not achieve zero deliveries below maximum capacity with one PSV, as shown in Figure 10.

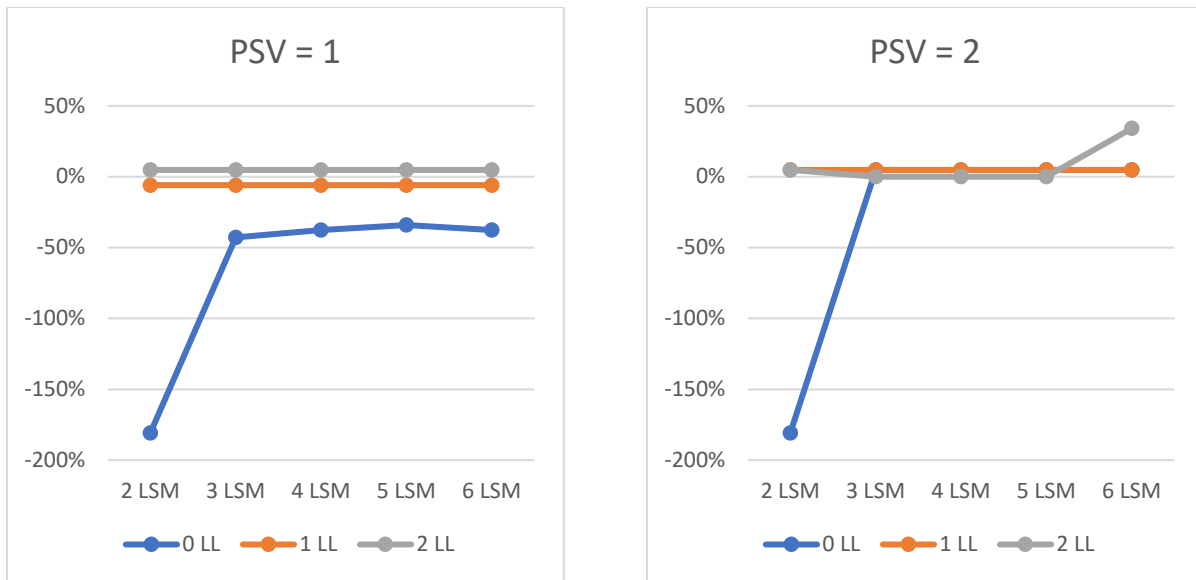


Figure 10. Surge Demand Deliveries Below Maximum Capacity, East CONSOL, With Prepositioned Assets (Rodriguez et al., 2023)

Adding a second PSV improved the results. CONSOL East achieved 0% delivery below maximum capacity by using three, four, or five LSMs, two PSVs, and two LLs, as shown in Figure 10. However, due to the model complexity, the 10-minute optimization run was insufficient for RASP to find a solution to the scenario with six LSM and two LLs.

Conclusion

This study demonstrates how fuel demand can impact asset selection for supporting different EAB configurations. For comparison, we standardized demand level at the EAB Company+ as 45,172 gallons of fuel per day during sustained operations, while each EAB Platoon needed 1,794 gallons per day. During surge conditions, the standard fuel demand at Company+ increased 50% to 69,045 gallons per day, and each Platoon's requirement increased nearly 40% to 2,477 gallons per day. These changes in fuel consumption would be driven by the operational tempo and the readiness level of equipment and aircraft, highlighting how fuel consumption is influenced by the size and composition of the EAB units and whether operations are ongoing or intensifying.

We used the RASP optimization model under multiple asset configurations to assess their respective performances. It was clear that fuel consumption patterns would shift significantly based on operational scenarios, the size of EAB units, and equipment selection and usage. By leveraging RASP, naval planners can determine the right combinations of replenishment ships and dynamic deployment approaches to sustain EABOs across a range of demanding, real-world conditions. The tool provides data-driven asset allocation recommendations to meet varying operational requirements while keeping EABs at or above safety capacity thresholds. RASP was also used to indicate when the asset configuration was insufficient to meet demand under the desired performance metrics.

To meet demand, the analysis identified the optimal mix of replenishment assets for each scenario. It was clear that almost no combination of LSM and PSV would be sufficient to meet demand at the EABOs; one or more LL would always be required. During sustained operations, as few as two LLs, two LSMs, alongside one PSV, could satisfy requirements from the East and South CONSOL stations, assuming 100% delivery asset availability.

However, to meet the demand during surge operations necessitated pre-positioning LSMs closer to EAB Platoons and adopting LLs dynamically to share the replenishment burden. Under these conditions, the model showed that three to six LSMs, two LLs, and two PSVs were required for on-time deliveries from any CONSOL stations. The importance of the LLs to supplement floating delivery assets cannot be overstated. Key insights include

- LSMs and PSVs can act as the core assets for continuous sustainment needs, if available in the right numbers.
- LLs are essential for meeting periodic surge demands.
- Distance between stations affects the number of delivery assets, regardless of assets' load capacity. The EAB Platoons could require dedicated assets if the delivery intervals are short.
- Pre-positioned assets are required to meet fuel demand during surge scenarios.
- With these considerations, EABOs require at least the following support:
- **Medium Landing Ships:** Four units are required to provide lift capacity from EAB Company+ to each EAB Platoon.
- **Platform Supply Vessels:** One unit would suffice to maintain support on EAB Company+ with a 1.5 million-gallon storage capacity at the stated sustained and surge demands if the CONSOL station were within 2,300 nautical miles of the hub. However, because our study focused on the East CONSOL station, further away, another PSV would be required to maintain the fuel stock at EAB Company+ above safety level thresholds.
- **Liberty Lifters:** The LL speed makes it a multiplying force, enabling quick drops to EAB Platoons in remote areas, supplementing the PSV delivery capacity.

To allow flexibility during surge operations, a fifth LSM and a second PSV would be recommended in the expansive geography of the INDOPACOM AOR. The ideal mix, however, depends on the risk tolerance of the decision-maker.

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PANEL 7. OPTIMIZING RELATIONSHIPS THROUGH CONTRACTING

Wednesday, May 8, 2024	
12:45 p.m. – 2:00 p.m.	<p>Chair: John G. (Jerry) McGinn, Executive Director, Center for Government Contracting, George Mason University</p> <p><i>Closing the Bid Protest Case Law Knowledge Gap The Contract Protest Diagnostic Tool (CPDT)™</i> Patrick Staesina, MITRE</p> <p><i>"LPTA By Any Other Name" - Recapturing Requirements Discipline in Solicitation and Award</i> David Berteau, Professional Services Council Foundation</p> <p><i>Policy Options to Improve Small Business Participation in the Industrial Base: An Analysis of the Competitiveness Demonstration Program of 1988 and of Small Business Act Authorities</i> Emily Murphy, GMU</p>

John G. (Jerry) McGinn, PhD—is the Executive Director of the Greg and Camille Baroni Center for Government Contracting in the Costello College of Business at George Mason University. In this role, he has established and is leading the first-of-its-kind university center for research, education and training, and collaboration on issues facing the \$500B+ government contracting community. The Center has published over 70 influential reports, white papers, and commentaries on issues such as defense innovation, government contracting, intellectual property, budget reform, industrial resilience, collaboration with allies and partners, and COVID-19. The impact of the Center's work led to recent \$7 million naming gift, the largest-ever cash donation to the College of Business. The Center has also been awarded over \$4 million in sponsored research and has had hundreds of interviews and media mentions with regional and national print, video, and audio outlets to date. Prior to joining GMU, he served as the senior career official in the Office of Manufacturing and Industrial Base Policy in the Department of Defense, leading efforts to analyze the capabilities and overall health of the defense industrial base, including the 2017-2018 interagency review of the manufacturing and defense industrial base. He also directed hundreds of reviews of high-profile mergers and acquisitions as well as transactions before the Committee on Foreign Investment in the United States. Previous to DoD, he spent a decade in senior defense industry roles at McGinn Defense Consulting LLC, Deloitte Consulting LLP, QinetiQ North America, and Northrop Grumman. Before industry, he served in DoD as Special Assistant to the Principal Deputy Undersecretary (Policy) and as a political scientist at RAND. McGinn is also a widely acclaimed thought leader and sought-after speaker. He has published influential George Mason reports and white papers, RAND monographs, and articles in The Hill, Business Insider, Defense News, Defense One, and other outlets. He has also testified before the U.S. Congress and the UK House of Commons and he has participated in advisory studies for the Homeland Security Advisory Council, the NATO Industrial Advisory Group, the Defense Science Board, and the Professional Services Council. He was the only university recipient of the prestigious Wash100 award in 2021 and 2022. Dr. McGinn was commissioned into the U.S. Army and served with distinction as an infantry officer and is a graduate of Ranger and Airborne Schools. He has received numerous civilian and military awards and has earned a Ph.D., M.S., and M.A. from Georgetown University as well as a B.S. from the United States Military Academy.



Closing the Bid Protest Case Law Knowledge Gap

The Contract Protest Diagnostic Tool (CPDT)™

Patrick Staesina, CPCM, CFCM—is an Acquisition Principal and Group leader for The MITRE Corporation, providing high-level acquisition support to help solve some of the government's most complex acquisition problems. Before his employment at MITRE, Staesina served 31 years in the Army and Army National Guard, retiring at the rank of Colonel as the Chief of Operational Contracting at the National Guard Bureau. He has over 23 years of contracting officer experience.
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Patrick Butler, JD—is an Attorney and Consultant specializing in federal government contracts. He is an independent contractor with the MITRE Corporation, where he serves as the primary researcher and writer for the Contract Protest Diagnostic Tool (CPDT). Butler served on active duty for 21 years as an Army Judge Advocate, retiring at the rank of Colonel. Butler served in a variety of contract and fiscal law assignments in the Army, culminating as the Chief of Contract and Fiscal Law for the National Guard Bureau. He published a book in 2014 entitled Key Case Law for Government Contract Formation. [pat@pbi-consulting.com]

Abstract

Federal contract formation is governed by three main types of legal authorities: statutory, regulatory, and decisional. Contracting officers have easy access to statutory and regulatory authorities but do not have easy access to decisional authorities (bid protest decisions). Most federal contracting officers do not have subscriptions to expensive legal research tools such as LexisNexis or Westlaw and are forced to research bid protest information through myriad ways ranging from Google searches to government contracting blogs. Despite this lack of access to published bid protest decisions, the Federal Acquisition Regulation (FAR) 1.602-1 mandates that “no contract shall be entered into unless the contracting officer ensures that all requirements of law ... have been met.” Some of those “requirements of law” are created through published protest decisions from the Government Accountability Office, the U.S. Court of Federal Claims, and the U.S. Court of Appeals for the Federal Circuit. In response to this access and knowledge gap, the MITRE Corporation has created a “Contract Protest Diagnostic Tool” (CPDT)™. It is currently being sponsored by the Office of the Director of National Intelligence (ODNI). This paper explains this problem and how the CPDT delivers bid protest information to the federal acquisition workforce.

Introduction

In FY2023, the federal acquisition workforce obligated over \$765B in federal funds through thousands of contracting actions (Edwards, 2024). In executing this massive mission, contracting officers are responsible for ensuring all these contract awards fully comply with applicable procurement laws (FAR 1.602-1(b)). Further, the laws governing contract formation are comprised of statutes, regulations, executive orders, and decisional authorities (e.g., bid protest case law). Contracting officers have easy online access to all these sources of law—except for the *decisional* authorities. This lack of access to protest case law is a longstanding and well-known problem for the procurement community. The MITRE Corporation has developed an innovative tool to close this knowledge gap. It is called the Contract Protest Diagnostic Tool. This paper explains the need for this tool and its capabilities.

The Importance of Federal Contracts to Agency Operations

The Federal Government relies heavily on contracts to keep it running daily. These contracts provide critical supplies and services necessary to perform a broad range of Government functions and support all federal agencies and programs. This spans



everything from low-dollar supplies to multi-billion-dollar weapons systems. The Department of Defense (DoD) annually obligates more money on federal contracts than all other federal agencies combined (Peters, 2023), as shown in the GAO¹ FY2022 chart below depicting federal contract obligations by federal department.

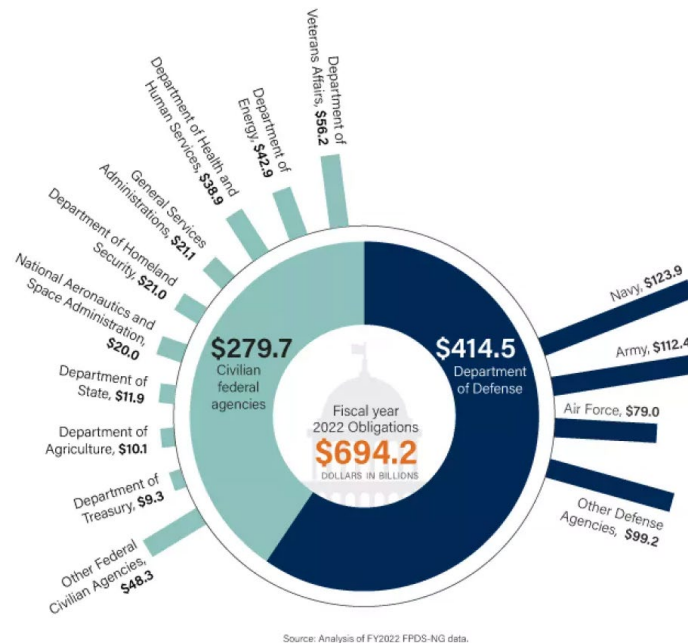


Figure 1. High-Level Overview of FY2022 Contract Obligations by Agency

The Statutes, Executive Orders, and Regulations Governing Federal Contracting

Federal contracts are awarded and administered according to well-defined statutory authorities established by Congress. These statutes are mainly codified in the U.S. Code at Title 10 (Armed Forces) and 41 (Public Contracts). They are readily accessible to the public through several online sources, including the House of Representatives Office of the Law Revision Counsel's website.² Executive orders are likewise well-organized and easily accessible online through the Code of Federal Regulations (CFR) website.³

These statutory authorities and executive orders are implemented in regulation through the federal rulemaking process. The Federal Acquisition Regulation (FAR) is the central government-wide regulation that executive agencies follow when awarding contracts. The FAR is codified in Title 48 of the Code of Federal Regulations and is easily searchable through the Federal Government's acquisition.gov website.⁴ Agency supplements to the FAR, such as the Defense FAR Supplement (DFARS), are also found on that site. Procurement-adjacent regulations, such as those promulgated by the Small Business Administration, are also easily searchable through the Government's eCFR website.⁵

¹ See GAO Blog (2023, August 15), *A Snapshot of Government-Wide Contracting for FY 2022*. [A Snapshot of Government-Wide Contracting for FY 2022 | U.S. GAO](#)

² See: [OLRC Home \(house.gov\)](#)

³ See: [Federal Register :: Executive Orders](#)

⁴ The FAR, and its supplements, is most easily searchable through the Federal Government's acquisition.gov website: [FAR | Acquisition.GOV](#)

⁵ See e.g., the SBA's "Government Contracting Programs" regulations at 13 C.F.R. Part 125. [eCFR :: 13 CFR Part 125 -- Government Contracting Programs](#)

The Decisional Authorities Governing Federal Contract Awards

In addition to the statutes, regulations, and executive orders discussed above, bid protest decisions are essential to the law governing federal contract formation. These decisions explain the protest forums' application of the laws to various fact patterns. In some cases, these decisions *create* legal rules not evident from a plain reading of the statutes and regulations.

There are three protest forums: (1) the awarding agency, (2) the Government Accountability Office (GAO), and (3) the Court of Federal Claims (COFC). All three of these forums must issue a written decision on the protest. Unlike agency decisions, GAO and COFC protest decisions are *published*, creating precedent that contracting officers must follow to avoid a sustained protest. Further, the Court of Appeals for the Federal Circuit (CAFC) publishes important protest decisions following appeals from the COFC's protest decisions.

This paper is focused on the protest decisions issued by the GAO, the COFC, and the CAFC. These three forums (combined) publish an average of 400 protest decisions per year. The GAO publishes the most (around 300 published decisions annually), followed by the COFC (around 100 protest decisions).⁶ The CAFC, by contrast, only publishes a few (albeit important) protest decisions each year (ranging between five to fifteen protest decisions in recent years). These decisions are added to thousands of existing protest decisions that span decades. These decisions are critically important to the law governing contract formation, yet unlike statutes and regulations, they are much more difficult to access and understand.

Lack of Access to Protest Decisions

As stated, contracting officers have easy online access to all procurement authorities *except* decisional authorities. Most contracting officers do not have a paid subscription to legal research services such as Lexis-Nexis or Westlaw. As a result, contracting officers are left to toggle through various websites when researching bid protest decisions relevant to their contracting action. Compounding this problem is that experienced procurement attorneys are an extremely limited resource within most federal agencies. Accordingly, contracting officers often rely on their own case law research to resolve day-to-day contract formation issues.

⁶ A review of published protest decisions shows that in FY2023 alone, there were 289 decisions published by the GAO, 100 decisions published by the COFC, and three decisions published by the CAFC.



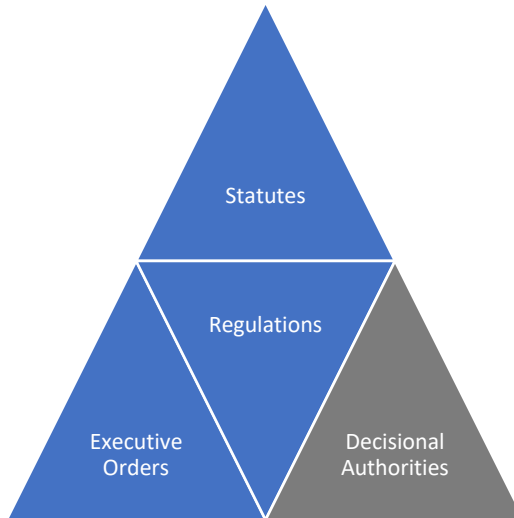


Figure 2. Laws and Regulations Governing Contract Formation

No single government-wide website pulls these decisions together in one easily searchable location. This makes it difficult for contracting officers to carry out their responsibilities and heightens the risk that they will unknowingly make a procurement error that is noticed for the first time during protest litigation. In other words, the important rules that emerge from these decisions are not being effectively or efficiently communicated to the federal acquisition workforce.

Unlike statutes, executive orders, and regulations, researching bid protest case law is not simply a “click, read, and understand” process. Rather, these decisions are often nuanced and require significant research and study to apply accurately. This lack of access to (and understanding of) bid protest decisions creates a significant knowledge gap that places federal contract awards at unnecessary risk of either a sustained protest or the agency having to take voluntary corrective action.

A few examples of common bid protest pitfalls include the following:

- Misapplication of pass/fail evaluation factors.
- Misapplication of a “price realism” analysis.
- Awarding GSA schedule contracts that are not within the scope of the underlying schedule.
- Not understanding the impact of the offeror’s lapsed SAM.gov registration.
- Errors made when performing multi-step evaluations or a down-select procedure.
- Accepting (or rejecting) a late proposal.
- Misapplying the rules for mentor–protégé joint ventures in source selections.
- Conducting oral presentations that trigger the “discussions” rules under FAR Part 15.

Protest decisions from the GAO, the COFC, and the CAFC have established certain red lines that agencies must be aware of during the contract formation process. If these red lines are crossed, the agency risks losing a protest. The challenge is translating these red lines into the same “click, read, and understand” format that defines all the other sources of law governing contract formation.

Further, there are thousands of bid protest decisions—dating back decades—that contracting officers need to be aware of as they move through the contract formation process. Although some protest decisions involve a straightforward application of the facts to the Federal Acquisition Regulation (FAR) to the facts, other decisions *create* rules that are

not evident from the plain text of the FAR. Finally, new protest decisions are published daily, challenging even the most experienced contracting professional to stay current.

Finding on-point case law is challenging for the acquisition workforce. When relevant bid protest case law is identified and available, contracting officers often find it difficult to quickly extract and apply those rules to their contracting action. The protest decisions are factually and legally dense—with some of the more complex COFC decisions exceeding 100 pages.⁷ It is unrealistic to expect that the average overworked and understaffed contracting team will be able to spend many hours poring over such decisions. Additionally, most protest decisions, especially those rendered by the COFC or CAFC, are composed in formal legal language, commonly described by laypeople as “legalese.” For example, these decisions often start with many pages explaining the Court’s technical ruling on complex jurisdictional issues that must be decided before addressing the protest’s substance. The vast majority of the acquisition workforce does not have a Juris Doctor degree, and it is often difficult for this workforce to efficiently extract the pragmatic rules formed by these lengthy and complex decisions. A capability is needed to translate the “legalese” from these protest decisions into “plain English” for the acquisition workforce charged with abiding by such decisions.

Why Do We Need to Fix this Problem?

Some commentators have argued that bid protests are an exaggerated problem when compared to the many thousands of contracting actions that pass through annually without a protest (Gordon, 2013). Regardless of their relative infrequency, however, there is no denying that protests pose a significant risk to most procurements. This includes large, high-dollar procurements. In the last few years, the large CIO-SP4 contract awarded by the National Institutes of Health has experienced over 350 protests. As any contracting officer who has received a protest knows, they are incredibly disruptive events. The compressed time frames for bid protest litigation require an overtasked contracting officer to suddenly drop everything else to focus on assembling the administrative report (or agency record) and various other legal filings in short order.

Disruption to Mission

As any seasoned government contracting officer or program manager knows, bid protests can significantly disrupt the execution of a complex procurement. Even meritless protests can lead to costly delays to the contract schedule and often require the contracting officer to scramble to get a “bridge contract” in place. Further, protests quickly absorb the one resource that most contracting officers do not have—time. If the protest has merit, it worsens the problem because it forces the agency to take corrective action or risk receiving a sustained protest from the GAO or the Courts. Even a protest that the GAO denies can be filed anew at the COFC. Further, the Court of Appeals for the Federal Circuit (CAFC) can overrule a COFC decision that denied the protest.

These protests, particularly if meritorious, trigger a cascade of negative repercussions for federal agencies, including:

- Immediate stoppage of contract award or performance.
- Protracted delays in the contract schedule.
- Funding complications—particularly when using one-year appropriations.
- The necessity of costly bridge contracts.
- Diverting constrained contracting office resources to focus on protest litigation.

⁷ See e.g., *Palantir USG, Inc. v. United States*, 129 Fed. Cl. 218 (Fed. Cl. November 3, 2016)



- Dissatisfied government customers.

This situation invariably leads to mission disruption. The risk can be reduced or prevented if the acquisition team is more knowledgeable and better equipped with decision support tools while building their contract. By identifying protest risks in advance, the team can work to mitigate those vulnerabilities before contract award.

Avoiding Recurring Procurement Errors

Every fiscal year, the GAO submits a “Bid Protest Annual Report” to Congress. That report summarizes bid protest activities for the prior fiscal year (*GAO Bid Protest*, 2023). As required by the Competition in Contracting Act (CICA), the report includes a summary of the “most prevalent grounds for sustaining protests.” Almost every annual report lists the following as the most prevalent sustained protest grounds: (1) unreasonable technical evaluation, (2) flawed selection decision, and (3) unreasonable cost or price evaluation. The fact that the same sustained protest grounds are listed yearly reflects that the Federal Government is not learning the lessons from previous mistakes. A capability is needed to deliver these lessons learned to the acquisition workforce to enable the Federal Government to improve on the whole and avoid making the same mistakes repeatedly.

Workforce Development.

Within most contracting offices, several high-performing employees proactively seek to improve their knowledge by continuously reading contracting articles, scanning protest decisions, following contracting blogs, and attending conferences, webinars, and other training. The absence of readily accessible bid protest information impedes these motivated workers and constrains their professional growth. The Contract Protest Diagnostic Tool (CPDT) provides these individuals with a capability that they can use to further their technical expertise, which is then shared with other professionals in that office.

Answering the Most Challenging Contracting Questions.

Often, the most complex contracting questions cannot be resolved through statutes, regulations, or established best practices alone. Contracting officers frequently encounter unique issues not covered by existing statutes, regulations, or best practice guides. Instead, the answers to these nuanced questions are often found in a bid protest decision. Such challenging issues include (1) Determining the threshold between in-scope and out-of-scope modifications to contracts, (2) Understanding the fine line between “clarifications” and “discussions,” or (3) Understanding the impacts of “bait and switch” situations involving a vendor’s key personnel. In these situations, contracting officers must be capable of conducting advanced research independently and swiftly. The CPDT is focused on providing this capability.

Lack of Information Suppresses Smart Innovation.

FAR § 1.102(d) is often cited when discussing innovation in Federal Contracting. It states:

The role of each member of the Acquisition Team is to exercise personal initiative and sound business judgment in providing the best value product or service to meet the customer’s needs. In exercising initiative, Government members of the Acquisition Team may assume if a specific strategy, practice, policy or procedure is in the best interests of the Government and is not addressed in the FAR, nor prohibited by law (statute or case law), Executive order or other regulation, that the strategy, practice, policy or procedure is a permissible exercise of authority.



This language is important because it emphasizes that what is not expressly prohibited is permitted, granting contracting officers significant leeway to innovate within the procurement process. However, this freedom is not absolute; it obligates contracting officers to be well-versed in what constitutes prohibited actions, particularly bid protest case law. To innovate effectively and responsibly, contracting officers must have easy access to the rules formed through bid protest decisions. This knowledge is crucial for developing informed acquisition strategies and integrating innovative solutions successfully.

A Proposed Solution – The Contract Protest Diagnostic Tool (CPDT)™

In response to this challenge, the MITRE Corporation, in partnership with the Office of the Director of National Intelligence (ODNI) and the Naval Postgraduate School (NPS), created an innovative capability called the “Contract Protest Diagnostic Tool” or “CPDT.” The CPDT is a 100% free online tool that distills the most common bid protest grounds into nine main “categories” comprised of 64 separate “subcategories.” The CPDT further breaks the subcategories into “Hot Spots,” which alert users to risky protest areas. Underneath each “Hot Spot,” the user can click on the protest decisions that inform the “plain English” explanation in the Hot Spot. The goal is to allow users to quickly cut through the fog and zero in on their protest topic and its corresponding decisions.

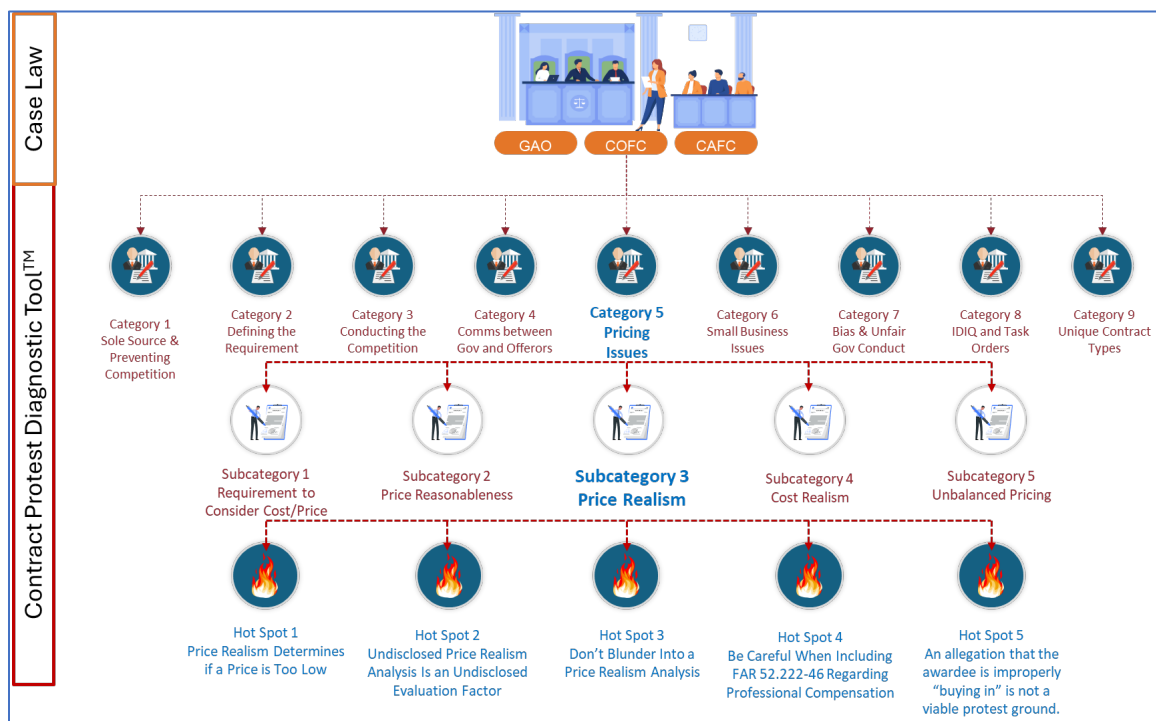


Figure 3. CPDT Breakdown of Protest Case Law

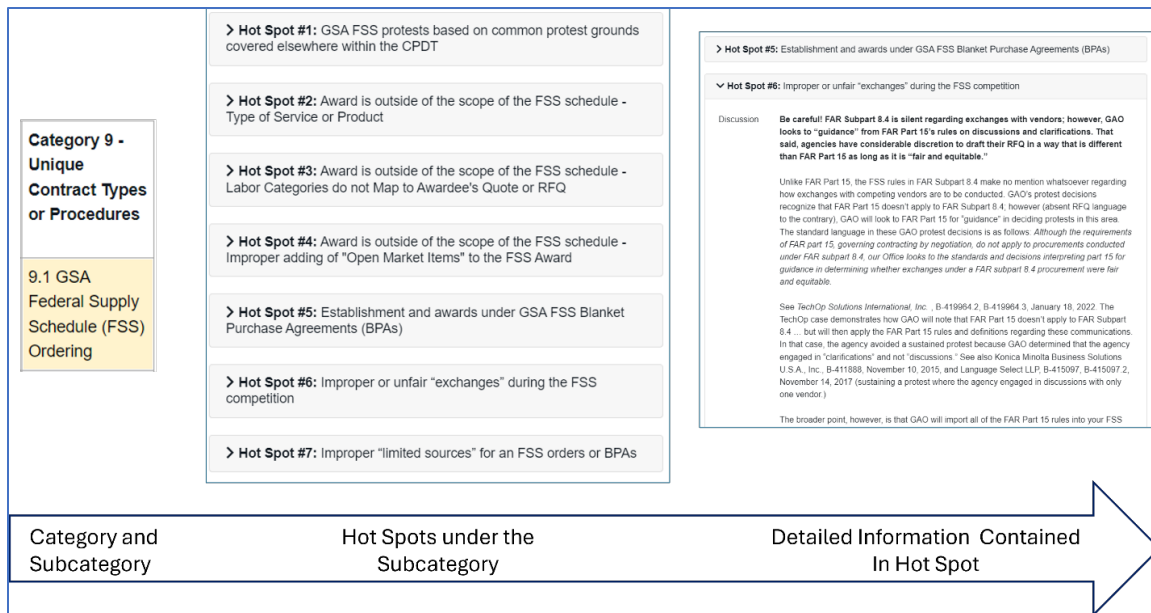


Figure 4. CPDT Example of the Flow of Information from Category to Hot Spot

The CPDT also has a questionnaire-based functionality, allowing users to plug in information from real-world contracting actions to identify the applicable protest rules/decisions at play. The user can apply the questionnaire to the entire contracting action (a "deep dive") or to just the subcategories that a contracting professional is worried about (a "quick dive"). Finally, the CPDT includes a "Protest Knowledge Center" that gathers publicly available protest information (including blog posts and news feeds) into one centralized location.

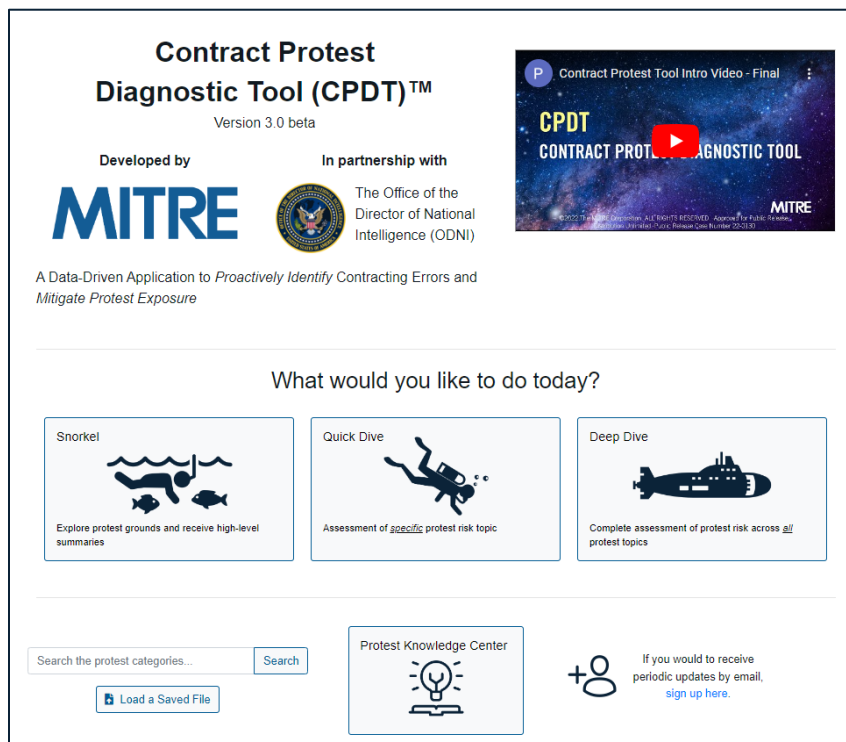


Figure 5. Home Screen of the Contract Protest Diagnostic Tool

This tool is designed to benefit the federal acquisition workforce by providing pragmatic and meaningful explanations of protest-related issues in a proactive, easy-to-search, and easy-to-understand way. The goal is to enable the Government to avoid potential protest pitfalls and execute the contracting process correctly. This, in turn, allows vendors to have greater confidence that the contract award process was conducted fairly and in accordance with the terms of the solicitation, regulations, and laws (including case law).

Under the terms of MITRE's Federally Funded Research and Development Corporation (FFRDC) sponsoring agreement, the Federal Government possesses full Government Purpose Rights for use. This tool was deployed in April 2023 and is freely accessible to the public via MITRE's Acquisition in the Digital Age (AiDA) website at <https://aida.mitre.org/protest-tool/>. A short 3-minute introductory video can be viewed on YouTube at https://www.youtube.com/watch?v=tFWG-n_qlpw.

The CPDT is still technically a prototype (with some categories under construction), but it contains valuable information and analysis to help the contracting community today. Further, it tackles complicated areas such as "Price Realism," "GSA Schedule Contracting," and "Self-Scoring." The goal is to complete all "under construction" areas by the end of the 2024 calendar year.

Category 1 - Sole Source & Preventing Competition	Category 2 - Defining of the Requirement	Category 3 - Conduct of the Competition	Category 4 - Communications Between the Government & Offerors	Category 5 - Pricing Issues	Category 6 - Small Business Issues	Category 7 - Bias & Unfair Government Conduct	Category 8 - IDIQ and Task Orders	Category 9 - Unique Contract Types or Procedures
1.1 Lack of Advance Planning	2.1 Writing the Specifications	3.1 Commercial Products and Services	4.1 Clarifications	5.1 Requirement to Consider Cost or Price	6.1 Bundling and Consolidation (Research Ongoing)	7.1 Availability of Solicitations (Research Ongoing)	8.1 Protests against base IDIQ contract awards	9.1 GSA Federal Supply Schedule (FSS) Ordering
1.2.1 Sole Source - Only One Responsible Source Exception	2.2 Improper Use of "Brand Name or Equal" Descriptions	3.2 Responsibility Determinations	4.2 Discussions	5.2 Price Reasonableness	6.2 Limitations on Subcontracting	7.2 Organizational Conflicts of Interest (OCIs)	8.2 Protestability of Task/Delivery Orders	9.2 Reserved
1.2.2 Sole Source - Unusual and Compelling Urgency	2.3 Ambiguities in the Solicitation	3.3 Negotiated Procurements: Tradeoff Process	4.3 Debriefings	5.3 Price Realism	6.3 HUBZone Contracting Procedures (Research Ongoing)	7.3 Offeror's Responsibility to Obtain Solicitation Documents (Research Ongoing)	8.3 Pre Award Protests of IDIQ Task/Delivery Orders	9.4 Simplified Acquisition Procedures (SAPs) (Research Ongoing)
1.2.3 Sole Source - Other Exceptions to Competition	2.4 Unduly Restrictive Specifications	3.4 Competitive Range	4.4 Oral Presentations and Demonstrations	5.4 Cost Realism	6.4 Certificate of Competency	7.4 Government Independence and Alleged Bias	8.4 Post-Award Protests of IDIQ Task/Delivery Orders	9.5 Other Transaction Authority (OTA)
1.3 Contract Was Modified Beyond the Scope	2.5 Changed Requirements & Solicitation Amendments	3.5 Evaluation in Strict Accordance with the Solicitation		5.5 Unbalanced Pricing	6.5 SBA's 8(a) Program (Research Ongoing)	7.5 Proposal Compliance with the Terms of the Solicitation	8.5 Self-Scoring	9.6 Basic Ordering Agreements (BOAs) (Research Ongoing)

Figure 6. Partial List of Protest Grounds Provided in the CPDT

Proposed Path Forward

As discussed above, the prototype is fully operational, much of the protest research has been completed, and the federal acquisition workforce is currently using the CPDT. In other words, much of the hard work has been completed. What remains is to establish a process and resources for completing the remaining research topics and provide updates and sustainment to keep the information current and accurate.

MITRE and the Government have made significant investments in developing and operationalizing this much-needed capability to fill this critical gap in protest-related



information and guidance for the federal acquisition workforce. Currently, the solution is ready to transition to the federal government. The authors propose that the CPDT can be sustained for a very low annual cost at the Simplified Acquisition Threshold (currently set at \$250K), which seems insignificant considering the \$765B the Federal Government spends annually via the contracting process.

Conclusion

Although acquisition professionals have easy access to statutes and regulations (e.g., the FAR), they lack that same level of access to bid protest decisions. These decisions are important because they form part of the law governing contract formation. The absence of a readily available resource for accessing and understanding them increases the risk that agencies will inadvertently fall into a protest pitfall. On the other end of the spectrum, this knowledge gap can lead to agencies taking overly risk-averse decisions based on perceived protest risks that may not be warranted. The CPDT provides a sensible and practical solution to bridge this knowledge gap.

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Policy Options to Improve Small Business Participation in the Industrial Base: An Analysis of the Competitiveness Demonstration Program of 1988 and of Small Business Act Authorities

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Abstract

In 2023, officials from the Department of Defense stated that unless small business participation improves, “[w]e risk losing mission-critical domestic capabilities, innovation and strong supply chains” and that the Department must work, “to strengthen our small business supply chains, increase competition and attract new entrants.” However, analysis based on the Department’s FY 2021 Industrial Capabilities Report to Congress suggests that small business utilization is not fully supporting the needs to the Department. To that end, it is worth examining the lessons learned from the Small Business Competitiveness Demonstration Program (Comp Demo), established by the Small Business Competitiveness Demonstration Program Act of 1988 (Comp Demo Act). Comp Demo attempted to realign small business spending from industries where small businesses were winning large shares of contracts to those where small businesses were underrepresented. This program was terminated by the Small Business Jobs Act of 2010, P.L. 111–240.

The Small Business Act requires that the government assure, “that a fair proportion of the total purchases and contracts for goods and services of the Government in each industry category” be awarded to small businesses (15 USC 644(a)). However, within the last 10 years, amendments have been made to the Small Business Act that allows the Small Business Administration (SBA) to create new size standards within or outside of the existing system of North American Industrial Classification System (NAICS) codes, “due to unique Federal buying patterns or requirements.” Additionally, the annual report on small business goals was amended to require that small business participation be tracked by NAICS. The SBA has not acted upon either. By examining the successes and failures of the Comp Demo program, and the opportunities created by the changes to the Small Business Act, the author expects to identify opportunities to provide targeted assistance to small businesses in underrepresented industries, specifically those businesses providing advanced and emerging technologies.

The Current State of Small Business in the Industrial Base

The Small Business Act has long recognized that small business participation in federal procurement is of crucial importance, requiring that small businesses “shall receive any award or contract if” the award is, in the determination of the SBA and contracting agency, “in the interest of (A) maintaining or mobilizing the full productive capacity of the United States; (B) war or national defense programs; or (C) assuring that a fair proportion of total purchase or contracts for goods and services of the Government in each industry category . . . are awarded to small business concerns” (15 USC 644(a)).

To that end, Congress established prime and subcontracting goals for small business utilization. Since 1997, the Small Business Act has mandated a governmentwide goal of awarding at least “23% of the total value of all prime contract awards for each fiscal year” (15 USC 644(g)(1)(A)(i)). As part of the National Defense Authorization Act (NDAA) for FY



2016, this provision was amended to add the requirement that “[i]n meeting this goal, the Government shall ensure the participation of small business concerns from a wide variety of industries and from a broad spectrum of small business concerns within each industry.” The goaling provisions were concurrently amended to require that the annual goaling report include: “(C) The number of small business concerns, small business concerns owned and controlled by service-disabled veterans, qualified HUBZone small business concerns, small business concerns owned and controlled by socially and economically disadvantaged individuals, and small business concerns owned and controlled by women awarded prime contracts in each [NAICS] code during the fiscal year and a comparison to the number of awarded contracts during the prior fiscal year, if available.”

If success is measured by sheer dollars awarded to small businesses, this program has been a success. According to the Federal Procurement Data System (FPDS), in every year since 2000, the government has awarded at least 21% of prime contracts to small businesses. Since 2013, the lowest percentage awarded to small businesses was 23.39%, and in the past five years a minimum of 25% of prime contracts were awarded to small businesses. However, SBA has not published the required data on the number of companies winning contracts nor the distribution amongst NAICS codes.

Within the Department of Defense (DoD), the dollars to small business paint a similar picture: in each of the past six fiscal years, the DoD has exceeded the 23% goal, often topping even 25%. Yet the number of entities winning contracts at the DoD has dropped significantly. According to SBA’s Small Business Data Hub, in 2009 there were 73,409 unique companies winning work with the Department, and 60,042 of those were small businesses. In FY 2022, the total number of businesses had dropped to 37,896 and the number of small businesses had fallen to 29,991. This makes the industrial diversification of these businesses increasingly important.

According to the standard FPDS Total Actions by NAICS report, in FY 2023 the DoD spent about \$456 billion through prime contracts.¹ Of this, \$91.7 billion, or 20.1%, was awarded to small businesses. This spending occurred across 980 distinct NAICS codes. As illustrated in Table 1, small businesses dominate the base in a substantial number of these industries. In 322 NAICS, small businesses received more than 80% of prime contract dollars awarded by the DoD, accounting for nearly \$11.4 billion of the DoD’s small business spend. In 160 of these NAICS, all spending was with small businesses. In 662 NAICS—about two thirds of the industries where the DoD makes purchases—small businesses received at least 23% of the dollars. While these 662 industries account for just under 42% of the DoD’s total outlays, they account for nearly 82% of its small business spending. Small businesses received only between 10% and 23% of spending in 94 NAICS and between 5% and 10% of spending in 38 NAICS. However, there were 169 NAICS where small businesses received less than 5% of all DoD spending, even though these NAICS accounted for \$153 billion, or over a third of the DoD’s total spend for the year. In 125 NAICS, small businesses received less than 1% of dollars.

¹When the FPDS goaling rules were applied, this number dropped to \$362 billion in small business eligible spend, and \$91.2 billion in actual spend, for a result of 25.18% to small business. However, for purposes of this analysis the more inclusive set of contracts is used.



Table 1. Distribution of Small Business Spending Across NAICS in FY 2023 DoD Spending

	# of NAICS	\$ Spent in Subject NAICS	SB Spend in Subject NAICS	% of All DoD Spend	% of SB Spend
Small business received more than 80% of dollars	311	\$12.0 b	\$11.4 b	2.6%	12.4%
Small business received between 60% and 80% of dollars	127	\$10.0 b	\$7.1 b	2.2%	7.8%
Small business received between 40% and 60% of dollars	125	\$54.2 b	\$25.9 b	11.9%	28.2%
Small business received between 23% and 40% of dollars	99	\$114.9 b	\$30.6 b	25.2%	33.3%
Small business received between 10% and 23% of dollars	94	\$71.9 b	\$11.7 b	15.8%	12.7%
Small business received between 5% and 10% of dollars	38	\$39.8 b	\$2.9 b	8.7%	3.2%
Small business received less than 5% of dollars	169	\$153.0 b	\$2.2 b	33.6%	2.4%

Source: FPDS

While this distribution raises questions, it is more important to look at how small businesses are faring in industries most important to the Department. The DoD's FY 2021 Industrial Capabilities Report to Congress (2021 ICR) identified sector challenges around kinetic capabilities, energy storage and batteries, castings and forgings, and microelectronics. It also highlights challenges for aviation, biomanufacturing, ground system electrification, and the submarine industrial base. However, it is often difficult to map these sectors to specific NAICS. For example, the ICR specifies that for energy storage and batteries, they are focusing on "high-capacity batteries, with a particular focus on lithium batteries." Batteries actually have a series of NAICS devoted to them—NAICS 335910, 335911, and 335912 cover battery manufacturing, storage battery manufacturing, and primary battery manufacturing. The challenges presented in the ICR suggest that it is also necessary to include NAICS 212290, other metal ore mining and NAICS 212390, lithium mineral mining. Lithium compound manufacturing is in NAICS 325180, other basic inorganic chemical manufacturing. All of these receive awards recorded in FPDS, but the last three include items that may not meet the needs of this sector. Likewise, NAICS 335999 includes semiconductor and other battery charging manufacturers, but it also includes the manufacture of bells and gongs. This makes it difficult to identify these segments of the industrial base using FPDS.

Instead, I analyzed the top 10 NAICS codes by dollars at the DoD, and the top 10 NAICS codes for small businesses at the DoD. As shown in Table 2, this yielded 17 industries, of which 10 implicated at least one of the ICR Sectors. Of the seven industries not included in the ICR, five were among the top 10 NAICS for small businesses but not in the top 10 for overall DoD spending. Of the two remaining NAICS that did not implicate an ICR sector, one was health insurance, and the other was commercial construction. The top 10 NAICS accounted for 56% of all DoD contract dollars last year, with just under 6.6% going to small businesses. When only looking at the top 10 NAICS that supported an ICR sector, those numbers fall to 48% and 4.6% respectively.



Table 2. NAICS Codes Accounting for the Greatest Spend at DoD in FY 2023

NAICS Code (Description)	Rank By Total Dollars at DoD	Rank By SB Dollars at DoD	Total Dollars	Small Business Dollars	% Small Business Dollars	ICR Sector
336411 (Aircraft Manufacturing)	1	23	\$59.9 b	\$0.7 b	1.25%	Aviation
541330 (Engineering Services)	2	2	\$37.1 b	\$8.8 b	23.69%	Multiple
541715 (Research and Development, Physical, Engineering & Life Sciences (Except Nanotechnology and Biotechnology))	3	3	\$28.7 b	\$6.8 b	23.69%	Multiple
336611 (Ship Building & Repairing)	4	13	\$25.5 b	\$1.8 b	7.21%	Multiple
336414 (Guided Missile & Space Vehicle Manufacturing)	5	118	\$23.1 b	\$0.08 b	0.35%	Multiple
236220 (Commercial & Institutional Building Construction)	6	1	\$21.7 b	\$9.0 b	41.58%	none
334511 (Search, Detection, Navigation, Guidance, Aeronautical, & Nautical System & Instrument Manufacturing)	7	25	\$16.4 b	\$0.7 b	4.29%	Multiple
336413 (Other Aircraft Parts & Auxiliary Equipment Manufacturing)	8	12	\$15.9 b	\$1.9 b	12.11%	Multiple
524114 (Direct Health & Medical Insurance Carriers)	9	707	\$14.1 b	\$0.0001 b	0.0009%	none
336412 (Aircraft Engine & Engine Parts Manufacturing)	10	91	\$13.6 b	\$0.1 b	0.83%	Multiple
324110 (Petroleum Refineries)	11	10	\$11.9 b	\$2.3 b	19.11%	none
561210 (Facilities Support Services)	12	8	\$10.7 b	\$2.7 b	25.22%	none
541519 (Other Computer Related Services)	13	4	\$8.5 b	\$5.1 b	59.68%	none
237990 (Other Heavy & Civil Engineering Construction)	15	9	\$8.0 b	\$2.3 b	29.1%	Multiple
541712 Research and Development, Physical, Engineering & Life Sciences (Except Biotechnology))	18	7	\$7.4 b	\$2.8 b	38.33%	Multiple
339999 (All Other Miscellaneous Manufacturing) ²	23	5	\$3.7 b	\$3.5 b	93.49%	none
423850 (Service Establishment Equipment and Supplies Merchant Wholesalers)	26	6	\$3.1 b	\$3.1 b	99.99%	none

Source: FPDS

All small businesses spending in non-ICR categories detailed in Table 2 account for 28% of all the dollars the DoD spent with small businesses that year. This should not suggest that there isn't value in having small construction contractors or facility support services providers. Rather, it is to raise the question of whether such a substantial portion of

² According to NAICS.com, this includes the manufacturing of amusement machines, artificial flower arrangements, atomizers, beach umbrellas, bone novelties, candles, non-orthopedic canes, Christmas trees and ornaments, cigarette holders, lighters, and lighter flints, coin- or card-operated amusement machines (except jukeboxes), decalcomania work (except on china, glass), electronic cigarettes, feather dusters, feathers for use in apparel and textile products, fire extinguishers, artificial flowers, fly swatters, frames, mirror and picture, artificial fruits, garden umbrellas, globes, hair nets, hairpieces, hat blocks, mannequins, marionettes, anatomical models, music boxes, novelties, parasols, shoe patterns, pinball machines, pipe cleaners, potpourri, puppets, sewing and mending kits, shell novelties, slot machines, theatrical scenery, tinsel, tobacco pipes, toupees, artificial trees, wreaths, and plants, and wax figures.

the DoD's small business spending should be in areas where the small business is passing through items. Indeed, in just these NAICS codes, \$8.2 billion was spent where the small business is the wholesaler/distributor.

Table 3. NAICS Codes Accounting for the Greatest Spend at DoD in FY 2013

NAICS Code (Description)	Rank By Total Dollars at DoD	Rank By SB Dollars at DoD	Total Dollars	Small Business Dollars	% Small Business Dollars
336411 (Aircraft Manufacturing)	1	11	\$46.0 b	\$0.9 b	1.93%
541330 (Engineering Services)	2	3	\$25.0 b	\$3.8 b	15.17%
336611 (Ship Building & Repairing)	3	13	\$15.4 b	\$0.8 b	5.26%
541712 (Research and Development, Physical, Engineering & Life Sciences (Except Biotechnology))	4	2	\$15.4 b	\$4.1 b	26.48%
561210 (Facilities Support Services)	5	5	\$11.3 b	\$1.8 b	15.88%
336413 (Other Aircraft Parts & Auxiliary Equipment Manufacturing)	6	8	\$10.8 b	\$1.1 b	10.47%
324110 (Petroleum Refineries)	7	6	\$10.6 b	\$1.5 b	14.52%
336414 (Guided Missile & Space Vehicle Manufacturing)	8	479	\$10.6 b	\$2.5 b	0.02%
236220 (Commercial & Institutional Building Construction)	9	1	\$10.5 b	\$4.6 b	43.84%
524114 (Direct Health & Medical Insurance Carriers)	10	942	\$9.7 b	\$8.6 b	0.00%
541519 (Other Computer Related Services)	13	4	\$5.2 b	\$1.9 b	37.10%
237990 (Other Heavy & Civil Engineering Construction)	15	7	\$4.4 b	\$1.2 b	26.67%
541512 (Computer Systems Design Services)	19	9	\$3.5 b	\$1.0 b	30.84%
562910 (Remediation Services)	31	10	\$2.0 b	\$1.0 b	53.02%

Source: FPDS

While the 2023 numbers certainly suggest challenges with where the DoD spends with small businesses, it is worth looking at them on as part of a trend. In FY 2013, the Department spent \$309.3 billion, including \$49.3 billion with small businesses. First, this means that the dollars awarded to small business have substantially increased, both by absolute amounts and by percentages in the past 10 years. Actual dollars to small businesses increased by over \$40 billion. In 2013, small businesses received only 6% of the spend in the top 10 NAICS, while last year it was 6.5%. Additionally, the small business share of the top 10 NAICS has grown—in FY 2013 small firms received 15.9% of prime contract dollars, as opposed to 20.1% last year.

However, funding is now further concentrated in a few NAICS—in 2013, half of all DoD spending took place in 10 industries categories, while last year it was over 56%. About 45% of all small business spending occurred in 10 NAICS in 2013, while in 2023 it was 50.6%. In 2013, aircraft manufacturing—a top ICR category—was the top NAICS by dollar for all businesses, and the eleventh for small businesses. By 2023, while it remained the top overall spending category and grew by about \$14 billion, it had fallen to the 23rd most valuable NAICS for small firms, and small firm spending had dropped by about \$200 million. Additionally, in 2013 the top 10 small business industries did not include any wholesalers or manufacturers of miscellaneous items, suggesting that the 2013 spending had more actual small business production.



While dollars are an important measure of the base, another important factor is the number of firms. In FY 2013, there were 73,422 unique vendors doing business with the DoD, and 24,294 of those were small businesses. By 2023, the total had dropped to 48,352 firms including 15,668 small businesses.

Table 4. Total Number of Businesses and Small Businesses by NAICS

NAICS Code (Description)	Total Number of Firms 2013	Total Number of SB 2013	Total Number of Firms 2023	Total Number of SB 2023
336411 (Aircraft Manufacturing)	664	494	759	556
541330 (Engineering Services)	2257	1439	4269	2999
541715 (Research and Development, Physical, Engineering & Life Sciences (Except Nanotechnology and Biotechnology))	1827	1390	3841	2939
336611 (Ship Building & Repairing)	521	401	800	491
336414 (Guided Missile & Space Vehicle Manufacturing)	47	8	62	10
236220 (Commercial & Institutional Building Construction)	2069	1807	2220	1669
334511 (Search, Detection, Navigation, Guidance, Aeronautical, & Nautical System & Instrument Manufacturing)	1286	840	1333	808
336413 (Other Aircraft Parts & Auxiliary Equipment Manufacturing)	2372	1904	2330	1539
524114 (Direct Health & Medical Insurance Carriers)	1	0	17	1
336412 (Aircraft Engine & Engine Parts Manufacturing)	688	507	702	451
324110 (Petroleum Refineries)	312	246	546	303
561210 (Facilities Support Services)	892	722	955	664
541519 (Other Computer Related Services)	1437	1069	1434	965
237990 (Other Heavy & Civil Engineering Construction)	725	581	625	441
541712 Research and Development, Physical, Engineering & Life Sciences (Except Biotechnology))	2759	2027	496	286
339999 (All Other Miscellaneous Manufacturing)	901	734	522	647
423850 (Service Establishment Equipment and Supplies Merchant Wholesalers)	26	22	16	12

Source: SBA Small Business Data Hub and FPDS

As Table 4 illustrates, in FY 2013 small businesses accounted for 75% of the firms winning awards in the top NAICS codes, but by FY 2023 that number had dropped to 70% of these 10 industries. However, the total number of firms grew by 4,601 overall and 2,673 small businesses in these top NAICS. The vast majority of the growth occurred in the top four NAICS—Aircraft Manufacturing, Engineering Services, Research and Development, Physical, Engineering & Life Sciences (Except Nanotechnology and Biotechnology), and Ship Building & Repairing. These four industries alone added 4,400 firms, including 3,261 small businesses. However, this also reflects that in 10 of the 17 industries, including some of the largest for small businesses, small businesses lost firms.

For the NAICS supporting the ICR challenges, the report acknowledges the need to better engage small businesses, and offers five recommendations. These are: (1) increasing access to the defense marketplace, using the Office of Small Business Programs and Procurement technical assistance centers; (2) implementing a more unified management

structure and resourcing for the DoD's small business programs; (3) updating and executing the Department's small business strategy to identify barriers to entry; (4) measuring and scaling the effect of current DoD programs such as mentor protégé and SBIR; and (5) increase small business participation by addressing credits under category management and developing market intelligence tools.

While all of these have merit, they ignore that in 2023 a substantial portion of small business dollars were going to industries where small businesses received the vast majority of the work. If we analyze broader industry categories such as a three-digit NAICS and then exclude areas where the DoD spends less than \$10 million annually or where small businesses receive less than 50% of prime contract dollars, it leaves 23 industry categories. If we further exclude hospitals, accommodation, and real estate, which are location driven, it takes us to 20 industry categories in Table 5.

Table 5. Three Digit NAICS with More Than \$10 Million in FY 2023 DoD Spend and Greater Than 50% of Dollars to Small Businesses

Industry Category	Sum of Total Dollars	Sum of SB Dollars	% SB
115 (SUPPORT ACTIVITIES FOR AGRICULTURE AND FORESTRY)	\$21,182,624	\$20,698,892	98%
211 (OIL AND GAS EXTRACTION)	\$26,069,210	\$17,026,143	65%
212 (MINING (EXCEPT OIL AND GAS))	\$66,285,506	\$59,817,553	90%
238 (SPECIALTY TRADE CONTRACTORS)	\$2,864,967,393	\$1,530,956,708	53%
315 (APPAREL MANUFACTURING)	\$1,402,801,686	\$714,597,927	51%
316 (LEATHER AND ALLIED PRODUCT MANUFACTURING)	\$127,022,844	\$106,558,004	84%
321 (WOOD PRODUCT MANUFACTURING)	\$86,530,114	\$63,856,955	74%
327 (NONMETALLIC MINERAL PRODUCT MANUFACTURING)	\$93,053,746	\$80,997,837	87%
331 (PRIMARY METAL MANUFACTURING)	\$141,946,826	\$109,099,299	77%
337 (FURNITURE AND RELATED PRODUCT MANUFACTURING)	\$468,161,084	\$351,077,075	75%
339 (MISCELLANEOUS MANUFACTURING)	\$4,085,519,908	\$3,749,623,536	92%
423 (MERCHANT WHOLESALERS, DURABLE GOODS)	\$5,354,929,245	\$3,825,319,459	71%
443 (ELECTRONICS AND APPLIANCE STORES)	\$180,084,767	\$107,899,686	60%
444 (BUILDING MATERIAL AND GARDEN EQUIPMENT AND SUPPLIES DEALERS)	\$12,695,530	\$7,948,717	63%
512 (MOTION PICTURE AND SOUND RECORDING INDUSTRIES)	\$27,996,855	\$20,758,357	74%
523 (SECURITIES, COMMODITY CONTRACTS, AND OTHER FINANCIAL INVESTMENTS AND RELATED ACTIVITIES)	\$15,914,861	\$16,038,353	101%
562 (WASTE MANAGEMENT AND REMEDIATION SERVICES)	\$3,490,167,195	\$1,914,900,216	55%
624 (SOCIAL ASSISTANCE)	\$91,032,183	\$85,712,466	94%
712 (MUSEUMS, HISTORICAL SITES, AND SIMILAR INSTITUTIONS)	\$19,185,788	\$11,158,102	58%
713 (AMUSEMENT, GAMBLING, AND RECREATION INDUSTRIES)	\$19,036,212	\$12,058,809	63%

Source: FPDS

At first glance, the high number of manufacturing sectors suggests that small businesses are active in the manufacturing industry. Under the non-manufacturer rule found at 13 CFR 121.406, small businesses must either manufacture a product itself or deliver the product of another small business. However, an exception to this exists if SBA deems that there is no domestic small business manufacturing the product, in which case the small business may provide a product produced by another manufacturer. Unfortunately, FPDS



does not allow for an easy way of querying whether items purchased in the above referenced industries were subject to waivers.

Interestingly, 13 CFR 201 states that NAICS groups 423, 443, and 444 “shall not be used to classify Government acquisitions for supplies. They also shall not be used by Federal Government contractors when subcontracting for the acquisition for supplies. The applicable manufacturing NAICS code shall be used to classify acquisitions for supplies. A Wholesale Trade or Retail Trade business concern submitting an offer or a quote on a supply acquisition is categorized as a nonmanufacturer and deemed small if it has 500 or fewer employees and meets the requirements of the nonmanufacturer rule.” This raises substantial questions about how approximately \$5.5 billion in purchases were classified under NAICS codes that weren’t permitted under the SBA’s rules, especially with small businesses winning over 60% of these dollars. In any case, it is clear that within industry sectors, the prime contractors are passing through products rather than producing the items, adding little more than distribution capacity to the industrial base.

In the past, Congress sought to take sectors where small businesses were winning the majority of dollars and redirect some portion of that spend to industries where small businesses were underperforming. In 1988, Congress found that previous Congressional reforms intended to “implement the mandate for small business participation in a fair proportion of Federal Procurements” as required by section 15 of the Small Business Act had resulted in:

- (A) a concentration of procurement contract awards in a limited number of industry categories, often dominated by small business concerns, through the use of set-asides, for the purpose of assuring the attainment of the agency’s overall small business contracting goals; and
- (B) inadequate efforts to expand small business participation in agency procurements of products or services which have historically demonstrated low rates of small business participation despite substantial potential for expanded small business participation. (Comp Demo Act at § 702)

Consequently, Congress enacted the Comp Demo program. Under the direction of the Office of Federal Procurement Policy (OFPP), the SBA was supposed to test whether small businesses in certain industries could successfully compete for prime contracts without relying on small business set asides, although other types of socio-economic set asides and sole source awards such as 8(a) contracts were still permitted. At the time, the small business prime contracting goal was 20%, but Comp Demo established a 40% small business goal in four “Designated Industry Groups” (DIGs) industries: (1) construction (excluding dredging); (2) refuse systems and related services; (3) architectural and engineering services (including surveying and mapping) (A&E); and (4) non-nuclear ship repair (Comp Demo Act at § 717).³ For these industries, small businesses were to compete

³ Construction was originally defined as (1) Major Group 15 (Building Construction—General Contractors and Operative Builders), (2) Major Group 16 (Construction Other Than Building Construction—General Contractors and Dredging), and (3) Major Group 17 (Construction—Special Trade Contractors). Refuse was defined as standard industrial classification codes 4212 or 4953. A&E was defined as standard industrial classification code 7389 (if identified as pertaining to mapping services), 8711, 8712, or 8713. The law further created a segmentation of the shipbuilding and ship repair industries into: (1) nuclear shipbuilding and repair; (2) non-nuclear shipbuilding; and (3) non-nuclear ship repair, which shall be further segmented by, at least, East Coast and West Coast facilities. By 2009, the Federal Acquisition Regulation had assigned the following codes to these industries: Construction, except dredging, included NAICS Codes 236115, 236116, 236117, 236118, 236210, and 236220; Heaving and Civil Engineering Construction included NAICS 237110, 237120, 237130, 237210, 237310, and 237990; Specialty Trade Contractors included NAICS 238110, 238120, 238140, 237150.



without small business set asides at the DoD and nine other agencies.⁴ The law provided that if the annual dollars going to small businesses in those industries fell to 40% within that agency, the agency should reimplement set asides for components failing to meet the 40% goal.⁵ Each of these agencies were also supposed to identify targeted sectors where that individual agency would make an effort to increase small business participation. While originally designed as a three-year pilot program, Comp Demo was reauthorized in 1992, 1996, 1997, and then made permanent at the end of 1997 (1997 Emergency Supplemental Appropriations Act; Omnibus Consolidated Appropriations Act for 1997; Small Business Credit and Business Opportunity Enhancement Act of 1992; Small Business Reauthorization Act of 1997). While technical corrections and changes to reporting cadences were made throughout the years, the only major change came in 2004 when landscaping and pest control services were added to the list of DIGs (NDAA for FY 2004).

In 2005, an effort was made to restrict the use of Comp Demo within the DoD. When considering the FY 2006 appropriations bill, Representative Nydia Velázquez offered an amendment prohibiting the use of appropriated funds to implement Comp Demo (Congressional Record for June 20, 2005). While the amendment failed, the rationale presented Rep. Velázquez is important given that she has served as either the Chair or Ranking Member of the House Small Business Committee since 1997. Noting that as of 2005, the federal government had failed to meet its 23% small business goal for the prior four years, the Congresswoman reasoned that this meant small businesses had lost out on \$15 billion in contracts. Further, she reasoned that if the DoD had been allowed to set aside work in the “industries where small businesses excel” then the DoD could have awarded an additional \$4.3 billion to small firms. In support of her argument, she pointed to a request by the DoD to “eliminate the [CompDemo] program altogether in the DoD’s legislative package for 2006.” However, the Department’s request does not cite any challenges meeting the small business goals, but instead states that “[t]he re-establishment of small business set-aside procedures will encourage small business concerns to participate in DoD prime contracting requirements.” Indeed, the request states that the experience “gained by small business in the prime contracting arena generally supports those small businesses in their efforts to become subcontractors,” suggesting that the true goal is not more small business primes in these industries. Finally, the request states that there would be administrative advantages to repealing Comp Demo, noting that it would “streamline and simplify DoD contract data collection and reporting requirements and reduce the administrative effort necessary” to comply with Small Business Act.

While only Congresswoman Velázquez spoke in favor of the amendment, it was opposed during debate by three Republican members of leadership: Bill Young, Chairman of the House Appropriations Committee; Tom Davis, Chairman of the Committee on Government Reform and Oversight; Don Manzullo, Chairman of the House Small Business Committee. Rep. Danny Davis, a Democratic member of the House Small Business Committee, also spoke in opposition. While Mr. Young’s objections were procedural, the other members offered substantive defenses of the program. Chairman Davis argued that reinstating set asides in industries where “they are going to win anyway” would keep small

⁴ These included the Departments of Agriculture (USDA), Energy, Health and Human Services (HHS), Interior, Transportation, and Veterans Affairs (VA) as well as the General Services Administration (GSA), Environmental Protection Agency (EPA), and National Aeronautics and Space Administration (NASA).

⁵ The Comp Demo Act directed that no more than 50% of clothing and textile purchases were to be set aside, and that the small business goals for prime and subcontracts for dredging services were to increase to 30% by 1992, with 10% of total dollars to “emerging small businesses” (§ 721–722). These emerging small businesses were defined as “a small business concern whose size is no greater than 50% of the numerical size standard applicable to the standard industrial classification code assigned to a contracting opportunity.” No reliable data is available for the emerging small businesses nor the textile provisions.



businesses from penetrating other parts of the federal market. Chairman Manzullo pointed out that the Small Business Act required that small businesses receive a fair proportion of government contracts in each industry rather than just a few, and stated that prior to Comp Demo, “small businesses were relegated to industries dominated by small businesses” where “Federal agencies could say they met their overall small business goals while not doing much to provide more contracts to small businesses in more higher-end, higher-paying industries” (Congressional Record for June 20, 2005).

While Comp Demo survived in 2005, it was quietly repealed by the Small Business Jobs Act of 2010. The Committee report for the underlying bill—H.R. 5297—fails to mention the Comp Demo program in any way. A related Senate bill, S. 2989, the Small Business Contracting Revitalization Act of 2010, sought to repeal the provision. In conference, this repeal was adopted. However, the report accompanying S. 2989 only states “the Committee believes that it is time to end the [Comp Demo] Program. Accordingly, this legislation repeals this program” (Report Accompanying S. 2989). After reviewing Congressional hearing transcripts from the same period, the only negative reference to Comp Demo is from a roundtable held by the Senate Small Business and Entrepreneurship Committee, where an SBA official suggests repealing the program but provides no context (Roundtable). In the House, despite holding 75 hearings during the 110th Congress, the only transcript to mention Comp Demo spoke positively about the program (*Small business participation*). However, the DoD-proposed NDAA language again suggested repeal, providing the only analysis. In addition to the prior arguments about administrative savings for the Department, this time the proposal suggested that “in an acquisition environment that is dominated by large businesses, it is counterproductive to eliminate any potential advantage for small business”(DoD, 2010).

Based on this argument, one would expect to see the small business share of each DIG drop after implementation of Comp Demo, and then increase again after the repeal of the program. However, this is not always the case—as the data below will show, the DoD almost always performed worse in these NAICS in the five years after the repeal of Comp Demo. Unfortunately, Comp Demo data is very sparse prior to the transition from the Federal Procurement Data Center (FPDC) to the FPDS in FY 2004. While FPDS does provide Comp Demo reports from 1989, the data in these reports is not reliable.⁶ Prior to 2004, the best data is from a 1992 hearing before the Senate Committee on Small Business, the transcript of which includes Comp Demo results for calendar year 1991. As this data was released at the same time agencies were beginning to implement the 1988 law, it serves as an imperfect baseline (S. Hrg 102-1055).

The Effects of Comp Demo

To examine the effects of Comp Demo on the designated industry groups, this paper looked first at how small businesses fared overall under Comp Demo versus after its repeal. It then looks at the performance of small businesses at the 10 covered agencies during those periods. Next, it looks at more granular elements of performance for each DIG at the covered agencies, comparing performance in each of the original DIGs in 1991, FY 2009,⁷ FY 2015, and FY 2023. As there are more complete records around Landscaping and Pest Control Services, those results are analyzed from FY 2003 through FY 2010, and in FY 2015 and FY 2023. In each DIG, the questions posed for each agency are whether small

⁶ For example, for FY1992–FY2003, FPDS has two Comp Demo records from USDA, 10 from VA, and 27 from DOT. While FPDS reports that the DoD had 3,995 actions in that period, that would suggest that only about 330 transactions occurred each year.

⁷ While the legislation repealing the program was signed by President Obama on September 27, 2010, the FAR was updated on December 30, 2010, effective January 31, 2011.



businesses received a greater proportion of work: (1) in the baseline year than in the last year of Comp Demo; and (2) post repeal of Comp Demo than in the last full year of the program; and (3) how small businesses are faring in those DIGs today.

The State of Small Business Under Comp Demo and Post Repeal

First, the general question must be asked as to whether small businesses writ large did better under Comp Demo or after its repeal. Unfortunately, government contracts records from before 2004 are not uniformly available, because they were manually input and kept by the FPDC. According to the Government Accountability Office (GAO), its analysis of FPDC data “shows that small businesses have received between 25% and 28% of [prime contract dollars] between fiscal years 1993 and 1999” (GAO, 2001a). This would be supported by Congress’ decision to raise the small business prime contract goal from 20% to 23% in 1997 (Small Business Reauthorization Act of 1997). A later GAO report established that in 2000, 22.26% of prime contract dollars were awarded to small business (GAO, 2001b). Finally, an article in the *Journal of Public Procurement* reports that in FY 2002, “small businesses were awarded 22.62% of direct federal contracts” which “amounted to \$53.6 billion being awarded to small businesses.” Further, it noted that in “FY 2003, federal agencies exceeded the 23% small business contracting goal by awarding 23.6%, or \$65.5 billion, of federal contracting dollars to small businesses.” So while granular data is not available from the 1988 start of Comp Demo, small businesses were receiving at least 20% of prime contracts prior to 1997. FPDS data shows that during the last five years of Comp Demo, small businesses received between 20.5% and 23.4% of all prime contract dollars.

In the five years after the program’s repeal, small businesses received between 21.6% and 25.7% of dollars, suggesting that repeal helped the federal government do more with small businesses. However, it is worth noting that between 2005 and 2010, dollars to small businesses increased by nearly \$23 billion, whereas between 2011 and 2015 they fell by almost \$766 million.⁸ Therefore, it unclear whether the repeal of Comp Demo resulted in more opportunities for small businesses, or if agencies had simply not figured out how to adjust to the rapid increase in spending during the part of the Global War on Terror, but were able to better allocate opportunities to small businesses once the spending patterns were better established.

When we look at mean and median percentages of dollars awarded to small businesses under Comp Demo and after its repeal, no clear pattern emerges. Energy, Interior and EPA all saw declines in their small business percentages, with Interior’s small business share declining by over 30%. GSA, Transportation, and HHS did substantially better post-Comp Demo. The remaining agencies saw minor fluctuations in their results, as illustrated in Table 6.

Table 6. Average Percentage Awarded to Small Businesses by Subject Agencies During and Post Comp Demo

	FY05–10 Mean % to Small Business	FY05–10 Median % to Small Business	FY11–16 Mean % to Small Business	FY11–16 Median % to Small Business	Change to Mean % Post Comp Demo	Change to Median % Post Comp Demo
USDA	52.68%	53.20%	53.29%	53.38%	0.61%	0.18%
DoD	19.64%	20.02%	21.88%	21.84%	2.24%	1.82%
Energy	5.86%	6.02%	5.40%	5.36%	-0.46%	-0.65%

⁸ In contrast, from 2017 until 2022, small business contracting increased by over \$48 billion, while consistently exceeding a 25% share.



HHS	22.76%	21.54%	37.97%	38.46%	15.21%	16.92%
Interior	53.64%	53.81%	22.89%	23.07%	-30.75%	-30.74%
Transportation	40.49%	40.07%	46.00%	45.00%	5.51%	4.93%
VA	31.30%	32.32%	33.52%	34.25%	2.22%	1.93%
EPA	39.55%	41.94%	41.42%	40.80%	1.87%	-1.14%
GSA	31.52%	31.89%	56.82%	56.62%	25.30%	24.73%
NASA	15.77%	15.61%	18.41%	17.95%	2.65%	2.34%

Source: FPDS

The State of the DIGS Under Comp Demo and Post Repeal

Small Business Performance in Construction

After looking at small business performance at each subject agency, it is necessary to further explore small business performance in each of the DIGs. Table 7 begins by looking at the three construction related DIGS.

Table 7. Percentage of Dollars Awarded to Small Business in Each Construction DIG

	Construction of Buildings				Heavy and Civil Engineering Construction				Specialty Trade Contractors			
	CY 91	FY 09	FY 15	FY 23	CY 91	FY 09	FY 15	FY 23	CY 91	FY 09	FY 15	FY 23
USDA	100	84	94	93	97	96	98	87	99	93	85	95
Defense	64	53	45	41	57	53	11	31	81	53	50	80
Energy	86	10	100	92	60	94	55	80	86	95	98	88
HHS	47	41	63	59	57	99	91	100	68	93	71	93
Interior	80	65	50	81	57	74	76	46	85	92	84	68
Transportation	56	27	80	67	67	46	69	54	83	92	96	57
VA	13	74	84	92	92	80	74	99	90	96	84	93
EPA	93	100	97	100	100	100	0	100	74	99	99	57
GSA	13	20	43	52	96	95	61	71	63	72	83	69
NASA	42	57	52	97	28	97	90	99	71	57	71	60

Source: CY 1991 Data from Senate Small Business Committee Hearing; All other data from FPDS.

As seen in Table 7, the Construction DIG was divided into three clear categories: construction of buildings, heavy and civil engineering construction, and the specialty trade contractors. For the construction of buildings, small businesses fared better at 60% of the agencies in 1991 than they did under Comp Demo in 2009. After Comp Demo was repealed, 70% of agencies saw an increase from 2009 to 2015, and 50% did better last year than in FY 2009. Overall, at 80% of agencies, small businesses are receiving a higher percentage of awards for construction of buildings than they did in 1991. The USDA and DoD are the two outliers, but at the USDA small businesses received all prime contracts in 1991, but only 93% last year. However, the DoD has seen awards to small business decline in each period, dropping from 64% in 1991 to 53% in 2009, then to 45% in 2015, and now to 41%.

For awards in heavy and civil engineering construction, small businesses fared better at 60% of the agencies in 1991 than they did under Comp Demo in 2009. However, only three agencies improved their small business performance from 2009 to 2015, and 60% of



agencies performed better in 1991 than they did last year. The DoD, Energy, EPA, and GSA each awarded a higher percentage of heavy and civil engineering dollars to small businesses under Comp Demo than they did in 2009 or 2023.

Within the specialty construction trades, 70% of agencies awarded more to small businesses under Comp Demo than they did in 1991, but only half did better in 2009 than they did in 1991, and only 40% awarded a greater percentage to small businesses in 2023 than they did in 1991. When compared with their 2009 results, in 2015 only four agencies improved small business participation, and that number drops to three agencies by 2023.

However, the percentage of contracts going to small businesses in each DIG is not the only measure of the health of the small business industrial base. Even if small businesses were receiving all of the work in an industry, if the number of companies successfully competing for work was falling, it would signal that the sector was at risk. Therefore, this paper next examines what the effects of Comp Demo and its repeal were on the size of the small business industrial base in each DIG. It does so by looking at the number of small businesses winning awards at each covered agency in FY 2004 and comparing it to FY 2010.⁹ This tells us whether the number small businesses winning contracts increasing or decreasing under Comp Demo. Next, it compares FY 2004 and FY 2015, to examine whether more small businesses won awards after Comp Demo was repealed. Third, it compares FY 2004 with FY 2023, to see if there has been any change in the number of small businesses successfully competing in the past 20 years. Finally, it looks at the change in successful small business participation from FY 2010 to FY 2023.

Table 8. Change in the Number of Small Businesses Receiving Awards for the Construction of Buildings

	Construction of Buildings				
	FY04–FY10	FY04–FY15	FY04–FY23	FY10–FY15	FY10–FY23
USDA	135%	102%	98%	75%	73%
Defense	138%	114%	92%	83%	67%
Energy	133%	152%	133%	114%	100%
HHS	163%	218%	261%	134%	160%
Interior	112%	84%	102%	75%	91%
Transportation	1550%	1550%	2983%	100%	192%
VA	239%	186%	123%	78%	51%
EPA	525%	425%	425%	81%	81%
GSA	115%	102%	74%	89%	65%
NASA	135%	158%	153%	117%	113%
All Covered Agencies	142%	119%	100%	84%	71%

Source: FPDS

For the construction of buildings, the number of small businesses winning contracts increased at every agency between 2004 and 2010. Within all covered agencies there were about 42% more small businesses winning contracts by 2010 than there were in 2004. However, within five years of Comp Demo's repeal, six agencies saw a decline of 11% to 25% in the number of small firms winning contracts, with Interior declining to 84% of the number of firms participating in 2004. Within all the covered agencies, this was still nearly a 20% increase in the number of small businesses from 2015 over 2004, but a drop of 16% from 2010 to 2015. By 2023, six agencies had substantially fewer firms winning contracts than did in 2004, with VA falling to only 51% of the total number of successful small

⁹ While it would have been preferable to compare 1991 data with FY 2010 data, this data is not available.

businesses it had in 2004. Overall, there were the same number of small businesses winning contracts in 2023 as there were in 2004, but only because some agencies had enough growth to offset the loss of more than 700 prime contractors at the DoD.

Table 9. Change in the Number of Small Businesses Receiving Awards for Heavy and Civil Construction

Heavy and Civil Engineering Construction					
	FY04–FY10	FY04–FY15	FY04–FY23	FY10–FY15	FY10–FY23
USDA	202%	96%	96%	47%	47%
Defense	111%	86%	71%	78%	64%
Energy	65%	121%	79%	186%	123%
HHS	172%	246%	226%	143%	131%
Interior	135%	83%	65%	61%	48%
Transportation	296%	281%	293%	95%	99%
VA	486%	312%	269%	64%	55%
EPA	80%	20%	20%	25%	25%
GSA	157%	143%	34%	91%	22%
NASA	114%	90%	33%	79%	29%
All Covered Agencies	146%	98%	84%	67%	57%

Source: FPDS

Among contracts for heavy and civil engineering work, the number of small prime contractors increased by nearly 50% from 2004 to 2010. Three agencies doubled the size of their small business base, with Transportation nearly tripling the number of successful small firms participating and VA almost quintupling its small business base during this period. Energy and EPA were the only two agencies where the base declined under Comp Demo. Once the program was repealed, the total number of firms returned to 2004 levels. While Energy and HHS saw the number of firms increase between 2010 and 2015, this served to balance the losses experienced by all other agencies lost contractors. Notably, EPA fell to only one small business receiving a prime contract in 2015, a trend that continued in 2023. As of last year, the overall number of firms had fallen 16% since 2004, 43% since 2010. Transportation maintained the growth it saw in its small business base under Comp Demo through 2015 and 2023, while Energy and HHS saw slight improvements between 2010 and 2023. The latter two combined added a total of 25 companies to their small business base over 20 years. At the remaining seven agencies, small firms fared worse than they had in 2004, 2010, or 2015. Of note, the DoD lost more than 700 small prime contractors between 2010 and 2023.

Table 10. Change in the Number of Small Businesses Receiving Awards for Specialty Trade Contractors

Specialty Trade Contractors					
	FY04–FY10	FY04–FY15	FY04–FY23	FY10–FY15	FY10–FY23
USDA	367%	268%	192%	73%	52%
Defense	128%	90%	58%	70%	45%
Energy	93%	127%	60%	137%	65%
HHS	1386%	1879%	1486%	136%	107%
Interior	334%	249%	165%	74%	49%
Transportation	1146%	1008%	1221%	88%	107%
VA	714%	440%	392%	62%	55%
EPA	689%	178%	144%	26%	21%
GSA	170%	138%	44%	81%	26%
NASA	200%	158%	74%	79%	37%
All Covered Agencies	199%	145%	97%	73%	48%

Source: FPDS



Within the specialty trades, the number of small businesses nearly doubled from 2004 to 2010. Nine agencies saw significant growth in their small business industrial between 2004 and 2010—only Energy saw a decline of four firms. The DoD added nearly 1,400 small prime contractors during this period, which was the smallest growth rate by percentage (128%). Among the other agencies, growth rates were as high as nearly 1400%. When Comp Demo was repealed, eight agencies lost small business prime contractors, and the overall number of companies fell by more than 3,400 firms (27%). As with the Heavy and Civil DIG, only Energy and HHS saw any growth between 2010 and 2015; EPA lost 75% of its small prime contractors while losses at the other agencies range from 12% to 38%. As of last year, the total number of small firms across the designated agencies was about 220 firms less than in 2004, and about 6,500 less than in 2010.

Thus, when looking at the Construction DIGs, in general the percentage of dollars awarded to small firms increased when Comp Demo was repealed, but the number of small firms receiving awards fell. While there are some outliers, this suggests that under Comp Demo more small businesses chose to compete even though there were no set asides, but that many of those businesses exited these DIGs when Comp Demo was repealed.

Small Business Performance in Non-Nuclear Ship Repairs

Non-nuclear ship repairs especially relevant, since they also fall within a sector highlighted by the IRC for special focus. However, because the sector is so focused on the DoD, it is more difficult to extrapolate from civilian agency results.

Table 11. Percentage of Dollars Awarded to Small Businesses for Non-Nuclear Ship Repairs

Non-Nuclear Ship Repair				
	CY 1991	FY 2009	FY 2015	FY 2023
Defense	64	40	16	22
Interior	100	100	100	100
Transportation	92	92	63	0

Source: Source: CY 1991 Data from Senate Small Business Committee Hearing; All other data from FPDS.

As seen in Table 11, only the DoD, Interior, and Transportation have been active in this space. Interior has continued to award all its work to small business regardless of the Comp Demo program. Transportation awarded the same percentage of work to small businesses in 1991 and 2009, indicating that Comp Demo itself did not affect these awards. However, when Comp Demo was repealed, Transportation's spend with these companies fell to 63% in FY 2015, and in FY 2023 it awarded all its contracts to large firms. The DoD saw a substantial drop in awards to small business after the implementation of Comp Demo, but repealing Comp Demo triggered an improvement. Instead, the FY 2015 number was less than half the percentage awarded in FY 2009, and the FY 2023 results were still only 55% of the market share under Comp Demo.

Table 12. Change in the Number of Small Businesses Receiving Awards for Non-Nuclear Ship Repair

Non-Nuclear Ship Repair					
	FY04–FY10	FY04–FY15	FY04–FY23	FY10–FY15	FY10–FY23
Defense	47%	34%	50%	72%	106%
Interior	57%	14%	86%	25%	150%
Transportation	180%	340%	120%	189%	67%
All Covered Agencies	49%	38%	51%	78%	105%

Source: FPDS



The number of small firms active in the non-nuclear ship repair DIG dropped dramatically under Comp Demo, and never recovered. The DoD accounts for almost all of the firms in this space. In FY 2004, the DoD awarded contracts to 311 in this DIG, but by FY 2010 the number had fallen to only 145 firms. While it rebounded to 154 firms last year, this is a mere fraction of the 718 companies receiving prime contracts in 2005. While Interior and Transportation have far fewer small business primes in this DIG—each had only 6 last year—Interior has begun to add new firms since 2010. Transportation grew under Comp Demo only to decline since 2015.

Given that both the percentage of dollars and numbers of firms dropped for the DoD under Comp Demo, this should be treated as a cautionary tale. While correlation is not causation, the ongoing challenges for market share and new entrants suggests that applying Comp Demo to an industry critical to the industrial base did not provide agencies with enough flexibility to nurture this critical industry.

Small Business Performance in A&E Contracting

Table 13. Percentage of Dollars Awarded to Small Businesses for A&E Contracting

Architectural and Engineering Services (Including Surveying and Mapping)				
	CY 1991	FY 2009	FY 2015	FY 2023
USDA	99	33	41	95
Defense	35	29	27	22
Energy	2	20	4%	88
HHS	28	93	66	14
Interior	55	23	32	31
Transportation	44	13	45	33
Veterans Affairs	82	41	59	100
EPA	6	78	75	25
GSA	43	28	47	37
NASA	17	28	45	33

Source: Source: CY 1991 Data from Senate Small Business Committee Hearing; All other data from FPDS.

Table 13 shows how small businesses fared in the case of A&E contracts. From 1991 to 2009, 60% of agencies reduced the percentage of A&E contracts awarded to small businesses. However, there were dramatic increases during this period—at the EPA small businesses grew from 6% to 78%, HHS increased by 65% points, and at Energy the small business share was 10 times higher under Comp Demo than it was previously. Post repeal, six of the 10 agencies saw an increase in small business share by 2015, which grew to seven agencies by 2023. Unfortunately, only four agencies were doing better in 2023 than they were in 1991. Of the agencies that declined after the repeal of Comp Demo, EPA had dropped back to 25% last year, HHS was at 14%, and the DoD was at only 22%.

Table 14. Change in the Number of Small Businesses Receiving Awards for A&E Contracting

Architectural and Engineering Services (Including Surveying and Mapping)					
	FY04–FY10	FY04–FY15	FY04–FY23	FY10–FY15	FY10–FY23
USDA	127%	110%	112%	87%	89%
Defense	72%	75%	86%	104%	119%
Energy	120%	180%	240%	150%	200%
HHS	168%	216%	136%	129%	81%
Interior	75%	70%	139%	92%	184%



Transportation	107%	104%	74%	97%	69%
Veterans Affairs	219%	16%	100%	7%	46%
GSA	200%	75%	175%	38%	88%
EPA	141%	112%	66%	79%	47%
NASA	55%	70%	42%	128%	78%
All Agencies	100%	78%	96%	78%	96%

Source: FPDS

In terms of the number of firms, A&E contracting delivers another unusual pattern as seen in Table 14. Overall, the number of small prime contractors grew by only seven firms from 2004 to 2010, and fell by just over 400 firms (22%) from 2010 to 2015, and then regained all but 91 of those firms by last year. However, within agencies the swings were far more dramatic. The DoD is still 15% below where it started in 2004, but that is an increase from its lowest point in 2006. The GSA has only 42% of the small prime contractors it had in 2004, but the agency had its best years from 2008 to 2010. The VA doubled the number of small primes it had between 2004 and 2010, only to lose 20% of them by 2015, and over half of them as of last year.

Small Business Performance in Refuse Systems and Related Services

Table 15. Percentage of Dollars Awarded to Small Businesses for Refuse Contracting

Refuse Systems and Related Services ¹⁰				
	CY 1991	FY 2009	FY 2015	FY 2023
USDA	88	87	98	68
Defense	82	62	60	56
Energy	100	96	57	71
HHS	89	67	47	95
Interior	97	69	100	66
Transportation	98	87	95	17
Veterans Affairs	67	35	71	85
GSA	89	67	49	79
NASA	56	94	75	100

Source: Source: CY 1991 Data from Senate Small Business Committee Hearing; All other data from FPDS.

Waste and Refuse contracts, as seen in Table 15, had the clearest drop in small business participation with the implementation of Comp Demo. From 1991 to 2009, eight agencies declined, with only NASA improving its performance by a noteworthy 38 percentage points. However, when the program was repealed, only four agencies improved from FY 2009 to FY 2015. Four agencies fell again from FY 2015 to FY 2023, and six agencies performed worse last year than they did in 1991. DoD small business participation declined in each interval.

Table 16. Change in the Number of Small Businesses Receiving Awards for Refuse Contracting

Refuse Systems and Related Services					
	FY04–FY10	FY04–FY15	FY04–FY23	FY10–FY15	FY10–FY23
USDA	221%	179%	124%	81%	56%
Defense	99%	93%	78%	94%	79%
Energy	63%	68%	32%	108%	50%

¹⁰ As the EPA only awarded contracts in this DIG in FY 2009, it is excluded from this analysis.



HHS	220%	400%	260%	182%	118%
Interior	118%	113%	95%	95%	81%
Transportation	67%	100%	100%	150%	150%
Veterans Affairs	431%	438%	477%	102%	111%
GSA	68%	84%	42%	123%	62%
NASA	400%	200%	100%	50%	25%
All Covered Agencies	120%	115%	95%	96%	79%

Source: FPDS

As shown in Table 16, the number of successful refuse small businesses contractors increased by 20% from 2004 to 2010, only to drop by 21% as of last year. This represents a total loss of 24 firms from 2004 to 2023, but 123 fewer firms from 2010 to last year. However, these trends were not consistent across agencies. Under Comp Demo, three agencies saw a decline of about a third, and the DoD remained constant. Post-repeal, three agencies saw significant growth, five remained essentially the same, and two saw sizeable drops. As of last year, Energy had lost over two-thirds of the small firms it had in 2004, and the DoD was down 22%, but the VA had nearly five times as many small prime contractors.

Small Business Performance in Landscaping and Pest Control

Unlike all of the other DIGs, FPDS has a fairly complete history of small business performance in landscaping and pest control. This DIG was statutorily added to Comp Demo on October 28, 2004, and the FAR amended in March 2005, so FY 2006 is the first full year when Comp Demo applied to this industry. This makes FY 2004 the perfect baseline for the program.

Table 17. Landscaping and Pest Control DIG—Percentage of Awards to Small Businesses

	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 15	FY 23
USDA	89	91	95	78	76	33	36	62	72
Defense	79	47	44	63	75	74	77	67	62
Energy	73	79	75	53	75	44	79	17	41
HHS	92	35	8	69	78	91	94	87	37
Interior	85	82	77	70	58	61	66	65	96
Transportation	86	88	95	91	86	86	72	89	76
VA	91	80	73	79	89	80	82	83	92
EPA	100	96	81	83	84	80	81	83	20
GSA	87	76	95	86	88	90	85	57	78
NASA	12	12	30	25	83	94	95	100	100

Source: FPDS

When comparing small business achievements in FY 2004 and FY 2006, half of the agencies saw their performance decline, but half saw an improvement. The most dramatic shift was at HHS, which saw its small business performance fall from 92% to 8% percent. The DoD saw a drop from 79% to 44%. At agencies that saw a growth in small business contracting during this period, the increases ranged from 2 to 18 percentage points.

From 2006 to 2010, there are three distinct patterns, and one outlier. First, there are agencies that continue to see their small business percentages decline. These include USDA, which falls from 95% to 36%, and Transportation, which declines from 95% to 72%. Second, there are agencies that saw an initial decline only to then improve in the latter years of the program. These include the DoD, HHS, Interior, and NASA. It is worth noting that



NASA and HHS ended up performing better in 2010 than in 2004, and the DoD was only 2 percentage points below its 2004 results. Despite some fluctuation in the first years of Comp Demo, VA, EPA, and GSA each ended up awarding a consistent 79% to 90% of work to small businesses from FY 2007 to 2010. Energy was the true outlier, fluctuating by 20 to 30 percentage points each year.

When Comp Demo ended in 2010, seven of the agencies were performing at a level below their 2004 achievements, although NASA notably grew from 12% small business in 2004 to 95% small business in 2015 and every agency except the USDA was awarding at least 66% of its prime contracts to small businesses. By 2015, half of the agencies had improved from 2010, but half had declined. The greatest changes were at Energy, which fell from 79% to 17%, and the GSA which fell from 85% to 57%. Six agencies were above the 66% threshold. By 2023, while six agencies were doing worse than they did in 2004, eight were still awarding at least 40% of dollars to small businesses.

Table 18. Landscaping and Pest Control DIG—Number of Small Businesses Prime Contractors

	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 15	FY 23
USDA	38	80	115	128	139	220	306	277	246
Defense	61	135	709	856	855	916	975	871	709
Energy	7	11	17	20	20	24	20	22	20
HHS	7	11	15	14	13	23	27	37	39
Interior	106	116	117	115	131	222	272	212	263
Transportation	8	7	11	20	22	26	33	82	75
Veterans Affairs	57	66	83	91	139	184	210	240	225
EPA	2	6	6	9	10	8	12	11	4
GSA	80	82	96	95	110	114	115	121	73
NASA	4	5	3	3	5	4	4	7	5
All Covered Agencies	370	519	1172	1351	1444	1741	1974	1880	1659

Source: FPDS

Instead of presenting the percentage changes, Table 18 instead shows the actual number of small prime contractors each year of Comp Demo as well as in 2015 and 2023. When examining the covered agencies, the total number of small primes increases each year of Comp Demo, from 370 firms in 2004 to a high of 1,974 by 2010, representing growth of 534%. NASA was the only agency that did not experience growth, never exceeding seven firms over the past 20 years. However, when Comp Demo was repealed, four agencies began to see a decline in the number of small prime contractors, and by last year, half of the agencies were doing worse than they had in 2010. At the DoD, there were 27% fewer prime contractors last year in this DIG than there were in 2010. Even with these declines, every agency except for the GSA performed better in 2023 than they did in 2004.

Conclusions on Comp Demo

Comp Demo did not exist in a vacuum, and other policy changes affected small businesses both during and post Comp Demo. For example, from 1991 until 1999, and again post-2014, the Department of Energy has been allowed to count first tier subcontracts awarded by its Management and Operations contractors towards the department's prime contracting goal, which has caused substantial fluctuations on Energy's small business



goalings reports (Consolidated Appropriations Act of 2014).¹¹ Likewise, in 2016, the Supreme Court's decision in *Kingdomware Technologies v. United States* required the VA to apply the rule of two to SDVOSBs and VOSBs before any other awards could be made.¹² The Biden Administration has increase goals for small disadvantaged businesses each year since 2021. All of these changes serve to increase the prime contracting dollars reported for small businesses.

While it is important not to attribute all changes to small business contracting in the DIGs to Comp Demo, some conclusions may be drawn. In each DIG other than A&E Services, the number of small businesses winning contracts increased under Comp Demo, which supports a healthy industrial base in those areas. Further, based on the statutory language, Comp Demo started with the goal of awarding at least 40% of prime contract dollars to small businesses for each DIG at each agency. In FY 2009, this goal was met about 83% of the time, whereas in the baseline year it was met 86% of the time. In 2015, the 40% goal was met about 88% of the time, and last year it was met 80% of the time. This suggests that Comp Demo did roughly as well as set asides in maintaining a substantial level of small business participation in the DIGs, even if it did not match the same percentage of total dollars awarded in each agency. Under Comp Demo small businesses exceeded 20% of prime contract dollars for each DIG within each agency 97% of the time, which is better than these firms fared in the base line years or in the years since Comp Demo was terminated. Indeed, when comparing the various time frames studied, small businesses consistently received above 60% of the dollars in each DIG at each agency between 60% and 65% of the time, suggesting that 60% awards to small business may have been a better goal. The lack of transparency on how small businesses outside of the DIGs fared under Comp Demo poses a significant challenge in judging the merits of the program, but the fact that the average dollars to small business saw only minor changes at the majority of agencies post repeal suggests that under Comp Demo contracting agencies had to carefully structure contracts within the DIGs so that they remained suitable for small businesses, and had to focus on creating opportunities for small businesses in other industries.

Application to Current Procurements

The analysis of the ICR and current contracting trends at the DoD suggest that the issue Congress was trying to address with Comp Demo remains unsolved. Specifically, substantial small business dollars are spent in areas where small businesses are winning all or almost all of the procurements. As noted earlier, there are 169 industries where small businesses receive less than 5% of dollars, even though these industries account for more than a third of the DoD's total spend. In contrast, small businesses receive more than 80% of awards in 322 industries, and while these industries account for just 2.6% of the DoD's total contract dollars they account for about 12.5% of the small business dollars. This suggests that the current goaling system is not fulfilling the statutory requirement to insure "that a fair proportion of total purchase or contracts for goods and services of the Government in each industry category . . . are awarded to small business concerns" (15 USC 644(a)). More important even that the concept of equity however is that of readiness, and this division further suggests that the current system is not using small businesses to effectively "maintaining or mobilizing the full productive capacity of the United States [or its] war or national defense programs" (Id.).

¹¹ Section 318 of the Consolidated Appropriations Act of 2014 ("CAA"), (Public Law 113-76)

¹² *Kingdomware Technologies, Inc. v. United States*, 136 S. Ct. 1969 (2016).



One of the challenges is that the current NAICS system does not adequately capture the DoD's needs. NAICS were designed to allow for industrial comparisons across North America, and are revisited every five years by the United States, Canada, and Mexico. While a substantial improvement to the prior SIC system, the 2022 version of the NAICS codes still does not have a code for cyber, and cloud and platform as a service are listed as the same NAICS as data entry and diskette conversion services (518210). Artificial intelligence (AI) is only included under research and development, and in the same NAICS as aerospace research, fisheries research, and experimental farming (541715). Given that NAICS are a primary method vendors use to search for contract opportunities, and they are a relatively easy way to track procurement trends and breakdowns, this poses challenges. First, it means that we are not accurately measuring the work the federal government does in these industries. Consequently, it follows that we are failing to track which vendors, small and large, are participating in these important segments. It also means that how we identify a firm as small is not tailored to the specific industry. Conflating the size of a company that duplicates floppy disks and CDs with a company that provides cloud services does no favors to either industry.

Congress has already recognized this issue, and provided SBA with the ability to create new industry codes and size standards in order to better measure and incentivize participation in areas where the government has a defined need or operate differently than the private or commercial sectors. General size standard authority is provided to SBA in section 3 of the Small Business Act, which defines a small business as “one which is independently owned and operated and which is not dominant in its field of operation” (15 USC 631(a)(1)). The agency is then given the authority to establish size standards by industry, so long as the “size standard varies from industry to industry to the extent necessary to reflect the differing characteristics of the various industries and consider other factors deemed to be relevant” by the SBA (15 USC 631(a)(3)). However, when discussing the role of small business in federal procurement, SBA is told that it may “limit an industry category to a greater extent than provided under” the NAICS codes if SBA receives “evidence indicating that further segmentation of the industry category is warranted . . . due to unique Federal buying patterns or requirements; or to recognize a new industry” (15 USC 644(a)(2)).

This authority has existed since 2016, but SBA has not exercised it. This creates an opening for the DoD to use the data it has collected in the ICR and similar reports to approach SBA with requests for new industry categories. This would permit the two agencies to tailor their authorities in a manner that would respond quickly to the challenges exposed by the Comp Demo program, and to proceed more strategically in areas where the DoD needs better visibility into its industrial base and wished to attract new participants.

For example, in addition to kinetic capabilities, energy storage and batteries, castings and forgings, and microelectronics, the priority defense sectors the ICR highlights challenges for aviation, biomanufacturing, ground system electrification, and the submarine industrial base. The ICR specifies for energy storage and batteries, they are focusing on “high-capacity batteries, with a particular focus on lithium batteries.” Batteries actually have a series of NAICS devoted to them—NAICS 335910, 35911, and 335912 cover battery manufacturing, storage battery manufacturing, and primary battery manufacturing. The challenges presented in the ICR suggest that it is also necessary to include NAICS 212290, other metal ore mining and NAICS 212390, lithium mineral mining. Lithium compound manufacturing is in NAICS 325180, other basic inorganic chemical manufacturing. All of these receive awards recorded in FPDS, but the last three include items that may not meet the needs of this sector. Likewise, NAICS 335999 includes semiconductor and other battery



charging manufacturers, but it also includes the manufacture of bells and gongs. This makes it difficult to identify these segments of the industrial base, and to attract small businesses or non-traditional businesses to the base.

Recommendations

1. The DoD should work with SBA to develop industry codes and size standards that would allow it to attract, utilize, and measure critical sectors of its industrial base. This would allow the DoD to target at risk and developing segments of its industrial base.
2. The SBA should, in accordance with the FY 2016 NDAA, report annually on the “number of small business concerns, small business concerns owned and controlled by service-disabled veterans, qualified HUBZone small business concerns, small business concerns owned and controlled by socially and economically disadvantaged individuals, and small business concerns owned and controlled by women awarded prime contracts in each North American Industry Classification System code during the fiscal year and a comparison to the number of awarded contracts during the prior fiscal year” (Sec. 868). This information would provide contracting officers and policy makers with useable information. It would quickly signal changes in the industrial base, including when agencies are not attracting enough new entrants or when consolidation threatens a segment. It would also provide information on how to structure procurements to reach more small firms. Finally, it would give Congress and agencies quick feedback should they every attempt to create a program similar to the Comp Demo program, or wish to revisit the treatment of retailers and wholesalers under the Small Business Act.

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PANEL 8. STRATEGIES FOR FINANCING DEFENSE INNOVATION

Wednesday, May 8, 2024	
2:15 p.m. – 3:30 p.m.	<p>Chair: Todd Lyons, Colonel, USMC (Ret.) Vice President, Research, Naval Postgraduate School Foundation & Alumni Association</p> <p><i>VCs as Transition Partners: Leveraging Networks and Expertise to Improve Fielding Outcomes</i> Matthew MacGregor, MITRE</p> <p><i>Assessing the Impact of DoD-Funded Assistance Projects on the Availability of New Warfighting Capabilities</i> Amanda Bresler, PW Communications</p> <p><i>How the U.S. Department of Defense Can Leverage Alternative Funding Mechanisms for Strategic Impact</i> Nicholas Velazquez, The Center for Strategic and International Studies</p>

Todd Lyons, Colonel, USMC (ret.) – is the Vice President for the Naval Postgraduate School Alumni Association and Foundation. In this role, he bridges the divide between industry, academia, and DoD entities to accelerate the responsiveness of NPS to the challenges arising from great power competition and emerging technology. Lyons also serves as a volunteer instructor for Innovation Leadership at NPS.

Lyons served in the Marine Corps for 30 years. In his last assignment, he served as the Senior Marine Representative and the Associate Dean of Research at the Naval Postgraduate School. In those roles, he connected the work of students and faculty to the operational challenges of the Marine Corps, the Navy, and the broader DoD. As an innovation leader, he leveraged the research at NPS and the operational experiences of the students to drive the adoption of new practices across the Naval Services.

After graduating from the Naval Postgraduate School in 2000, Lyons became a Middle East Foreign Area Officer and an Intelligence Officer with assignments at the Marine Corps Intelligence Activity and the Defense Intelligence Agency. Todd spent nine of his last eighteen years in the Marine Corps serving in a variety of assignments across the Middle East, including Qatar, Israel, Oman, and Iraq.

Lyons earned a Master of Arts with honors in National Security Affairs from the Naval Postgraduate School. He earned a Master of Science degree from the University of Haifa and was the Honor Graduate from the Israeli National Defense College in 2007. For his reporting during the Israeli withdrawal from Gaza in 2005, he received the Department of State Superior Honor Award. He received a second Superior Honor Award from the Department of State for his service in Oman from 2011-2014.

Lyons is married and has three daughters. He enjoys being active and keeping up with his family.



VCs as Transition Partners: Leveraging Networks and Expertise to Improve Fielding Outcomes

Matthew MacGregor—is a Fellow at the Acquisition Innovation Research Center. He previously worked for the MITRE Corporation as an Acquisition SME and spent 21 years as a military and civil service program manager across the space, command and control, weather, and aircraft portfolios. His last PM assignment was as the F-35 Deputy Program Manager and his last five years in government were at the Pentagon, where he served in multiple acquisition leadership roles. His passion is reforming our current industrial age acquisition system for the 21st century.
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Stephanie Halcrow—recently served as a Professional Staff Member on the House Armed Services Committee (HASC) where she led efforts to develop, position, and implement the HASC Ranking Member's acquisition reform strategies and industrial base policies into tangible legislative solutions, garnering bipartisan and bicameral support as well as soliciting industry and federal government input. Halcrow is deep-rooted in academic and public policy communities and currently serves as a Senior Fellow with the Baroni Center for Government Contracting at GMU and National Defense Industrial Association. She also serves as an external advisor and subject matter expert to AIRC.
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Abstract

Venture capital (VC) firms focused on the defense market investments should serve as transition partners with their portfolio companies helping them identify potential defense customers, overcome integration challenges, and scale in advance of demand to improve fielding outcomes just as commercial-focused VC firms assist their portfolio companies with entering new markets, finding additional funding, and connecting with key industry players. Over the years, the DoD created multiple Service innovation organizations to support the identification and maturation of emerging commercial technologies. However, the reported transition rates of commercial technology into programs of record appears to be incredibly low despite the efforts of multiple government offices. The DoD recently created the Office of Strategic Capital to more squarely focus on leveraging private investment capital to meet defense customer requirements. Even still, VC firms find the DoD marketplace challenging to navigate. For VC firms to fully exploit their private investments, and to benefit national security, defense-oriented VC firms must transform their commercial-focused investment best practices into defense focused business engagement models that extend beyond raising capital.

Introduction

With venture capital (VC) in defense technology increasing dramatically in the last 10 years, there should be demonstrable improvements in joint force capabilities as commercial innovation rapidly addresses unmet capability gaps. Yet, Department of Defense (DoD) procurement of technology backed by VC has remained roughly the same (percentage-wise) as it was in 2013 when investments in defense tech were minimal. The failure of companies using venture capital funds to successfully garner substantial contracts is often, unfairly, levied only at the DoD. Regardless, the DoD is at risk of losing this relatively new source of innovation funding.

This novel paper explores the potential role that VCs might have in extending their services to portfolio companies beyond just financial backing but becoming active partners in assisting companies navigate the DoD bureaucracy and successfully scale. For context, this paper provides a primer on venture capital, identifies trends in defense focused venture capital and resulting DoD contracts. It also offers an in-depth description of the services VCs provide and how those services might be tailored for defense. Finally, it offers actionable



steps for VCs in the defense space to become a transition partner with startup founders, the DoD, broader industry, and Congress.

Venture Capital

Venture capital is a type of financing that investors provide to startup companies and small businesses in different stages of maturity that are viewed as having high growth potential. The funds to support venture capital efforts come from private investors, investment banks, and financial institutions (Hayes, 2024). In return for investments, VCs usually form a limited partnership with the respective business and share in any profits or losses with VC liabilities only up to the level of investment made (Tarver, 2023).

VC firms usually take ownership stakes of less than 50%, invest in a wide variety of companies, will group with other VC firms, and have little to no management control in the day-to-day operations of the company (although they may have board seats; Baldrige, 2023). For distinction, VC is a form of private equity (PE) but is different than private equity strategies exercised by PE firms like Blackstone and The Carlyle Group. Those PE firms are focused on a smaller subset of mature companies, they take a full ownership stake, and have broad management control to streamline operations and exit their investment as they choose (Team, 2024).

VC firms meanwhile have varied investment strategies with some focused on earlier-stage startups that may only have a prototype and others who are more focused on scaling a promising technology that has a demonstrated market fit. While most VCs will not acquire a controlling interest like a PE firm, there are different strategies that can be employed. VCs focused on later-stage investments will want at least a 10%–15% stake while those in the earlier stages are willing to take a much smaller share commensurate with their lower investment (SVB, n.d.). These different entry points provide support for companies to undertake different business activities and impacts the VC investment return expectations (see Table 1; Orn, 2024). In 2023, 70% of deals were considered early-stage with mid and late-stage equaling 18% (CB Insights, 2023).

Table 1. Stages of VC Investment and Expected Return

Stage	Business Activity	Expected Return
Seed	Building a Prototype; Business Startup	100X
Series A	Marketing; Revenue Generation; Plan to Scale	10–15X
Series B	Commercial Viability; Scaling Production and Sales	5–10X
Series C+	New Products and Markets; New Customers; Acquisitions	3–5X

There are tradeoffs for companies accepting VC funds. Investors may require a large share of equity that dilutes the founder's ownership, company leadership may lose creative control if investors press for faster returns; and founders may be forced to choose a non-preferred exit strategy that sacrifices long-term growth goals (Thangavelu, 2023). Exit strategies may include acquisition from another company, an initial public offering, liquidation of the company; or stock buybacks (Guest, 2022). The downsides of accepting VC funds are what makes grants from the Small Business Innovation Research (SBIR) program attractive to investors—the funding is nondilutive and the government never gets directly involved in operations (SBA, n.d.).

The United States pioneered the VC model with the establishment of the American Research and Development Corporation in 1946 and access to capital is considered a key reason why the United States leads the world in entrepreneurship and innovation.



Entrepreneurs need funding and support to transform their ideas into viable businesses and the United States offers a robust financial infrastructure, with venture capital firms, angel investors, and well-developed capital markets (Calimanu, 2023). McKinsey & Company, in their Playbook for Innovation Hubs and Ecosystems have “*Capital and Funding*” as number 3 on their list of key actions for building a robust innovation ecosystem (Davis et al., 2023).

In 2015, public companies that received VC backing accounted for 20% of the market capitalization and 44% of the R&D spending of U.S. public companies (Gompers et al., 2021). Over the last decade, venture investing has grown significantly, with the value of deal investment growing five times from 2009 to 2019, and the number of deals doubling (Figure 1; Gabbert, 2020). Median deal size for earlier-stage companies is at an all-time high (Figure 2) and Q4 of 2023 was extremely active indicating ample opportunities for aspiring companies (Stanford, 2023).

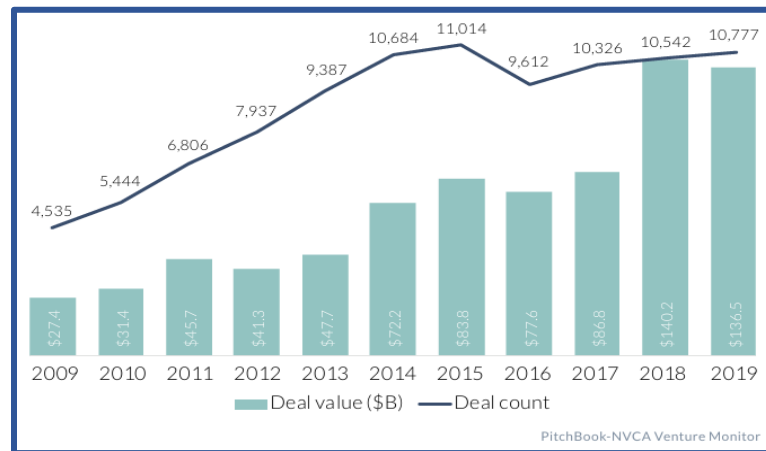


Figure 1. U.S. VC Deal Activity

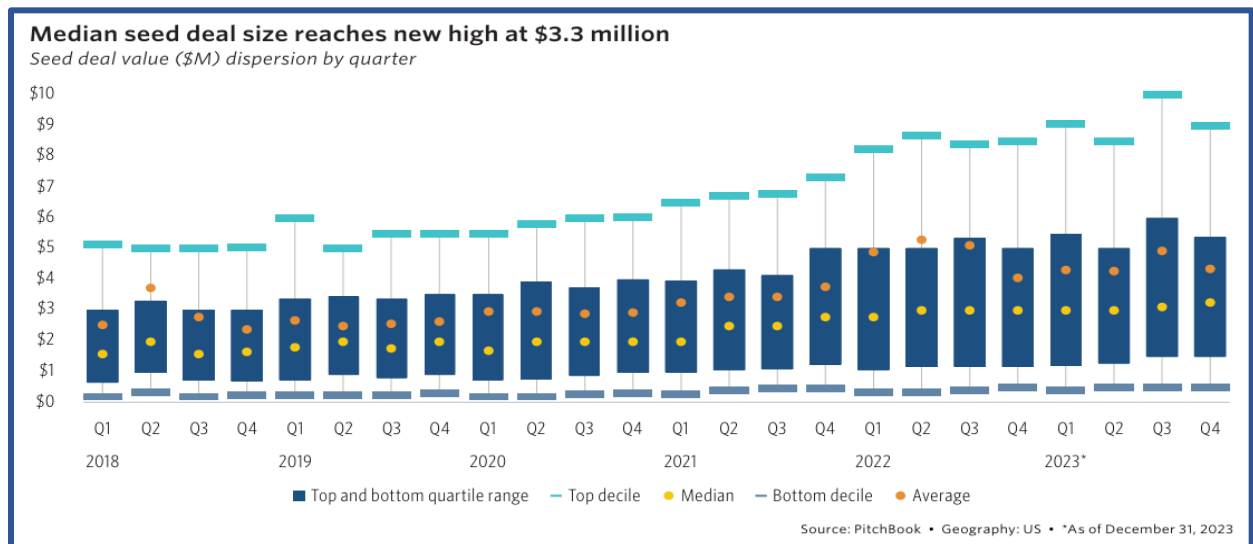


Figure 2. Median Seed Deal Size

VC Shift to Defense Market

For the last two decades, the United States has been focused on conflicts where the adversary had inferior capabilities and where current military capabilities were sufficient for

the missions undertaken. In recent years, however, there has been substantial literature on how unprepared the United States and allied defense establishments are for a global and protracted conflict with a peer adversary. The Ukraine-Russian conflict has been demonstrative of how legacy systems designed for the Cold War can be compromised in the face of new high-tech systems such as proliferated satellite networks and artificial intelligence as well as high mass, low-cost drone manufacturing that can target capital assets like ships, tanks, and advanced aircraft.

The DoD's willingness to consider new technology that is not exclusively developed by large defense primes created an opening for dual-use commercial companies to potentially gain a share of the large defense market. Innovation hubs like AFWERX and Defense Innovation Unit (DIU) have also increased expectations for aspiring startups by providing a new level of government to industry engagement not previously seen from the defense enterprise. Defense Secretary Ash Carter envisioned this very scenario when creating DIU. Former Deputy Secretary of Defense Bob Work described DIU as the DoD's effort to create a "beachhead in Silicon Valley" (Albon, 2023). The success of companies such as SpaceX, Anduril, Palantir, Shield AI, Hawkeye 360, Rebellion Defense, Skydio, and Epirus (all defense tech unicorns) have also demonstrated that large-scale success is possible in defense even if the path was not always easy (Temkin, 2023).

Silicon Valley has responded to this outreach by expanding VC investment in the defense-tech sector. Rapid growth was seen from 2016 to 2022 with \$135.3 billion invested across 4,744 deals. Investors expect this trend to grow to \$184.7 billion by 2027, "driven by the government's growing demand for innovative dual-use technologies to meet its national security goals" (Figure 3; Javaheri, 2023). The leading startup accelerator, Y Combinator recently jumped into the defense space on the heels of other prominent VC firms such as Sequoia, Bessemer Venture Partners Andreessen Horowitz's a16z (Alamalhodaie, 2024).

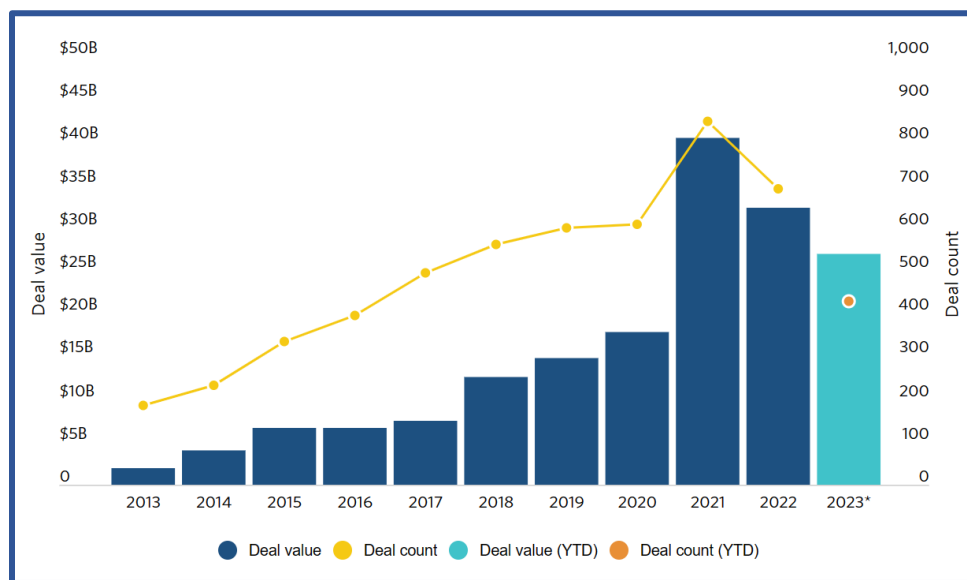


Figure 3. VC Activity in Defense Technology

Given the initial focus on dual-use technology, this jump in interest may not seem as significant for meeting defense-specific needs, but in recent years VC investments have expanded beyond just artificial intelligence, space launch, and space imagery into more kinetic domains that have less dual-use applicability. As Mike Brown, a partner at Shield

Capital and former director of DIU noted, “We are seeing more VCs saying they are comfortable investing in start-ups doing . . . tech that can have a kinetic effect used purely for the military” (Kinder, 2023). Palmer Luckey, founder of Anduril, went even further saying, “We want to build the capabilities that give us the ability to swiftly win any war we are forced to enter” (Thompson, 2024). This expanded view has led Anduril to make significant investments in loitering munitions, such as the Altius, and for leading investors such as Founders Fund, Andreessen Horowitz, General Catalyst, 8VC, and Lux Capital to be willing to make serious bets on those military-centric capabilities (Martin, 2022). Further diversity of investment is demonstrated with the varying portfolios of the 10 most active VC investors in defense and aerospace technology (see Figure 4; Robbins, 2023).

VC Firm	Focus	Median Deal Size	Portfolio Companies
Soma Capital	Satellite imagery, hydrogen fuel jets and broad portfolio	\$4M	Albedo, Destinus
SpaceFund	Reusable satellites, aerospace refueling	\$8.5M	Space Forge, Axiom Space
Alumni Ventures	Drones and air defense	\$29.2M	Red 6, SkySafe
Space Capital	Intelligence payloads	\$77.5M	Iceye, Impulse Space
Seraphim Space	Drones, satellite imagery and aerospace launch	\$18.6M	Nightingale Security, Edgybees
Gaingels	Smart gun tech, drone defense and AI services	\$15.6M	Shield AI, Biofire Group
Founders Fund	AI and augmented reality	\$43.6M	Anduril, Biofire Group
Hemisphere Ventures	Communication, drones, intelligence and refueling.	\$12.8M	Skyfront, Nightingale Security
Draper Associates	Aerial intelligence, smart gun tech and drones.	\$8.1M	Biofire Group, Natilus
Liquid 2 Ventures	Satellite intelligence	\$10M	Anduril, Prenav

Figure 4. VC Activity in Defense Technology

Given the factors highlighted, there are now numerous what might be termed “defense-involved” VC firms, which means they have and are making serious bets on the defense sector (Figure 5).

Lux Capital	Marque Ventures	Decisive Point	Iron Gate Advisors
RIOT	Refinery Ventures	Squadra	Scout Ventures
A16z	Snowpoint Ventures	Shield Capital	Insight Partners
Founders Fund	America’s Frontier Fund	USIT	Moonshots Capital
8VC	Point 72 Ventures	Sequoia	General Catalyst
Space Capital	Acorn Growth Companies	Cubit Capital	Generation Space
Silent Ventures	GulaTech Adventures	Red Cell	Roadrunner Venture
Vision Fund	Accel Partners	Prosus Ventures	Champion Hill Ventures
Techstars	SoftBank Vision Fund	The Veteran Fund	Pallas Ventures

Figure 5. VC “Defense-Involved” Firms



The VC arena has become so attractive that even large defense primes are entering the game. Lockheed Martin established Lockheed Martin Ventures with 16 different focus areas and \$200 million in investments across 35 companies (Lockheed Martin, 2024). Boeing established AE Industrial Partners (ae HorizonX) with five primary focus areas and investments in 29 platform companies (AE Industrial Partners, 2024). RTX established RTX Ventures with a focus in four areas and an undisclosed portfolio that includes promising companies such as EpiSci, Hermeus, Impulse Space, Neural Propulsion Systems and H55 (RTX, 2024). Booz, Allen, Hamilton initiated Booz Allen Ventures with a focus on Joint All Domain Command and Control technologies and have invested in at least nine companies in that space (Booz, Allen, Hamilton, 2024). L3Harris Technologies uniquely formed a strategic partnership with VC firm Shield Capital (L3Harris, 2022).

Defense Challenges for Startups

Even with the increased investments over the past 10 years, the creation of new defense-tech startups and expressed interest from DoD leadership, the military has not taken advantage of the private capital flowing into the defense space. While there have been some isolated, decently sized contracts to some of the larger non-traditionals, in FY23, venture-backed companies were awarded less than 1% of the total awarded DoD contracts (according to data collected by Govini) which is roughly the same margin as 2010 when venture investment in defense was minimal (Figure 6; Somerville, 2024).

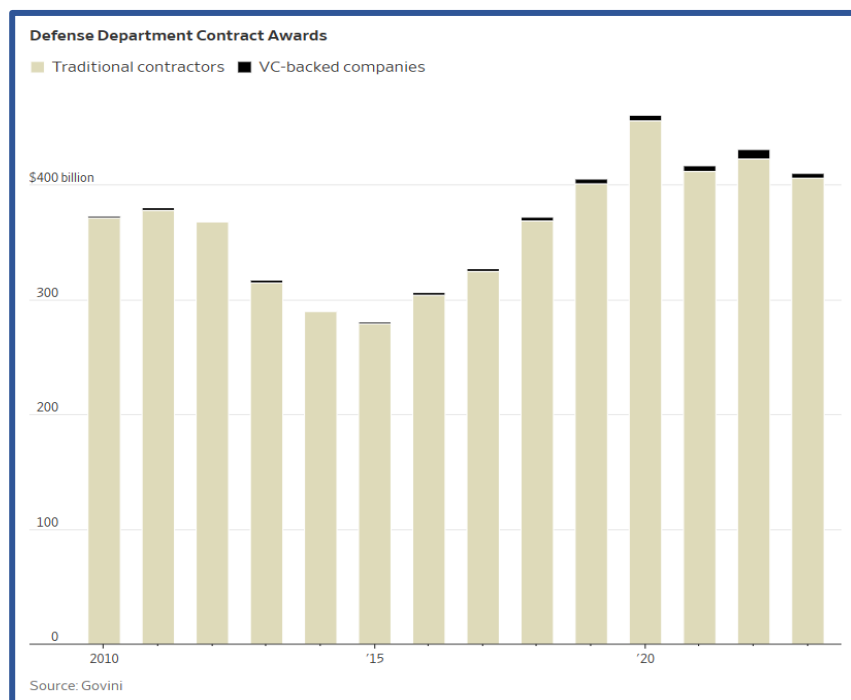


Figure 6. DoD Contract Awards and Share of VC-Backed Companies

There is no shortage of challenges for defense startups to penetrate the DoD market. One investor aptly summarized the problem as “risk aversion, bureaucracy, red tape, heavy regulation, and a culture that values the status quo over change are stalling the pace of innovation” (Yakulis, 2023). A major one is funding timelines. DoD budget cycles and acquisition processes take years to build a new program into the long-term resourcing plan, while startups are operating on very lean budgets with often little margin. Venture funding may only be available for a one-to-two-year window leaving startups with a critical gap (often

referred to as the valley of death) between when a product may be available for purchase and when the DoD would have the funds and approvals to begin procurement. This gap makes it harder for startups to continue to raise funds as military commitments are hard to predict until they are placed on contract. As one VC put it, “if a technology is not in a program of record with a budget line item, that is an Achilles heel to the entire commercial integration effort where we put years of effort, and nothing comes out of it” (Erwin, 2023).

While Small Business Innovation Research (SBIR) funding can be helpful for many companies, it is a poor substitute for substantial and recurring revenue streams. It is critical for defense-involved startups to have technologies that are formalized into the acquisition system and have a programmed budget line. One startup founder compared getting a new technology into the DoD’s budget as a “Field of Dreams,” so this is no easy task given the DoD’s numerous priorities (Somerville, 2024).

Another key challenge that constrains the application of innovative commercial technology to military problems is the requirements process that underpins the creation of any long-term acquisition program. The DoD is notorious for requiring large, multi-mission and exquisite solutions to problems that few startups would have the expertise, security clearances, or certifications to win the contract for or to successfully complete the work. This is compounded by the dictation of specific components or subsystems in highly detailed specifications that often preclude alternative solutions (Erwin, 2023). This is the reason why defense primes have dominated defense procurement over the many decades. There has been progress in the various innovation shops using novel requirements approaches and streamlined contracting vehicles (Toliver, 2022). However, as some studies have noted, the “DoD has effectively divorced defense innovation from defense procurement [by] detaching the development of cutting-edge capabilities from the production of major systems and platforms” and created a system of “innovation tourism” where innovation offices lack the financial resources necessary to drive wholesale modernization across the DoD (Flagg & Corrigan, 2021). This is a challenge that startups need help in overcoming to effectively sell their products and potentially a challenge that VCs can help the DoD overcome.

Deputy Defense Secretary Kathleen Hicks rightly characterized the most looming challenge for startups when she said, “I think transition clearly is one of our biggest problems [with] the so-called ‘Valley of Death,’ scaling up to fielding and full-scale production” (Metzger, 2023). As one CEO noted, “Program managers are not necessarily incentivized to bring in cutting-edge innovation . . . their duty is to deliver cost, schedule and performance on those programs of record, which are tied to a congressional budget line” (Erwin, 2023). A recent Reagan Foundation report noted that the government is failing to transition SBIR contracts to production with even the top 25 awardees generating a tiny fraction of revenue from follow-on Phase III contracts (Zakheim, 2024). The reality is that not all commercial technology is easily assimilated into warfighting capabilities as the military has become accustomed to procuring and fielding integrated platforms. This means that careful planning is needed when deciding the best approach for selling a product to the DoD. A new sensor may be game-changing, but it may need to be integrated into an existing system to be of use to military forces. A new analytics tool may be more powerful than any other DoD capability, but it faces the reality of having to replace a product that has already been scaled to thousands of military users. A new application may have superior functionality, but it has not undergone the security testing of other products and may not be immediately fieldable on an operational network. New commercial space services may be able to provide better coverage and resolution than existing military satellites, but program offices may not know how to contract for different business models and operational users may not understand how to integrate the commercial capability across different classification



domains. While there have been notable changes to statute, regulations, and policies requiring program managers to embrace commercial standards for open systems that would make this an easier process, challenges remain in achieving seamless integration of cutting edge solutions.

Requirements, funding, and transition (RFT or RIFT) barriers are all substantial but can be overcome with the right application of technology, appropriate planning, user engagement and advocacy building. There are examples of the innovation ecosystem breaking through the legacy approaches that go to the same vendors for solutions (McNamara et al., 2023). Unfortunately, it is not happening at the rate needed to sustain the capital market investments long-term. Even when former military officers, like Even Rogers of True Anomaly have tried to convey to DoD decision makers that “venture capital will fund the hard stuff, building prototypes and testing,” the DoD has yet to reward that behavior at scale by buying the finished products that they say they need. Tara Murphy Dougherty, chief executive of Govini, characterizes the situation as risky with “venture looking at the defense market as a failed experiment.” Mike Brown has commented that without a shift in the concentration of contracts going to these new, innovative startups, the “VC investment will dry up” (Somerville, 2024).

Founder Support

Venture capital is sometimes viewed as merely financial resourcing. While financial capital is highly important for startups to hire top talent, make key investments, produce high-quality products, and evolve their product line, VC support also comes as technical or managerial expertise. This expertise can be viewed as different forms of capital, namely “intellectual capital” and “relationship capital” (Chan, 2007).

Intellectual capital can be comprised of services such as human resources, sales, negotiation, marketing, branding, pitch, design, and manufacturing expertise along with coaching, mentorship, and executive support to a founder from an experienced hand in that business sector. One VC firm, MGCV, makes sales expertise a core part of their offering and supports founders “through every step of becoming a master of sales—everything from which digital systems to use to in-person pitch practice” (Schroder, 2021). One forward-leaning VC firm even connects its startup founders “with wellness and personal development services, like executive coaching, sleep support, peer groups, team coaching, therapy, nutritionists, and culture building” (Graumann, 2023).

Relationship capital is more focused on leveraging a VC’s extensive networks to support continued fundraising, help with recruitment of experienced board members and senior employees, navigate complex regulatory environments, and facilitate introductions to potentially strategic clients. One VC partner noted, “that it can’t be overstated how helpful it is to have investors provide operational support, facilitate connections to prospective clients or give guidance on expanding into regional markets” (Schroder, 2021).

The strategic relationships element might be the most critical offering a VC can provide given the downstream ramifications and why it is important for that firm to have experience in the same domain. For instance, a pharmaceutical startup would be taking a greater risk partnering with a VC who has only invested in the AI space since they may not have the necessary connections to help accelerate a drug approval, be connected with the right universities to run a trial, or get prioritization for drug manufacturing (Zapflow, 2022). This is why it’s key for startup companies to understand their strengths and weaknesses when choosing a VC partner to make sure they add value in helping to grow and scale the business (Schroder, 2021). This is also why the relationship between a company and an



investor should not end after a financial investment has been made but rather serve as the beginning of a relationship (Yakulis, 2023).

In the defense VC space, this approach may even be more critical given the RIFT barriers, identified earlier, that the current defense acquisition imposes on startups. As Philip Bilden, a managing partner at Shield Capital noted, “You’ve got to have very specialized skills and capabilities to actually make money [investing in the defense sector]—you don’t just do this as a generalist” (Temkin, 2023). This also means that defense-involved VCs with smaller portfolios may be the best relationship partners given they can provide the focused support that is needed to navigate the maze of DoD stakeholders, get visibility on the startup’s offering, and work towards establishing them as a formal acquisition program. One successful investor noted that when he is actively involved in his portfolio companies, he more routinely achieves a return of 70%, whereas when he acts as a passive investor, success drops closer to 10% (Chan, 2007).

This type of hands-on engagement is critical as many startup companies may not understand the many nuances of how systems are fielded in the DoD, the various user groups that need to be engaged, the advocacy networks that need to be established, the processes that need to be navigated, and the approvals that need be garnered. The term “founder friendly” is used in the VC space and there are even advisory firms that propose using a Venture Capital Net Promoter Score “that incorporates feedback from startups and entrepreneurs in its portfolio to provide a more well-rounded picture of a VC firm’s success, beyond just its financial performance” (Graumann, 2023). This approach could be tailored to assess a VC’s “defense friendliness” and their ability to provide services that are necessary to achieve success in the defense space.

There is no standard template for venture capital services to startup companies. Each VC adopts their own unique approach based on their goals and investment strategy. An extensive survey of VC websites and media, combined with targeted interviews with experienced investors, informed the development of the Matrix of VC Services (Figure 7). While this is by no means exhaustive, it attempts to characterize the different offerings that a VC might provide to an aspiring startup in the commercial space. Even defense-involved VCs (as we are terming them) will, in most cases, have commercial aspirations so there is considerable overlap among the startup services that a “defense-involved” VC might offer (Figure 8).

Strategic Relationships	Product & Technology
Client Introduction	Operations
Branding/PR	Coaching/Mentoring
Sales & Marketing	Human Resources
Strategy Development	Recruitment
Sector Expertise	Finance & Admin
Legal / Regulatory	Investor Connections
Engineering Assistance	

Figure 7. Matrix of VC Services

While teaming arrangements certainly occur among commercial companies, in the defense context, this refers to teaming on government contracts where a larger company can provide the capital infrastructure and fielding expertise while the smaller startup provides more innovative or more cost-effective solutions. A good example of this is

Lockheed Martin’s teaming with Terran Orbital on the Space Development Agency’s Transport Layer Tranche 2 constellation where Terran provided satellite buses developed using advanced manufacturing processes that were produced with shorter lead times and at lower cost (Terran Orbital, 2023). Booz Allen Ventures specifically advertises helping portfolio companies find “subcontracting opportunities [and] proposing teaming agreements for proposals” (Booz, Allen, Hamilton, 2024). The agreement that Shield Capital and L3Harris signed is premised on L3 gaining access “to disruptive innovators for technology transfer, teaming arrangements, direct investments, or potential acquisitions and partnered contracts” (L3Harris, 2022). The Army has even taken steps to incentivize this type of teaming, so VC’s that can provide this service may be opening a pathway for easier entry to large DoD contracts, provided the partnership is structured equitably (Judson, 2023).

VC Services	Comparable Defense-Involved VC Services
Strategic Relationships	Government Relations: Providing access to or representing the interests of the portfolio companies with key stakeholders at the federal and state levels.
Client Introduction	Teaming Agreements: Teaming either as equal partners or in a subcontractor role to satisfy the needs of a government contract.
Branding/PR	HQ/ PEO/ PM Advocacy: Facilitating access to key stakeholders with influence on resourcing decisions and acquisition leaders with influence over acquisition and contracting strategies
Sales & Marketing	User Engagement: Engaging with appropriate user groups to bring awareness to the capability’s potential and garner feedback on specific features and overall feasibility for operations.
Strategy Development	Acquisition / Contracting: Aiding planning and execution of acquisition strategies and contractual arrangements acceptable to the startup’s founder/board as well as to the government.
Sector Expertise	Defense Primer: Explaining nuances of the defense system and various forces at play that impact the ability to garner a contract.
Legal / Regulatory	Compliance: Supporting efforts to ensure the startup’s product meets export, security, cyber, and assurance requirements.
Engineering Assistance	Integration / Fielding: Enabling the seamless integration and/or accelerated fielding of the startup’s product with expertise and infrastructure needed to reduce any barriers to government sales.

Figure 8. Matrix of Comparable Defense-Involved VC Services

Government relations is another service that defense-involved VCs can recommend to their portfolio companies. The congressional lobbying spend from the larger non-traditional defense unicorns like SpaceX, Anduril, and Shield AI, which exceeded \$5.7 billion in 2023, is indicative of how important this function is to be a major player in both defense authorization and appropriations. Only a handful of defense-involved VCs retain government relations support, although Andreessen Horowitz’s VC firm, a16z, recently activated an

internal lobbying shop for the defense-oriented companies in its portfolio (Edgerton & Chapman, 2024).

Government relations, or lobbying Congress, is not only advocating for increased funding in targeted areas but also engaging in conversations about setting the conditions for real, sustainable change. This advocacy often starts with changes to statute, regulations, and policies that may be favorable to a portfolio company's technology. VCs currently advocate on technology public policy but there is an opportunity to expand that outreach to defense acquisition reforms and industrial base policies favorable to small businesses and non-traditional defense contractors. Government relations also includes considering federal and state relationships with elected officials and their administrations. Eric Snelgrove, the founder of Revere Federal Strategies, a government relations firm that specializes in representing VC-backed defense technology startups, recommends VCs and their portfolio companies consider government relations in every business decision, to include where to locate the company's headquarters, when to pursue non-dilutive research and development funds, and when to start building champions in Congress (Snelgrove, 2024). A VC firm offering this type of government relations education and support, either directly or through external representation, would be elevating the odds of transition success.

Access to key government stakeholders at the headquarters, program office, and user levels is another valuable service that VCs can provide to portfolio companies. This is especially key for early-stage startups who may have founders who have never engaged with the military and need coaching on how to present the product as well as who should be engaged. The use of SBIR contracts to gain access to users and refine the product is useful but not a substitute for a full-throated engagement campaign. It borders on being an art form to understand the different stakeholders across the DoD that can be useful touchpoints. This includes understanding the different user bases, whether it is those individuals at the operational edge, those in the testing community, those users in planning roles, or those in programming who can directly influence the budget. At the acquisition level, it is important to know who the right leaders are and when to engage a program executive officer or program manager rather than engage with the engineering leaders on the program. The capability to navigate this stakeholder maze is a critical service that can set an aspiring startup on the path to long-term contracts or relegate them to obscurity.

Expertise in government processes, specifically acquisition and contracting ones, is another important service VCs can provide. VCs leverage defense accelerators that provide education and make connections. Techstars for instance has a comprehensive accelerator program that it uses for its portfolio companies (Techstars, 2024). In most cases however, that exposure is limited, and accelerators serve many customers which can diffuse the value of more targeted expertise. The managing partner of AE Industrial Partners, Kirk Konert, sees it as an important offering from his firm to help startups to "navigate through regulations and acquisition hurdles, making sure they can seamlessly fit within existing operating systems and ensuring they never compromise on security" (Konert, 2024). Raj Shah, partner at Shield Capital, sees it as important for companies entering the national security market to have "a venture partner who is fluent in government, including acquisition cycles, deciphering operational needs, and challenges" which is clearly a priority for his firm as they have deep expertise among both their advisors, partners and broader team (Alamalhodaie, 2023). Decisive Point advertises expertise "in using rapid acquisition authorities, executing government contracts, providing guidance on government relations, and opening access to deep relationships across the deep-tech ecosystem" (Decisive Point, 2024). This an important offering as many startups have challenges knowing where to access government opportunities and what proposals are worth allocating valuable time



pursuing. Time is money anywhere, but is especially important in a resource-constrained startup environment.

In the area of integration and fielding expertise, the defense prime VCs may be the most uniquely poised to provide this service given their experience and vast enterprises. Lockheed Martin (LM) Ventures advertises that it provides portfolio companies access to “our world-class engineering talent, state-of-the-art technologies . . . and supply chains” (Lockheed Martin, 2024). This was evidenced by a strategic partnership with the startup Regent, where the CEO noted that it planned to leverage LM’s expertise to “adapt sea gliders for defense use cases” (Regent, 2023). Booz Allen Ventures boasts that it help startups accelerate the necessary security requirements to get an Authority to Operate or satisfy requirements under the Federal Risk and Authorization Management Program (Booz, Allen, Hamilton, 2024). AE Industrial Partners touts their ability to help startups solve technical challenges and navigate regulatory environments (AE Industrial Partners, 2024). RTX Ventures provides “access to our global network of more than 60,000 engineers [and] connectivity to 10 enterprise wide capability development centers” (RTX, 2024). VCs that are not embedded in a defense prime can pursue partnerships similar to the one previously mentioned between Shield Capital and L3Harris (L3Harris, 2022). Defense prime VCs are also not the only firms to offer these services, but the level of specific expertise and historical exposure to challenges in fielding military products should make this service attractive for certain startups and should increase the odds of a successful transition.

Defense-involved VCs had been using the Defense Ventures Fellows program to gain access to expertise in these defense areas, but that program was recently cancelled. As Shyam Sankar, the CTO of Palantir, noted the program was an “institution that’s had an outsized impact in providing the connective tissue between America’s greatest entrepreneurial innovators, and the innovators within defense” (Jeans, 2024). The transfer of investor and technology expertise back to the DoD was also highly impactful as participants noted that it changed their perspective and made them better acquisition professionals. Reinstating this program or one similar should be a priority for those in defense acquisition leadership roles.

The takeaway from this broad assessment should not be that the VCs in the defense space are mostly disengaged investors who have no experience in managing these defense complexities. It is abundantly clear that many have significant expertise in leadership, advisory boards and staff that can provide value in these defense areas. It is also likely that many engage consultants to provide insight where they have gaps in skillsets. It is also likely that most are “founder friendly” and highly engaged. A Harvard study that surveyed nearly 900 VCs found that most VCs are active advisors with 88% reporting that they “interact substantially” at least once a week and that they provide substantial post-investment services including strategic guidance (87%), connections to other investors (72%), connections to customers (69%), operational guidance (65%), help hiring board members (58%), and help hiring employees (46%; Gompers et al., 2021).

The primary takeaway from this assessment should be that there is not clear visibility into the services that different VCs provide to help startups with aspirations to provide solutions to DoD problems and the effectiveness of those offerings. This would not normally be the government’s concern except for the fact that VCs are playing an increasingly important and interconnected role in bringing cost-effective and innovative solutions into the DoD. The Air Force’s AFWERX organization was the first to recognize the value of private capital as part of its Prime and TACFI/STRATFI programs. To date, they have garnered a 12:1 ratio of private funding to SBIR dollars and tracked private investments of more than \$27 billion towards AFVentures SBIR/STTR portfolio companies (Air Force, 2022). They



also stood up a Capital Initiatives shop to leverage private capital and market insights as capability (Air Force, 2024). Space Force has signed Cooperative Research and Development Agreements with some VC firms to improve ties between government and startups (Erwin, 2021). The DoD has also formed the Office of Strategic Capital (OSC) and requested \$144 million in the FY25 President’s Budget to support loan guarantees and grants (Erwin, 2024). Some politicians worry about the deeper connections between government and private investors but they miss the bigger point that it is not about the danger of private money flowing into defense, but rather how to maximize those funds to solve the military’s intractable challenges (Lipton, 2023).

Ultimately, founders bear the responsibility if their company is a success, and VCs are responsible to their investors to deliver returns, so it is not realistic to expect every VC with a defense-oriented company in its portfolio to offer every service listed in Figure 8. Different VCs and startups have exit strategies that may not be dependent on winning large defense contracts—i.e., their dual-use focus has a “commercial-first” bent and if they see success there, defense contracts may never be pursued. However, the reason the DoD should care about what VCs are most effective in helping startups transition technology into military solutions is that in the growing panoply of VCs, there may be increasing chances to direct funds, loan guarantees, and collaboration opportunities to different VC entities. While VCs contribution to the national economy and commercialization of new technologies is critically important, Congress and the DoD should find ways to prioritize those firms that can help startups rapidly move an abstract technology into a military solution and create a defense market for new capabilities. AFWERX already includes a different ratio of required private investment to government investment depending on if the technology is dual use or defense focused (Figure 9; Air Force, 2024) This type of model may deserve emulation in different areas across the DoD.

	Defense-Only	Dual-Use
TACFI	1:1 SBIR/STTR: Gov	1:1 SBIR/STTR: Private
STRATFI	1:2 SBIR/STTR: Gov	1:1:2 SBIR/STTR: Gov: Private

Figure 9. AFWERX TACFI/STRATFI Matching Ratios

The DoD should also care where defense-oriented VCs are investing their funds. As Jake Chapman, partner at Marque Ventures, has noted, “We don’t really need any more small unmanned aerial systems (sUAS), but there are plenty of interesting areas, including contested communications, positioning, navigation and timing technologies in GPS denied environments, advanced manufacturing techniques suited to edge manufacturing or to dramatically ramp up domestic production; directed energy technologies, and contested logistics” (Alamalhodaiei, 2023). OSC has issued its first investment strategy that clearly outlines a role to focus on “component-level technologies with broad commercial application that are also relevant to the national security of the United States and its allies and partners” (Figure 10; DoD, 2024).

Initial Priority Areas for the First OSC Program Activity: SBIC Critical Technologies Initiative

Priority areas (and their related *Critical Technology Areas*) for the first OSC program activity: the Small Business Investment Company Critical Technologies Initiative. These priority areas are intended to be broad enough for investors to take a portfolio approach but narrow enough to increase investment in key industries. OSC will announce priority areas for additional program activities as they become available.

- Nanomaterials and Metamaterials (*Advanced Materials*)
- Bioenergetics (*Biotechnology*)
- Synthetic biology (*Biotechnology*)
- Open RAN (*FutureG and 5G*)
- Sensor hardware (*Integrated Sensing and Cyber*)
- Assembly, Testing, and Packaging (*Microelectronics*)
- Materials (*Microelectronics*)
- Quantum computing (*Quantum Science*)
- Quantum security (*Quantum Science*)
- Quantum sensing (*Quantum Science*)
- Battery storage (*Renewable Energy Generation and Storage*)
- Space-enabled services and equipment (*Space Technology*)

Figure 10. Initial OSC Priority Areas

If the DoD can maintain awareness, likely through the OSC office, on the technology areas that defense-involved VCs are gravitating to, they can potentially send a clearer demand signal if major capability areas are being underrepresented. Quantum tech, for instance, may be more unrepresented than desired given the potential defense applications (see Figure 11 Bradbury, 2023). This is likely why OSC has prioritized quantum in their investment areas and why there may be other opportunities to subtly influence more private investment that has an interest in tapping into the defense space. Jackson Moses, founder and managing partner of Silent Ventures noted that there are also “unsexy areas of manufacturing, supply chain and logistics [that] offer a great opportunity for disruption and new companies and new approaches to be developed—[and are] very large markets that have not benefited from full modernization and will be vital for true national security” (Alamalhodaie, 2023). Tools could include advanced market commitments (AMCs) that can “guarantee a viable initial market for a product once it is successfully developed” (Ho & Taylor, 2021). VCs could establish industry forums for defense-centric areas for collaborative discussions with the DoD on future strategic efforts. There is a lot more creativity that can be applied to creating subtle channels of communication to help ensure that private capital with defense market goals generate the highest impact and improve a VC/startup’s chance of success.

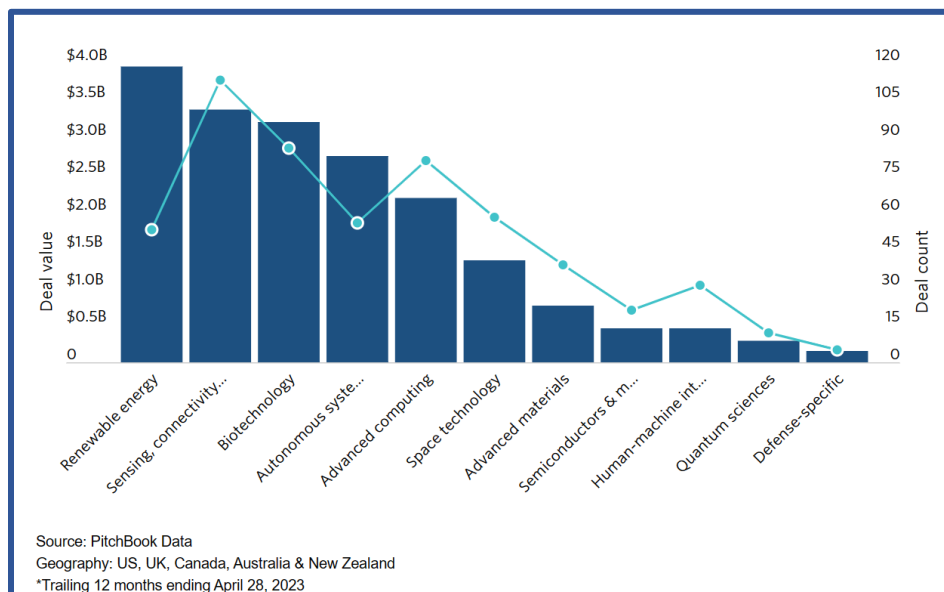


Figure 11. VC Technology Investment Areas

Going Forward

The focus on how VCs with an interest in the defense space can support transition of innovative technology is not intended to be a substitute for the DoD's responsibility in this area. The DoD needs to continue making progress on developing streamlined transition pathways for young, innovative companies and setting clear demand signals for industry to understand their greatest needs. There needs to be greater emphasis on moving more awards to non-traditional companies beyond the paltry amounts noted in this paper.

However, the DoD also needs to be proactive in using all of the resources at its disposal to make progress against the numerous capability gaps that still exist in the U.S. and allied military forces. There is an incredible amount of progress already happening in the commercial sector that the DoD needs to integrate and field. But given the size of the defense budget and the hopefully increasing amount of funding moving to new or emerging players in the space, the DoD also has the opportunity to influence how private investment is leveraged to address current needs and ensure continued focus as threats change over time. This influence can likely be achieved in multiple ways, beyond the good work of AFWERX and OSC.

It could include greater collaboration with organizations like R&E, AFWERX, SOFWERX, and Space Force Front Door that are working to connect startups with program offices and potentially support the co-development of transition strategies with open feedback loops from users. It could include the use of AMCs in certain tech areas to draw more funding. It could include tracking metrics on the most defense friendly VC firms (those actively engaged in transition success) to continue to incentivize those behaviors and encourage others. It could consist of other incentives that give preference to VC firms who are willing to invest in the unsexy but important areas and also in areas where more patient capital is needed. It certainly includes the award of more contracts to startups where VCs are already taking risks so that the desire to remain in the defense space continues to be attractive.

With all these things considered, VCs can serve as transition partners with their founders, the DoD, industry, and Congress.

VCs as Transition Partners with Founders: Defense-involved VCs can act as transition partners with their founders by focusing on long term return on investments and providing a variety of services to include strategic relationships, client introductions, branding, and DoD sector expertise. VCs can also help the startup focus on strategies for user engagement and compliance with cyber and security requirements. This includes creating realistic pathways for sales and marketing as well as integration of the product into weapon systems.

VCs as Transition Partners with the DoD: VCs can act as transition partners with the DoD by engaging in proactive, collaborative discussions to change the policies, incentives, and culture of the DoD. This includes highlighting the value proposition VCs brings to the DoD, identifying challenges, and proposing realistic solutions. Many VCs rely on the DIU to act as interpreter for the DoD. While the DIU will be long remembered as establishing the first DoD beachhead in Silicon Valley, there is no reason why VCs can't engage with the larger DoD directly. But to do so, VCs need a clear understanding of the RIFT (requirements, funding, and transition) processes and barriers.

VCs as Transition Partners with Industry: Defense-involved VCs can act as transition partners for industry by offering market research and introductions to startups with products ripe for integration in larger weapon systems. VCs can also support industry sectors with a pipeline of people, ideas, and products to continue to help established industry push existing technology limits .



VCs as Transition Partners with Congress: The laws enacted at the federal and state level are only as good as the feedback from the constituents the laws affect. VCs can act as transition partners with Congress by joining the public policy conversation and engaging on specific actionable solutions. Advocating for targeted appropriations should be balanced with engaging on policy solutions like embracing industry standards for open systems designs, defining requirements as capabilities instead of platforms, and organizing funding in portfolios.

In addition to offering ways VCs can serve as transition partners, this paper also provides a framework to build upon and to help both VCs and the DoD be more strategic as they garner more private investment and strive to be better partners for the advancement of national security.

As Steve Escavara and Adam Hammer, both private investors, have noted, Lacking a coherent strategy, the United States is leaving billions in private and public dollars on the table that could help shore up the nation's defense capabilities. The United States is ceding ground to China, which threatens the international order. The Pentagon must use its resources to leverage U.S. capital markets—one of our enduring advantages in strategic competition—and help promising dual-use tech companies scale, innovate, and deliver for the benefit of global democracy. (Escavara & Hammer, 2023)

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Assessing the Impact of DoD-Funded Assistance Projects on the Availability of New Warfighting Capabilities

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Abstract

The Department of Defense (DoD) spends billions of dollars annually on efforts intended to advance warfighting capabilities. This funding takes the form of “procurements” and “assistance.” Procurements, or government contracts, refer to the U.S. government (USG) acquiring property or services for the direct benefit-of or use-by the USG. “Assistance” refers to the transfer of a thing of value to the USG to carry out a public purpose or stimulation. Assistance includes grants, loans, and cooperative agreements; and since 2010, the DoD has outlaid nearly \$1 trillion in assistance awards. Grants and cooperative agreements pertaining to research and development (R&D) account for the majority of DoD assistance. Although assistance represents a significant and critical component of DoD resourcing for innovation, limited scholarship exists to assess the nature and effectiveness of such funding. In this paper, we leverage public data from USASpending to analyze defense-funded assistance awards from fiscal year (FY) 2018 through FY 2023. We explore the distribution of R&D-focused grants and cooperative agreements to better understand the nature of DoD-funded projects, as well as the pool of entities in receipt of the funding. Comparing these results to findings from our earlier research, which focused on procurement-funded DoD innovation initiatives, revealed that the pool of entities in receipt of assistance awards has remained comparatively stable. However, analyzing aspects of assistance data that contain information about the purpose of the funding, we found a disconnect between the military's stated priorities and direction of funds. We also identified significant duplication in efforts, along with a lack of synergy between projects funded via assistance, and DoD procurement. We offer a series of recommendations for the DoD to better coordinate its funding strategies to more effectively develop and deliver advancements in warfighting capabilities.

Introduction

The Department of Defense (DoD) spends billions of dollars annually to stimulate research and development (R&D). As the United States contends with dynamic security threats on multiple fronts, one important purpose for DoD-funded R&D is to improve military warfighting capabilities. Whereas our previous research focused primarily on assessing the extent to which DoD procurement initiatives resulted in new capabilities reaching the warfighter, a significant portion of DoD funding for R&D is directed through grants, cooperative agreements, and other forms of Federal Financial Assistance (“assistance”). In this paper, we sought to better understand how the DoD directs assistance funding in general and the ways in which it contributes to military innovation.



Procurements vs. Assistance

There are two forms of federal spending: “procurements” and “Federal Financial Assistance” (“assistance”). Procurements, or government contracts, refer to the U.S. government (USG) acquiring property or services for its direct benefit or use. Assistance refers to the transfer of a thing of value—most commonly, money—by the USG to “eligible recipients to support or stimulate a public purpose” (Grants.gov, n.d-a).

Analyzing Defense-Funded Assistance

The USG is required to publicize detailed information about federal spending at the unclassified level, and the official source for aggregating assistance funding is USASpending.gov (“USASpending”).¹ To analyze DoD assistance, we downloaded assistance award data in bulk from USASpending and filtered the data for assistance awards funded by the DoD from fiscal year (FY) 2018 through FY2023 (“analysis period”). Figure 1 shows total DoD assistance outlays annually. **From FY2018–FY2023, the DoD obligated more than \$51.7 billion in assistance, and DoD assistance funding grew approximately 54% over that period.**

Fiscal Year	Total DoD Assistance Funding
2018	\$6,617,043,955
2019	\$7,618,583,833
2020	\$9,222,099,811
2021	\$8,298,107,140
2022	\$9,832,531,017
2023	\$10,187,578,149
Total	\$51,775,943,906

Figure 1. DoD Assistance Funding, FY2018–FY2023

Types of Assistance

There are several forms of assistance, and USASpending classifies each assistance award by type. As shown in Figure 2, cooperative agreements and grants account for the majority of assistance funding.

Assistance Award Type	DoD Obligations, FY2018-FY2023
COOPERATIVE AGREEMENT	\$31,866,684,634
PROJECT GRANT	\$16,710,079,461
OTHER REIMBURSABLE, CONTINGENT, INTANGIBLE, OR INDIRECT FINANCIAL ASSISTANCE	\$2,695,948,421
BLOCK GRANT	\$353,110,170
DIRECT PAYMENT FOR SPECIFIED USE, AS A SUBSIDY OR OTHER NON-REIMBURSABLE DIRECT FINANCIAL AID	\$92,503,121
FORMULA GRANT	\$57,618,100

Figure 2. DoD-Funded Assistance by Award Type, FY2018–FY2023

¹ Given the nature of publicly-available USG spending data, we did not have access to information about assistance funding in the classified realm.

Who Receives DoD-Funded Assistance?

Each assistance award is assigned a unique identifying number known as a Federal Award Identification Number (FAIN), and USASpending contains a mandatory field for the FAIN. A FAIN is considered the primary unique identifier for an assistance award.

Because an entity can win multiple assistance awards, there are significantly more unique FAINs than unique awardees. To determine how many entities received DoD-funded assistance during our analysis period, we filtered each FAIN by its associated Unique Entity Identifier (UEI) and calculated the total number of unique UEIs, as shown in Figure 3. **The number of unique entities in the assistance realm grew 16% from FY2018 to FY2023.**

Fiscal Year	Count, Unique FAINs	Count, Unique Awardees
2018	11,233	1774
2019	12,230	1836
2020	12,963	1945
2021	13,748	1963
2022	14,483	2041
2023	14,996	2061

Figure 3. Total DoD Assistance Awardees Annually

Assistance award data from USASpending also contains a field for business type, so we then grouped UEIs by their USASpending-assigned business type. Figure 4 provides a breakdown of the \$51.7 billion in DoD-funded assistance by business type, and Figure 5 provides a breakdown of assistance awardees by business type in each year.²

Business Type	Total Obligations, FY2018-FY2023	Count, Unique Entities
STATE GOVERNMENT	\$15,168,587,623	277
PUBLIC/STATE CONTROLLED INSTITUTION OF HIGHER EDUCATION	\$13,784,597,987	495
NONPROFIT WITH 501C3 IRS STATUS	\$6,694,894,445	763
PRIVATE INSTITUTION OF HIGHER EDUCATION	\$5,858,347,288	277
FOR-PROFIT ORGANIZATION OTHER THAN SMALL BUSINESS	\$3,823,262,941	459
FOR-PROFIT ORGANIZATION SMALL BUSINESS	\$3,201,860,378	435
SPECIAL DISTRICT GOVERNMENT	\$1,002,121,654	65
INDEPENDENT SCHOOL DISTRICT	\$626,138,337	124
NONPROFIT WITHOUT 501C3 IRS STATUS	\$581,343,367	54
NON-DOMESTIC ENTITY	\$331,550,619	359
COUNTY GOVERNMENT	\$316,950,471	77
CITY OR TOWNSHIP GOVERNMENT	\$238,334,936	88
INDIAN/NATIVE AMERICAN TRIBAL GOVERNMENT/ORGANIZATION	\$78,267,550	42
REGIONAL ORGANIZATION	\$37,921,171	16
INDIVIDUAL	\$31,599,154	4

² Negative obligations can occur for a variety of reasons, including accidental overpayments that result in entities returning funds and/or administrative errors when data is uploaded into USASpending.

HISTORICALLY BLACK COLLEGE OR UNIVERSITY	\$763,270	3
PUBLIC/INDIAN HOUSING AUTHORITY	\$242,606	3
UNDISCLOSED	-\$839,892	4

Figure 4. DoD Assistance Funding, by Business Type, FY2018–FY2023

Business Type	Count of Unique Entities, FY2018	Count of Unique Entities, FY2019	Count of Unique Entities, FY2020	Count of Unique Entities, FY2021	Count of Unique Entities, FY2022	Count of Unique Entities, FY2023
CITY OR TOWNSHIP GOVERNMENT	31	28	33	39	34	35
COUNTY GOVERNMENT	31	31	32	36	25	34
FOR-PROFIT ORGANIZATION OTHER THAN SMALL BUSINESS	128	149	190	219	251	261
FOR-PROFIT ORGANIZATION SMALL BUSINESS	157	187	209	200	196	213
HISTORICALLY BLACK COLLEGE OR UNIVERSITY	0	0	0	0	0	3
INDEPENDENT SCHOOL DISTRICT	50	60	58	60	44	56
INDIAN/NATIVE AMERICAN TRIBAL GOVERNMENT/ORGANIZATION	17	26	23	28	27	26
INDIVIDUAL	4	1	2	1	2	2
NON-DOMESTIC ENTITY	247	216	188	164	157	141
NONPROFIT WITH 501C3 IRS STATUS	380	404	440	450	483	448
NONPROFIT WITHOUT 501C3 IRS STATUS	21	24	31	34	34	35
PRIVATE INSTITUTION OF HIGHER EDUCATION	169	165	169	167	196	197
PUBLIC/INDIAN HOUSING AUTHORITY	0	0	0	1	2	2
PUBLIC/STATE CONTROLLED INSTITUTION OF HIGHER EDUCATION	321	327	331	334	352	370
REGIONAL ORGANIZATION	5	4	10	6	9	2
SPECIAL DISTRICT GOVERNMENT	20	23	25	34	30	35
STATE GOVERNMENT	192	190	204	189	198	199
UNDISCLOSED	1	1	0	1	1	2

Figure 5. DoD Assistance Funding, by Entity Type, Annually

Next, for each year, we calculated the number of distinct awardees by business type with no prior defense revenue (no prior direct or indirect defense-funded procurement



contracts or assistance awards).³ As shown in Figure 6, **33% of “For Profit Organizations, Other Than Small Businesses” and 38% of “For Profit Small Businesses” that received DoD assistance funding between FY2018–FY2023 had no prior defense business.** The presence of entities new to the DoD indicates that expansion in assistance awardees is not solely the result of entrenched defense contractors expanding their market share via assistance awards.

Business Type	Count, Unique Entities	Entities New to DoD	% of Entities New to DoD
FOR-PROFIT ORGANIZATION OTHER THAN SMALL BUSINESS	459	151	33%
FOR-PROFIT ORGANIZATION SMALL BUSINESS	435	164	38%

Figure 6. New Entrants, “For-Profit Other than Small” & “For-Profit Small” Businesses- FY2018–FY2023

DoD Assistance Awardees Buck DIB Trends

Growth in assistance entities, and the fact that assistance programs attracted new entrants into the defense market, contrast the trends in the overall defense industrial base (DIB). In our 2020 research, we found that the number of unique entities working with the DoD shrank 36% from FY2010 to FY2019 (Bresler & Bresler, 2020). The share of new entrants into the defense market annually consolidated at an even greater rate: In 2010, 19% of entities working with the DoD had no prior defense business, compared to just 9% in 2019. Additional research is required to better understand what factors contributed to the growth in DoD assistance entities, particularly among for-profit companies with no ties to the defense market. It is important to determine if the growth was simply a byproduct of the significant expansion in overall DoD assistance spending or if it is the result of a concerted strategy.

Research Limitation: Assistance Entities as USG Intermediaries

Several of the entity types in the assistance realm—including the various government entities, institutes of higher education, and nonprofits with and without 501C3 IRS statuses—typically function as intermediaries between the USG and the ultimate recipients of assistance funding. In other words, these entities are the prime awardees and allocate a portion of the award funding to their administrative/overhead costs. However, they distribute the majority of the funding to sub-awardees via sub-assistance awards. We will refer to these types of entities as “allocators.” Whereas this paper leveraged publicly-available data at the prime level, in future research we recommend incorporating sub-assistance award/awardee data from USASpending. Doing so will enable a clearer, more specific understanding of the types of projects funded by DoD assistance.

Federal Assistance Programs

Assistance is directed through Federal financial assistance programs (“assistance programs”). SAM.gov maintains a catalog of assistance programs, which provides detailed descriptions of all distinct assistance programs. Each assistance program also has a corresponding Catalog of Federal Domestic Assistance (CFDA) identifier (ID), and USASpending data contains a field for CFDA. For all DoD-funded assistance awards during the analysis period, we linked the CFDA field from USASpending to the detailed descriptions

³ We joined data from the Federal Procurement Data System (FPDS), which contains data related to procurement awards.

of each assistance program from SAM.gov. We determined that the DoD obligated funding through 90 assistance programs from FY2018–FY2023, listed in Figure 7.

Assistance for R&D

Financial assistance is extremely broad, encompassing the “transfer of anything of value, most often money, from a federal agency to a non-federal entity” (Grants.gov, n.d-b). Accordingly, the 90 DoD-funded assistance programs were wide ranging and included many programs unrelated to R&D (e.g., “Air Force Academy Athletic Programs,” “Troops to Teachers Grant Program,” and “Youth Conservation Services”).

Because we were specifically interested in understanding how DoD assistance funding contributes to military R&D and innovation, we needed to isolate DoD assistance award data associated with R&D for further analysis. To do so, we reviewed the CFDA IDs associated with the 90 DoD-funded assistance programs and included all assistance programs that referenced “research” and/or “research and development” in the program name and/or CFDA ID. For the remaining assistance programs, we reviewed award details associated with their CFDA IDs to better understand the nature of their programs, and we included programs that appeared to relate to R&D and/or innovation. **We shortlisted 22 of the 90 DoD-funded assistance programs for further analysis on the basis that they pertained to R&D.** These programs (“DoD R&D Assistance Programs”) are highlighted in blue in Figure 7.⁴

Assistance Program	Assistance Program	Assistance program
NATIONAL GUARD MILITARY OPERATIONS AND MAINTENANCE PROJECTS	COLLABORATIVE RESEARCH AND DEVELOPMENT - CONSTRUCTION PRODUCTIVITY ADVANCEMENT RESEARCH CPAR PROGRAM	MILITARY HEALTH SERVICES RESEARCH
MILITARY MEDICAL RESEARCH AND DEVELOPMENT	ECONOMIC ADJUSTMENT ASSISTANCE FOR STATE GOVERNMENTS	SCIENCE, TECHNOLOGY, BUSINESS AND/OR EDUCATION OUTREACH
BASIC AND APPLIED SCIENTIFIC RESEARCH	READINESS AND ENVIRONMENTAL PROTECTION INTEGRATION PROGRAM - DOD REPI PROGRAM	TRANSPORTATION - DASH 102X AND WMATA 7M SHUTTLES - DASH 102X ROUTE AND WMATA 7M ROUTE
AIR FORCE DEFENSE RESEARCH SCIENCES PROGRAM	PAST CONFLICT ACCOUNTING - DEFENSE POW/MIA ACCOUNTING AGENCY DPAA PAST CONFLICT ACCOUNTING GRANTS AND COOPERATIVE AGREEMENTS PROGRAM DPAA GCAP	COMMUNITY ECONOMIC ADJUSTMENT ASSISTANCE FOR REDUCTIONS IN DEFENSE INDUSTRY EMPLOYMENT
BASIC SCIENTIFIC RESEARCH	THE LANGUAGE FLAGSHIP GRANTS TO INSTITUTIONS OF HIGHER EDUCATION - THE LANGUAGE FLAGSHIP	INTERNSHIPS, TRAINING AND WORKSHOPS FOR THE OFFICE OF AIR AND RADIATION
RESEARCH AND TECHNOLOGY DEVELOPMENT	AIR FORCE ACADEMY ATHLETIC PROGRAMS	SPACE TECHNOLOGY - STMD, SPACE TECH
COMMERCIAL TECHNOLOGIES FOR MAINTENANCE ACTIVITIES PROGRAM - CTMA	SCIENCE, TECHNOLOGY, ENGINEERING & MATHEMATICS EDUCATION, OUTREACH AND WORKFORCE PROGRAM	NATIONAL GUARD MILITARY CONSTRUCTION 12.400
BASIC, APPLIED, AND ADVANCED RESEARCH IN SCIENCE AND ENGINEERING	DEPARTMENT OF DEFENSE APPROPRIATION ACT OF 2003	COMMUNITY ECONOMIC ADJUSTMENT ASSISTANCE FOR REDUCTIONS IN DEFENSE SPENDING

⁴ Determining which DoD assistance programs to analyze on the basis of their relationship to R&D was inherently subjective, and we recognize that not all readers may agree with the programs we selected.



UNIFORMED SERVICES UNIVERSITY MEDICAL RESEARCH PROJECTS - UNIFORMED SERVICES UNIVERSITY USU	COMMUNITY ECONOMIC ADJUSTMENT ASSISTANCE FOR REALIGNMENT OR CLOSURE OF A MILITARY INSTALLATION	ARMY NATIONAL GUARD ARMY COMPATIBLE USE BUFFER PROGRAM - NGB ACUB
DEFENSE PRODUCTION ACT TITLE III - DPA TITLE III	RESEARCH AND TECHNICAL ASSISTANCE	FLOOD PLAIN MANAGEMENT SERVICES
MILITARY CONSTRUCTION, NATIONAL GUARD	HIGHWAY PLANNING AND CONSTRUCTION - FEDERAL-AID HIGHWAY PROGRAM, FEDERAL LANDS HIGHWAY PROGRAM	RESEARCH GRANTS
RESEARCH ON CHEMICAL AND BIOLOGICAL DEFENSE	FISHER HOUSE FOUNDATION	LANGUAGE GRANT PROGRAM - STARTALK
NATIONAL GUARD CHALLENGE PROGRAM - NATIONAL GUARD YOUTH CHALLENGE PROGRAM	RESEARCH AND DEVELOPMENT - MEDICAL AND PROSTHETIC RESEARCH AND DEVELOPMENT	DREDGED MATERIAL CONTAINMENT AREA - DITCHING WITHIN THE DREDGED MATERIAL CONTAINMENT AREA
COMMUNITY INVESTMENT	DOD, NDEP, DOTC-STEM EDUCATION OUTREACH IMPLEMENTATION	AGRICULTURAL RESEARCH BASIC AND APPLIED RESEARCH - EXTRAMURAL RESEARCH
SCIENTIFIC RESEARCH - COMBATING WEAPONS OF MASS DESTRUCTION	PACIFIC CENTER DISASTER PROGRAM - PDC DISASTER-AWARE COOPERATIVE AGREEMENT	PLANNING ASSISTANCE TO STATES
CONSERVATION AND REHABILITATION OF NATURAL RESOURCES ON MILITARY INSTALLATIONS - SIKES ACT	TROOPS TO TEACHERS GRANT PROGRAM - TROOPS TO TEACHERS PROGRAM	NAVY COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE - C4ISR
SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS EDUCATIONAL PROGRAM: SCIENCE, MATHEMATICS AND RESEARCH FOR TRANSFORMATION - SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS STEM	COMMUNITY ECONOMIC ADJUSTMENT ASSISTANCE FOR RESPONDING TO THREATS TO THE RESILIENCE OF A MILITARY INSTALLATION - COMMUNITY ECONOMIC ADJUSTMENT ASSISTANCE FOR MILITARY INSTALLATION RESILIENCE	UPPER SAN PEDRO PARTNERSHIP SUPPORT - UPPER SAN PEDRO PARTNERSHIP
CIVIL AIR PATROL PROGRAM	YOUTH CONSERVATION SERVICES	AIR FORCE MEDICAL RESEARCH AND DEVELOPMENT
CONGRESSIONALLY DIRECTED ASSISTANCE - ANNUAL CONGRESSIONALLY DIRECTED ASSISTANCE	COMMUNITY ECONOMIC ADJUSTMENT ASSISTANCE FOR ESTABLISHMENT OR EXPANSION OF A MILITARY INSTALLATION	FAIR HOUSING ASSISTANCE PROGRAM - FHAP
COMPETITIVE GRANTS: PROMOTING K-12 STUDENT ACHIEVEMENT AT MILITARY-CONNECTED SCHOOLS - THE DEPARTMENT OF DEFENSE EDUCATION ACTIVITY DODEA EDUCATIONAL PARTNERSHIP GRANT PROGRAM.	PEST MANAGEMENT AND VECTOR CONTROL RESEARCH - DEPLOYED WARFIGHTER PROTECTION PROGRAM	WATER USE AND DATA RESEARCH - WUDR
DEPARTMENT OF DEFENSE HIV/AIDS PREVENTION PROGRAM - DHAPP	MARINE CORPS SYSTEMS COMMAND FEDERAL ASSISTANCE PROGRAM	DONATIONS/LOANS OF OBSOLETE DOD PROPERTY
PROCUREMENT TECHNICAL ASSISTANCE FOR BUSINESS FIRMS - APEX ACCELERATOR PROGRAM/PROCUREMENT TECHNICAL ASSISTANCE PROGRAM PTAP	EASE 3.0 - EFFECTIVE ABSENTEE SYSTEMS FOR ELECTIONS 2.0	ORGANIZATION OF AMERICAN STATES PROGRAMS
STATE MEMORANDUM OF AGREEMENT PROGRAM FOR THE REIMBURSEMENT OF TECHNICAL SERVICES - DSMOA	MATHEMATICAL SCIENCES GRANTS - MSP	ESTUARY HABITAT RESTORATION PROGRAM
COMMUNITY ECONOMIC ADJUSTMENT ASSISTANCE FOR COMPATIBLE USE AND	DOD MENTOR-PROTEGE PROGRAM - DOD MP PROGRAM	FORT HUACHUCA SENTINEL LANDSCAPES FOR MILITARY TRAINING -



JOINT LAND USE STUDIES		SENTINEL LANDSCAPES
NATIONAL DEFENSE EDUCATION PROGRAM - STEM EDUCATION, OUTREACH, AND WORKFORCE DEVELOPMENT INITIATIVES	PARTNERSHIP AGREEMENTS	DISSERTATION YEAR FELLOWSHIP - CMH DISSERTATION FELLOWSHIP
NAVAL MEDICAL RESEARCH AND DEVELOPMENT	COMMUNITY ECONOMIC ADJUSTMENT ASSISTANCE FOR ADVANCE PLANNING AND ECONOMIC DIVERSIFICATION	NATIVE AMERICAN CONSULTATION TO IDENTIFY SACRED SITES AND TRADITIONAL CULTURAL PROPERTIES
LEGACY RESOURCE MANAGEMENT PROGRAM - DOD LEGACY PROGRAM	CENTERS FOR ACADEMIC EXCELLENCE	WILDLIFE SERVICES
ENGLISH FOR HERITAGE LANGUAGE SPEAKERS GRANTS TO U.S. INSTITUTIONS OF HIGHER EDUCATION - NATIONAL SECURITY EDUCATION PROGRAM NSEP	STARBASE PROGRAM - STARBASE	WATER CONSERVATION FIELD SERVICES - WATER CONSERVATION FIELD SERVICES PROGRAM WCFSP
TRAINING AND SUPPORT COMBATING WEAPONS OF MASS DESTRUCTION	PAST CONFLICT ACCOUNTING - VIETNAM - COOPERATIVE PROGRAM WITH VIETNAM TO ACCOUNT FOR VIETNAMESE PERSONNEL MISSING IN ACTION.	ROTC LANGUAGE AND CULTURE TRAINING GRANTS - ROTC PROJECT GO GLOBAL OFFICERS
ELECTRONIC ABSENTEE SYSTEMS FOR ELECTIONS	EMERGENCY REHABILITATION OF FLOOD CONTROL WORKS OR FEDERALLY AUTHORIZED COASTAL PROTECTION WORKS	AQUATIC PLANT CONTROL

Figure 7. Federal Assistance Programs in Receipt of DoD Funding, FY2018–FY2023. Programs highlighted in blue correspond to “DoD R&D Assistance Programs.”

DoD-Funded Assistance for R&D

As shown in Figure 8, DoD R&D assistance programs received more than half of all DoD assistance funding, and assistance funding for R&D nearly doubled from FY2018–FY2023.

Fiscal Year	Total DoD Assistance Funding	Total DoD R&D Assistance Funding
2018	\$6,617,043,955	\$3,805,222,335
2019	\$7,618,583,833	\$4,521,258,181
2020	\$9,222,099,811	\$5,576,549,778
2021	\$8,298,107,140	\$5,093,791,396
2022	\$9,832,531,017	\$6,213,365,287
2023	\$10,187,578,149	\$6,106,604,741
Total	\$51,775,943,906	\$31,316,791,717

Figure 8. Total DoD Assistance Funding vs. DoD R&D Assistance Funding, Annually

DoD R&D Assistance Entities

Calculating the number of unique entities that received DoD R&D assistance funding (“DoD R&D entities”) in each year, we found that the number of DoD R&D entities grew 14.4% during our analysis period, as shown in Figure 9.



Fiscal Year	Count, R&D FAINs	Count, Unique R&D Assistance Awardees
2018	9376	1375
2019	10,264	1421
2020	10,793	1485
2021	11,068	1491
2022	11,613	1586
2023	12,045	1574

Figure 9. Entities in Receipt of DoD R&D Assistance, Annually

Allocators & Sub-Assistance

Next, we filtered DoD R&D assistance funding by business type. As shown in Figure 10, allocators received most DoD R&D assistance funding, highlighting the military's dependence on universities, consortia, and other intermediaries to facilitate R&D.

Business Type	Total R&D Assistance Obligations, FY2018-FY2023	Count, Unique Entities
PUBLIC/STATE CONTROLLED INSTITUTION OF HIGHER EDUCATION	\$13,774,126,849	491
NONPROFIT WITH 501C3 IRS STATUS	\$6,442,893,490	622
PRIVATE INSTITUTION OF HIGHER EDUCATION	\$5,056,159,376	238
FOR-PROFIT ORGANIZATION OTHER THAN SMALL BUSINESS	\$3,863,162,448	437
FOR-PROFIT ORGANIZATION SMALL BUSINESS	\$955,849,603	424
NONPROFIT WITHOUT 501C3 IRS STATUS	\$650,042,132	45
NON-DOMESTIC ENTITY	\$301,404,213	381
STATE GOVERNMENT	\$172,685,437	33
COUNTY GOVERNMENT	\$55,385,104	13
CITY OR TOWNSHIP GOVERNMENT	\$19,652,451	16
INDIVIDUAL	\$10,751,158	4
INDEPENDENT SCHOOL DISTRICT	\$6,539,447	10
REGIONAL ORGANIZATION	\$3,443,539	4
INDIAN/NATIVE AMERICAN TRIBAL GOVERNMENT/ORGANIZATION	\$2,403,977	2
OTHER 5 OTHER ENTITY TYPES	\$2,292,491	13

Figure 10. DoD R&D Assistance Funding by Business Type, FY2018–FY2023



Sub-Award Analysis: HQ002420200007

Although we did not comprehensively analyze sub-assistance in this paper, we joined the sub-assistance data from USASpending for the largest DoD R&D assistance award in the data set.⁵ The prime recipient was the National Center for Manufacturing Sciences, Inc. (NCMS). NCMS, a nonprofit with 501C3 IRS status, is a member-based, cross-industry technology development consortium that lists a range of technology focus areas on its website, including 3D Printing, Robotics, and Cyber Security (National Center for Manufacturing Sciences, 2023). From the initial award action in March 2020 to the most recent publicly-available award action in September 2023, total award obligations for this award exceeded \$1.4 billion. Based on the sub-assistance data we pulled, NCMS allocated more than \$1.2 billion—approximately 84% of the total award funding—to sub-awardees across 530 sub-awards. Sub-awardees included nonprofits, universities, small/disadvantaged businesses, large for-profit companies like Siemens, Booz Allen, and Boeing; and other entity types. Each sub-award contained an award description that offered insight into the purpose of the sub-award.

The magnitude of this subaward data reinforces the need to incorporate it into future research to better understand the types of projects funded through DoD R&D assistance and capture better insights on the types of entities involved in this work. Follow-on research should also aim to establish a clearer picture of the role of the allocator in general. For instance, why do allocators exist, and how have their functions and strategies evolved, given that a significant share of R&D now occurs in the commercial realm? How do they market their opportunities to stakeholders outside of the traditional defense/USG market to ensure they do not favor entrenched entities that understand the system over those with the most promising R&D?

R&D For-Profit Companies

Approximately 15% of DoD R&D assistance funding was awarded to “For Profit Organizations, Other Than Small Businesses” and “For Profit Small Businesses” (collectively, “R&D for-profit companies”). Calculating the share of for-profit R&D companies with no prior DoD funding, we found that 32% of “For Profit Organizations, Other Than Small Businesses” and 38% of “For Profit Small Businesses” were new to the DoD, as shown in Figure 11.

Business Type	Count, Unique R&D Entities	Entities New to DoD	% of Entities New to DoD
FOR-PROFIT ORGANIZATION OTHER THAN SMALL BUSINESS	437	138	32%
FOR-PROFIT ORGANIZATION SMALL BUSINESS	424	161	38%

Figure 11. New DoD Entrants, “For-Profit Other than Small” & “For-Profit Small” Businesses- FY2018–FY2023- DoD R&D Assistance

We then calculated the number of R&D for-profit companies with no prior USG funding versus those that were new to the defense market but had directly or indirectly received funding from non-DoD agencies. **Approximately 84% of R&D for-profit companies with no prior defense funding had prior USG funding from non-DoD sources, whereas ~16% had no prior USG funding whatsoever.**

⁵ The FAIN for this award is HQ002420200007.



Our earlier research revealed that the military writ large—including procurement-funded DoD innovation initiatives—struggles to attract new entrants. From FY2010–FY2019, more than 90% of Phase I Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) funding was awarded to entrenched DoD suppliers (Bresler & Bresler, 2020).

Anti-competitive solicitation practices and arcane requirements are among the key reasons it is nearly impossible for new entrants to break into the DIB making (Bresler & Bresler, 2021). Although further research is required to better understand how they conduct their outreach and engagement, **our preliminary analysis suggests that DoD R&D assistance programs may make it easier for non-entrenched companies to participate. As the DoD implements new policies and programs aimed at preserving and expanding the DIB, DoD leaders should study assistance programs to identify possible best practices.**

Exploring R&D Assistance Awards: Trelliscope

To enhance our analysis of DoD R&D assistance, we leveraged Trelliscope, an open-source tool for managing, sorting, and visualizing data (Trelliscope, n.d). We built two Trelliscopes: one containing data associated with 26,569 unique R&D assistance awards during the analysis period (“Award Trelliscope;” [Trelliscope: DoD R&D Assistance Awards, FY2018-FY2023](#),”) and another containing data related to 2,733 unique entities that received R&D assistance awards during the analysis period (“Awardee Trelliscope;” [Trelliscope: DoD R&D Assistance Awardees, FY2018-FY2023](#)). Figure 12 provides screenshots of both Trelliscopes.

Functionally, Trelliscope is an interactive dashboard that allows users to sort and filter data based on any of the underlying fields. The panel on the left side of the screen contains fields from the data that users can explore. Additionally, users can easily add, remove, and/or reorder visible fields from the left panel. In the case of the Award Trelliscope, the panels to the right represent distinct R&D assistance awards, and the data contained in each panel highlights key aspects of the award, such as its corresponding assistance program, award description, and dollar value. In the case of the Awardee Trelliscope, each panel to the right represents a distinct entity that received DoD R&D assistance funding. The default view populates each panel with pertinent information, including the entity type, entity name (coded as “Company”), and the date of the entity’s first award.

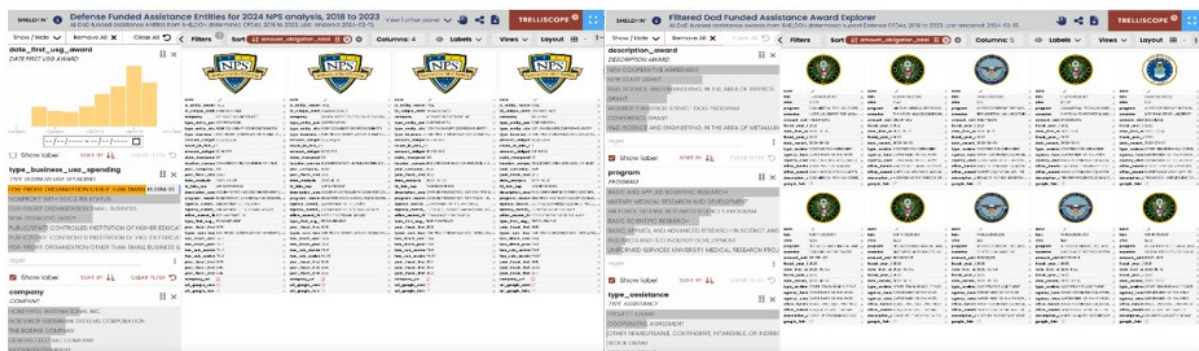


Figure 12. DoD R&D Award Trelliscope; DoD R&D Awardee Trelliscope

Research Limitation & Future Research

Exploring the Award Trelliscope, we noticed that some awards contained no useful text in the “award description” field. For instance, 89 awards contained only “NEW

COOPERATIVE AGREEMENT” in the description field. Hundreds more contained only “GRANT,” “CONFERENCE GRANT,” “NEW START GRANT,” “NEW REP GRANT,” “NEW START,” or other terms that offered no meaningful information about the purpose of the grant. Furthermore, as previously mentioned, allocators received a significant share of assistance awards. For many of these awards, the award description at the prime level included information about the administrative function(s) that the entity performed, rather than details about specific R&D projects funded at the sub-award level.

This research relied on text from the award descriptions for textual analysis, so the absence of useful information for a subset of awards was limiting. In addition to incorporating subaward data into future research, the Defense Technical Information Center (DTIC) maintains a library of publicly-available reports, abstracts, peer-reviewed publications, and other information about completed R&D/Science and Technology (S&T) projects funded by the DoD, which can often be linked back to the FAIN that funded the work. We recommend joining this information into future research to enable a more comprehensive understanding of DoD assistance projects.

How is DoD R&D Assistance Directed?

To establish a general picture of the types of projects funded via DoD R&D assistance, we calculated the total share of DoD R&D assistance funding directed into each DoD R&D assistance program during the analysis period. As shown in Figure 13, **“Military Medical Research and Development” received the largest share of funding, accounting for a staggering 25% of all DoD R&D assistance funding. Collectively, nearly one-third of all DoD R&D assistance funding was directed into assistance programs that referenced medical research (“medical R&D assistance,” “medical R&D programs”).**

Assistance Program	Total Obligations, FY2018-FY2023	% of Total R&D Assistance, FY2018-FY2023
MILITARY MEDICAL RESEARCH AND DEVELOPMENT	\$7,830,757,467	25%
BASIC AND APPLIED SCIENTIFIC RESEARCH	\$4,942,674,131	16%
AIR FORCE DEFENSE RESEARCH SCIENCES PROGRAM	\$4,459,941,512	14%
BASIC SCIENTIFIC RESEARCH	\$2,945,811,852	9%
RESEARCH AND TECHNOLOGY DEVELOPMENT	\$2,540,187,284	8%
COMMERCIAL TECHNOLOGIES FOR MAINTENANCE ACTIVITIES PROGRAM - CTMA	\$1,807,161,990	6%
BASIC, APPLIED, AND ADVANCED RESEARCH IN SCIENCE AND ENGINEERING	\$1,713,739,897	5%
UNIFORMED SERVICES UNIVERSITY MEDICAL RESEARCH PROJECTS - UNIFORMED SERVICES UNIVERSITY USU	\$1,658,592,440	5%
DEFENSE PRODUCTION ACT TITLE III - DPA TITLE III	\$1,417,559,803	5%
RESEARCH ON CHEMICAL AND BIOLOGICAL DEFENSE	\$1,188,918,975	4%
SCIENTIFIC RESEARCH - COMBATING WEAPONS OF MASS DESTRUCTION	\$467,826,228	1%
NAVAL MEDICAL RESEARCH AND DEVELOPMENT	\$141,774,087	0.4527%
COLLABORATIVE RESEARCH AND DEVELOPMENT - CONSTRUCTION PRODUCTIVITY ADVANCEMENT RESEARCH CPAR PROGRAM	\$100,510,633	0.3209%
RESEARCH AND TECHNICAL ASSISTANCE	\$60,114,662	0.1920%
RESEARCH AND DEVELOPMENT - MEDICAL AND PROSTHETIC RESEARCH AND DEVELOPMENT	\$32,150,848	0.1027%
MILITARY HEALTH SERVICES RESEARCH	\$4,903,267	0.0157%
SPACE TECHNOLOGY - STMD, SPACE TECH	\$1,632,518	0.0052%



RESEARCH GRANTS	\$1,134,664	0.0036%
AGRICULTURAL RESEARCH BASIC AND APPLIED RESEARCH - EXTRAMURAL RESEARCH	\$512,365	0.0016%
NAVY COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE - C4ISR	\$371,580	0.0012%
AIR FORCE MEDICAL RESEARCH AND DEVELOPMENT	\$300,000	0.0010%
WATER USE AND DATA RESEARCH - WUDR	\$215,517	0.0007%

Figure 13. DoD R&D Assistance Funding, by Assistance Program. Programs highlighted in red correspond to medical R&D programs.

Deep Dive: DoD Assistance for Medical Research

Medical research is important to the DoD for myriad reasons, from the threats posed by chemical and biological warfare to managing the unique needs of soldiers during and after battle. By analyzing text in the award description field, we determined that \$493.1 million in DoD R&D awards referenced “traumatic brain injury” or “TBI,” and \$113.7 million referenced “post traumatic stress disorder” or “PTSD.” Exploring the Award Trelliscope, we found that DoD medical R&D assistance also included funding to mitigate the effects of radiation exposure, develop new diagnostic platforms suited for the battlefield, restore sensory and nerve function after trauma, and other projects with an explicit link to military priorities.

However, as we explored details of the awards associated with the medical R&D assistance programs, we noticed that a significant share corresponded to broad medical topics. For instance, as shown in Figure 14, **1,803 R&D assistance awards referenced “cancer” in the description field. These awards corresponded to more than \$1.9 billion in funding—over 6% of all DoD R&D assistance funding. 478 of the cancer-related awards, totaling \$706.2 million, specifically referenced “breast cancer.”** By comparison, 218 awards totaling \$179.6 million in funding referenced “HYPERSONICS” and/or a related term in the award description.⁶ In other words, the **DoD directed 10x the amount of R&D assistance funding into cancer, as compared to hypersonics.** Hundreds of millions in DoD R&D assistance funding were also directed into projects related to obesity/diabetes, autism, heart disease, Parkinsons, and other general health/medical fields.

⁶ To identify related terms, we input “hypersonics” into the Defense Technical Information Center (DTIC) thesaurus. The DTIC thesaurus-generated corpus of related terms included ALTERNATE REENTRY SYSTEMS|BOOST GLIDE VEHICLES|COMMON AERO VEHICLES|HYPERSONIC|HYPERSONIC AIRCRAFT|HYPERSONIC CHARACTERISTICS|HYPERSONIC CRUISE MISSILES|HYPERSONIC DIFFUSERS|HYPERSONIC FLIGHT|HYPERSONIC FLOW|HYPERSONIC GLIDE VEHICLES|HYPERSONIC MISSILES|HYPERSONIC NOZZLES|HYPERSONIC REENTRY VEHICLES|HYPERSONIC TEST VEHICLES|HYPERSONIC VEHICLES|HYPERSONIC VELOCITY|HYPERSONIC WAVES|HYPERSONIC WEAPONS|HYPERSONIC WIND TUNNELS|RAMJET ENGINE|REENTRY VEHICLES



description_award	type_assistance	date_recent_award	agency
VENTION OF LETHAL METASTATIC BREAST CANCER BY ENHANCING TARGETING OF BREAST CANCER AND MOST OF SIGNALING PATHWAYS AND EFFECTIVE COMBINATION IN VIVO MECHANISTIC CHARACTERIZATION OF THE ANGIOGENESIS THERAPY FOR ENDOCRINE CANCER	PROJECT GRANT	2022-09-09	AMERICAN OVERSIGHT
TARGETING STRESS PATHWAYS IN ESOPHAGUS CANCER TO USING METABOLIC SIGNATURES FOR RISK-STRATIFICATION	COOPERATIVE AGREEMENT	2022-09-09	AMERICAN OVERSIGHT
...

Figure 14. Snapshot of DoD R&D Assistance Awards Referencing “Cancer”

Generalized Medical Research & the Mission of Military R&D

The merits of government-funded medical research are not in question. Advancements in these fields are critical—they stand to benefit large segments of the general population, as well as service members and their families. However, according to the website for the Office of the Secretary of Defense of the Under Secretary of Defense for Research and Engineering (OUSD USDR&E), the purpose of military R&D is to “provide the United States with the capability to produce technologies which are needed or may be needed to support the needs of National Security” (CTOInnovation.mil, n.d.). The prevalence of generalized medical research in the award data calls into question why such a significant share of funding earmarked for military R&D is directed as such.

Upon further research, we determined that a significant portion of military medical R&D is funded through a DoD appropriation known as the Congressionally Directed Medical Research Program (CDMRP). When CDMRP was established in 1992, it received \$25 million in appropriations. By FY2022, appropriations for CDMRP had grown to \$1.55 billion (Erwin, 2021). A 2022 Congressional Research Service report noted that “CDMRP funding has accounted for at least half of the [Defense Health Program] [Research, Development, Test, and Evaluation] account,” with the Breast Cancer Research Program, Prostate Cancer Research Program, and Peer-Reviewed Cancer Research Program among the CDMRP research topics in receipt of the greatest share of funding (Mendez, 2022). According to the CDMRP website, the program is intended to “to foster novel approaches to biomedical research in response to the expressed needs of its stakeholders—the American public, the military, and Congress.” CDMRP justifies the broad nature of its research funding on the basis that ***“health-related issues that affect service members or their dependents would fall within the purview of DoD medical research”*** (Congressionally Directed Medical Research Programs, 2024).

By this standard, all forms of medical research qualify. **This justification directly conflicts with the broader OUSD USDR&E mandate regarding the objectives of military R&D.** Furthermore, outside of the DoD, other federal departments direct billions of dollars into these same areas annually. In the case of cancer research, \$6.9 billion of the National Institutes of Health (NIH) budget was directed specifically into the National Cancer Institute (NCI) in FY2022 (American Institute for Cancer Research, 2024). The Advanced Research Projects Agency for Health (ARPA-H), the Department of Veterans Affairs (VA), and the Centers for Disease Control and Prevention (CDC) also direct hundreds of millions of dollars into cancer research annually (U.S. Department of Veterans Affairs, 2024; Centers for Disease

Control and Prevention, 2022; American Society for Radiation Oncology, 2023). Even medical fields that align with military priorities receive substantial R&D funding outside of the DoD. For instance, the VA and NIH collectively direct hundreds of millions of dollars in research funding for TBI every year (U.S. Department of Veterans Affairs, 2019; "Traumatic Brain Injury Research," 2024). While there are processes in place intended to minimize unnecessary duplication of effort in medical R&D, further research is required to assess if and how DoD-funded medical research differs materially from projects funded elsewhere in the government. Additional research is also required to understand if and how the results of these projects are shared with relevant stakeholders government-wide—as well as with relevant research communities outside of the government—to ensure they are leveraged to the maximum extent possible.

In earlier research, we assessed DoD-funded procurement programs that have the stated objective of helping the military access the best and brightest new technologies. We concluded there is a lack of coordination when it comes to developing requirements, including for areas where the government is seeking “innovation.” For instance, on one single day in October 2020, there were more than 100 open requirements on SAM.gov related to “drones” (Bresler & Bresler, 2021). Additionally, one significant reason why technologies funded and fielded through innovation programs often fail to achieve widespread adoption relates to the fact that stakeholders across the government are not made aware of these investments (Bresler & Bresler, 2023). It is unrealistic to assume that DoD medical R&D is immune to the information stovepipes and lack of collaboration that undermine the effectiveness of other government-funded R&D programs.

Recommendations: Combatting Mission Creep in Military Medical R&D

Military medical R&D has experienced mission creep, with funding for broad medical initiatives eclipsing projects explicitly linked to DoD priorities. As the DoD contends with budget constraints, personnel shortages, dynamic threats around the world, and other challenges, it is essential that major lines of effort tie back to a clear purpose and that the disparate stakeholders involved operate transparently and with a shared set of objectives. To that end, the DoD should comprehensively review all DoD medical R&D projects to assess their relevance to military priorities. Projects focused on the health of the general population should be spun-off to other departments and agencies that are engaged in similar research. Shifting projects out of the DoD will present difficulties, particularly for CDMRP initiatives that have been under the purview of the DoD for 30+ years. However, doing so will help reorient military medical R&D around a shared “National Security” objective.

Nonmedical DoD R&D

We then shifted our focus to the 16 DoD R&D assistance programs with no reference to “medical research” in the program name, which accounted for \$21.64 billion in DoD-funded assistance from FY2018–FY2023.

Keyword Extraction & Analysis: KeyBERT

Given the magnitude of the data associated with these 16 programs, we utilized an open source natural language processing (NLP) library called KeyBERT to facilitate our analysis of the award data. KeyBERT uses the Bidirectional Encoder Representations from Transformers (BERT) language model to extract keywords from large blocks of text (Grootendorst, n.d.). For each of the 16 nonmedical assistance programs, we joined the text



in the description field for all of their associated awards, and we used KeyBERT to identify the most commonly-referenced terms (“top keywords”).

Research Limitations & Future Research

As noted previously, some award descriptions offered little insight into how the R&D funding was ultimately directed. Most award descriptions also included highly general terms unrelated to the nature of a particular R&D effort, like “government,” “performance,” and “data.” These limitations impacted the quality of our KeyBERT analysis; thus, for certain assistance programs, KeyBERT produced useful/descriptive “top keywords,” but for others, it did not. We recommend that future research involve not only incorporating additional data into the analysis, but also refining the models to exclude certain terms.

Nonmedical DoD R&D Programs: Top Keywords

For programs with award description text that was conducive to KeyBERT, we found that a share of the top descriptive keywords appeared to reflect national security priorities and/or the mission objectives of the particular assistance program. For example:

- **BASIC AND APPLIED SCIENTIFIC RESEARCH:** Machine Learning, Modeling, Prediction, Physics
- **RESEARCH ON CHEMICAL AND BIOLOGICAL DEFENSE:** Biosafety Level, Coating Warehouse, Covid Vaccines
- **SPACE TECHNOLOGY - STMD, SPACE TECH:** Biomanufacturing, Space Travel, Variable Radiation Exposure
- **COMBATING WEAPONS OF MASS DESTRUCTION PROGRAM:** Radiation Effects, Chemical Warfare Agents, Radiation, Alphavirus Infections, Bacillus Anthracis
- **AIR FORCE DEFENSE RESEARCH SCIENCES PROGRAM:** Quantum, Machine Learning, Metallurgy
- **RESEARCH GRANTS PROGRAM:** Coupled Laser Diodes Systems, Cyber, Enhanced Signal Detection
- **DEFENSE PRODUCTION ACT TITLE III PROGRAM:** Domestic Production Capability, Critical Oxidizers, Increased Machining Capability
- **COLLABORATIVE RESEARCH AND DEVELOPMENT CONSTRUCTION PRODUCTIVITY ADVANCEMENT RESEARCH PROGRAM:** Erosion Control Assessment, Advanced Shipbuilding Enterprise, Hypersonic Flows
- **RESEARCH AND TECHNICAL ASSISTANCE PROGRAM:** Agile Manufacturing, Cyber Resiliency
- **AGRICULTURAL RESEARCH BASIC AND APPLIED RESEARCH - EXTRAMURAL RESEARCH:** Algorithms, Engineering Photonic Nanomaterials, Integer Quadratic Optimization
- **NAVY COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE - C4ISR:** Borne Pathogen Detection, Mission Adaptable Software

While KeyBERT helped us generate summary-level findings about these R&D assistance programs, more comprehensive research is essential. In particular, many of the



top domains in the DoD R&D assistance realm mirror the DoD priorities in receipt of significant procurement funding. To understand how assistance-funded projects contribute to advancements in warfighting capabilities, future research should evaluate how assistance-funded projects differ from the investments at the procurement level—and if and how technological breakthroughs achieved via assistance projects in these domains elevate the common operating environment.

Tracing the Path From R&D to Available Capabilities

Assessing the role of assistance funding as a means of advancing warfighting capabilities requires not only an analysis of the types of projects that receive funding, but also a way of tracking if capabilities developed under assistance programs are subsequently delivered, directly or indirectly, to defense end-users (“transition”). Unfortunately, there is no straightforward methodology for tracking transition, as there is no field in publicly-reported contracting data to indicate if aspects of a procurement contract corresponded to capabilities initially developed through an assistance program. Additional research is required to identify ways of proxying this metric. Initial ideas include:

- For entities that received assistance funding, either at the prime or sub-award level, identifying all subsequent contract and/or subcontract awards, and exploring the award details to determine if there appears to be a link between the products/services being procured, and the assistance-funded projects they undertook previously.
- Exploring the extent to which assistance-funded projects are cited in subsequent proposals.
- Linking assistance awardees’ patents to their assistance-funded projects using text analysis and searching for references to this intellectual property in procurement contract data.
- Exploring DTIC final reports to gauge technical readiness level(s) of assistance-funded projects.

Amplifying Transition Opportunities

Although we could not establish formal metrics to calculate transition, through qualitative research, including conversations with dozens of DoD stakeholders, we concluded that **DoD-funded assistance programs do not formally disseminate information about the results of their funded projects to the broad armed services community.** Although project reports are uploaded to DTIC, the DTIC repository is difficult to navigate and rarely consulted, particularly in the requirements development process. The lack of an efficient way for DoD stakeholders to learn about assistance-funded projects means that the results of these projects are not leveraged to the maximum extent possible.

New tools are required to make information about DoD R&D assistance programs more transparent, both to facilitate greater adoption of the R&D, as well as to ensure adequate oversight of the programs. While the need for information sharing is critical for projects across the DoD R&D assistance realm, **as part of the justification for their overhead/administrative burden, the DoD should require allocators, in particular, to widely disseminate information about the DoD R&D assistance projects they funded to potential beneficiaries.** In-person showcases, newsletters, and other ad-hoc programming are insufficient. Rather, allocators should be responsible for maintaining easily-explorable databases of the entities and projects they fund, designed specifically for USG stakeholders.



The nature of R&D is such that not all projects should result in transition-worthy capabilities. However, the overarching purpose of military R&D should not be to undertake experiments for experiments' sake. To position these programs so that they serve the warfighting community to the maximum extent possible, we recommend structuring and measuring them in new ways:

- The DoD should develop realistic and well-thought-through goals for what share of assistance-funded R&D projects should transition, either directly or indirectly. Goals should vary based on the technology domain and should include projects funded at the sub-assistance level.
- USG stakeholders and prime contractors should be incentivized/required to leverage capabilities developed via DoD-funded assistance programs.
- Prior to directing funding into new R&D projects, in either the assistance or the procurement realm, USG stakeholders must determine if materially-similar projects have already been funded.

Communities of Interest: A Model for the DoD

While there is a need for tools and processes to improve information sharing, we learned that one way information about R&D projects reaches potential beneficiaries is through a network of informal and formal **“communities of interest”** within the USG. These typically form around a particular technology area, and members from across the services communicate regularly—formally and informally—to share information about interesting projects and advancements in relevant fields. Although these initiatives are limited in reach and only highlight a fraction of R&D projects, the collaborative, bottom-up approach has clear benefits with respect to elevating projects within stakeholder communities that can leverage them. We recommend follow-on research to identify and study these communities of interest, and if appropriate, to invest resources into amplifying their efforts/reach.

Conclusion

New innovations that stand to benefit the military are being produced by a wide range of communities inside and outside of the USG, and assistance funding is one of the many tools available to the DoD to support/harness these efforts. As such, assessing the effectiveness of R&D assistance as a means of enhancing warfighting capabilities, in isolation, is meaningful only to a point. A serious commitment to advancing warfighting capabilities depends on three pillars:

- 1) Attracting and engaging the disparate stakeholders at the helm of relevant innovation—including those outside of the traditional DIB
- 2) Reducing duplicative efforts
- 3) Ensuring breakthroughs reach potential beneficiaries across the DoD as quickly as possible.

The various mechanisms by which the DoD directs resources into innovation—to include R&D assistance programs, SBIR/STTR, the Defense Innovation Unit (DIU), Futures Command, and more—must operate in concert with one another. We hope this paper serves as a springboard for DoD leaders to refine performance goals, establish metrics, develop new standards of accountability, and frame analysis questions that can be tracked and measured over time, to ensure that the military remains at the forefront of technological innovation.



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PANEL 9. HOW DO OTHER ORGANIZATIONS DO IT? PLANNING-PROGRAMMING-BUDGETING AND EXECUTION IN INTERNATIONAL AND NON-DOD FEDERAL GOVERNMENT AGENCIES

Wednesday, May 8, 2024	
2:15 p.m. – 3:30 p.m.	<p>Chair: Lara Sayer, Executive Director for the Commission on Planning, Programming, Budgeting and Execution (PPBE) Reform</p> <p><i>Planning, Programming, Budgeting, and Execution in Comparative Organizations: Case Studies of Selected Allied and Partner Nations</i> Megan McKernan, RAND</p> <p><i>Planning, Programming, Budgeting, and Execution in Comparative Organizations: Case Studies of Selected Non-DoD Federal Agencies</i> Heidi Peters, RAND</p> <p><i>Planning, Programming, Budgeting, and Execution in Comparative Organizations: Case Studies of China and Russia</i> Stephanie Young, RAND</p>

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Planning, Programming, Budgeting, and Execution in Comparative Organizations: Case Studies of Selected Allied and Partner Nations

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Abstract

The United States (U.S.) Department of Defense's (DoD's) Planning, Programming, Budgeting, and Execution (PPBE) System was originally developed in the 1960s as a structured approach for planning long-term resource development, assessing program cost-effectiveness, and aligning resources to strategies. Yet changes to the strategic environment, the industrial base, and the nature of military capabilities have raised the question of whether existing U.S. defense budgeting processes remain well aligned with national security needs.

The U.S. Congress called for the establishment of a commission on PPBE reform. As part of its data collection efforts, the commission asked RAND to conduct case studies of budgeting



processes across 16 comparative organizations: 10 international defense organizations and six U.S. federal government agencies.

In this paper, RAND researchers provide a summary of the case studies of the defense budgeting processes of Australia, Canada, and the United Kingdom (U.K.). Researchers conducted extensive document reviews and structured discussions with subject-matter experts with experience in the budgeting processes of the international governments. Each case study was assigned a unique team with appropriate regional or organizational expertise. The analysis was also supplemented by experts in the U.S. PPBE process.

Key Findings¹

- Australia, Canada, and the U.K. have a shared commitment to democratic institutions with the United States and converge on a similar strategic vision.
- Foreign military sales are an important mechanism for strategic convergence but pose myriad challenges for coordination and resource planning.
- The Australian, Canadian, and U.K. political systems shape the roles and contours of resource planning.
- Australia, Canada, and the U.K. have less legislative intervention in budgeting processes, relative to the United States, and do not need to confront the challenges of operating without a regular appropriation (as is the case under continuing resolutions).
- Strategic planning mechanisms in Australia, Canada, and the U.K. harness defense spending priorities and drive budget execution.
- Jointness in resource planning appears to be easier in Australia, Canada, and the U.K., given the smaller size and structure of their militaries.
- Australia, Canada, and the U.K. place a greater emphasis on budget predictability and stability than on agility.
- Despite the common emphasis on stability, each system provides some budget flexibility to address unanticipated changes.
- Similar budget mechanisms are used in Australia, Canada, and the U.K.
- Australia, Canada, and the U.K. have all pivoted toward supporting agility and innovation in the face of lengthy acquisition cycles.
- Australia, Canada, and the U.K. have independent oversight functions for ensuring transparency, audits, or contestability of budgeting processes.
- Despite the push to accept additional risk, there is still a cultural aversion to risk in the Australian, Canadian, and British budgeting processes.

Introduction

In light of a dynamic threat environment, increasingly capable adversaries, and rapid technological changes, there has been increasing concern that the U.S. Department of Defense's (DoD's) resource planning processes are too slow and inflexible to meet warfighter needs.² DoD's Planning, Programming, Budgeting, and Execution (PPBE)

¹ There is additional information on this topic in the full document: McKernan, M., et al. (2024). *Planning, Programming, Budgeting, and Execution in comparative organizations: Volume 2, Case studies of selected allied and partner nations* (Report No. RR- A2195-2). RAND. https://www.rand.org/pubs/research_reports/RRA2195-2.html

² See, for example, Section 809 Panel, (2018, June), pp. 12–13; McGarry (2022, July 11), p. 1; Greenwalt & Patt (2021), pp. 9–10.



System was originally developed in the 1960s as a structured approach for planning long-term resource development, assessing program cost-effectiveness, and aligning resources to strategies. Yet changes to the strategic environment, the industrial base, and the nature of military capabilities have raised the question of whether the DoD's budgeting processes are still well aligned to national security needs.

To consider the effectiveness of current resource planning processes for meeting national security needs and to explore potential policy options to strengthen those processes, Congress called for the establishment of a commission on PPBE reform in Section 1004 of the National Defense Authorization Act for Fiscal Year (FY) 2022.³ The Commission on PPBE Reform took shape as a legislative commission in 2022, consisting of 14 appointed commissioners, each drawing on deep and varied professional expertise in the DoD, Congress, and the private sector. In support of this work, the commission collected data, conducted analyses, and developed a broad array of inputs from external organizations, including federally funded research and development centers, to develop targeted insights of particular interest to the commission. The commission asked the RAND National Defense Research Institute to contribute to this work by conducting case studies of 16 comparative organizations: 10 international defense organizations and six other U.S. federal government agencies.

The Planning, Programming, and Budgeting System (PPBS), the precursor to DoD's PPBE process, took shape in the first decades after World War II and was introduced into DoD in 1961 by then-Secretary of Defense Robert McNamara.⁴ Drawing on new social science methods, such as program budgeting and systems analysis, the PPBS was designed to provide a structured approach to weigh the cost-effectiveness of potential defense investments. A central assertion of the PPBS's developers was that strategy and costs needed to be considered together.⁵ As Charles Hitch, Secretary McNamara's first comptroller and a key intellectual leader in the development and implementation of the PPBS, and Roland McKean (1960) noted, "There is no budget size or cost that is correct regardless of the payoff, and there is no need that should be met regardless of cost."

To make decisions about prioritization and where to take risk in a resource-constrained environment, DoD needed an analytic basis for making choices. Therefore, the PPBS first introduced the program budget, an *output*-oriented articulation of the resources associated with a given military capability projected out over 5 years.⁶ The PPBS then introduced an approach for assessing cost-effectiveness, termed *systems analysis*, which was institutionalized in the Office of Systems Analysis. Since 2009, the institutional successor to the Office of Systems Analysis has been known as Cost Assessment and

³ Public Law 117-81, National Defense Authorization Act (NDAA) for Fiscal Year 2022. (2021, December 27). Section 1004(f) of this Act is of particular relevance to our research approach: "Compare the planning, programming, budgeting, and execution process of the Department of Defense, including the development and production of documents including the Defense Planning Guidance (described in section 113(g) of Title 10, United States Code), the Program Objective Memorandum, and the Budget Estimate Submission, with similar processes of private industry, other Federal agencies, and other countries."

⁴ An oft-quoted assertion by Secretary of Defense Robert McNamara, which is pertinent to this discussion, is that "you cannot make decisions simply by asking yourself whether something might be nice to have. You have to make a judgment on how much is enough." See Enthoven & Smith (1971); see also Young (2009).

⁵ Or, as Bernard Brodie stated succinctly, "Strategy wears a dollar sign" See Brodie (1959).

⁶ On the need for an output-oriented budget formulation at the appropriate level to make informed choices, Hitch and McKean (1960) noted that the consumer "cannot judge intelligently how much he should spend on a car if he asks, 'How much should I devote to fenders, to steering activities, and to carburetion?' Nor can he improve his decisions much by lumping all living into a single program and asking, 'How much should I spend on life?'"



Program Evaluation (CAPE).⁷ At its inception, the PPBS was a process for explicitly linking resources to strategy and for setting up a structure for making explicit choices between options, based on transparent analysis of costs and effectiveness. Then, as today, the system introduced friction with other key stakeholders, including Congress and industry partners. Key features of the PPBS have become institutionalized in the DoD's PPBE System, and questions have arisen about whether its processes and structures remain relevant and agile enough to serve their intended purposes (Greenwalt & Patt, 2021).

To set up the discussion of case studies, it will be helpful to outline the key features of the PPBE process and clarify some definitions. Today, consideration of PPBE often broadly encapsulates internal DoD processes, other executive branch functions, and congressional rules governing appropriations. Internal to the DoD, PPBE is an annual process by which the department determines how to align military programs and resources to strategic guidance. The process supports the development of DoD inputs to the President's Budget and to a budgeting program with a 5-year time horizon (McGarry, 2022), known as the Future Years Defense Program (FYDP). Department of Defense Directive (DoDD) 7045.14, *The Planning, Programming, Budgeting, and Execution (PPBE) Process*, states that one intent for PPBE "is to provide the DoD with the most effective mix of forces, equipment, manpower, and support attainable within fiscal constraints." PPBE consists of four distinct processes, each with its own outputs and stakeholders. Select objectives of each phase include the following:

- **Planning:** "Integrate assessments of potential military threats facing the country, over-all national strategy and defense policy, ongoing defense plans and programs, and projected financial resources into an overall statement of policy" (DoD, 2017).
- **Programming:** "Analyze the anticipated effects of present-day decisions on the future force; detail the specific forces and programs proposed over the FYDP period to meet the military requirements identified in the plans and within the financial limits" (Tyszkiewicz & Daggett, 1998).
- **Budgeting:** "Ensure appropriate funding and fiscal controls, the phasing of the efforts over the funding period, and the feasibility of execution within the budget year" (Tyszkiewicz & Daggett, 1998); restructure budget categories for submission to Congress according to the appropriation accounts; and prepare justification material for submission to Congress (McGarry, 2022).
- **Execution:** "Determine how well programs and financing have met joint warfighting needs" (DoD, 2017).

Several features of congressional appropriations processes are particularly important to note. First, since FY 1960, Congress has provided budget authority to DoD through specific appropriations titles (sometimes termed *colors of money*), the largest of which are operation and maintenance (O&M); military personnel; research, development, test, and evaluation (RDT&E); and procurement (Tyszkiewicz & Daggett, 1998). These appropriations titles are further broken down into appropriation accounts, such as Military Personnel, Army, or Shipbuilding and Conversion, Navy (SCN). Second, the budget authority provided in one of these accounts is generally available for obligation only within a specified period. In the DoD budget, the period of availability for military personnel and O&M accounts is 1 year; for

⁷ In a discussion of the founding of PPBS, Enthoven (the first director of the Office of Systems Analysis) and Smith (1971) described "the basic ideas that served as the intellectual foundation for PPBS" as follows: (1) decision-making should be made on explicit criteria of the national interest, (2) needs and costs should be considered together, (3) alternatives should be explicitly considered, (4) an active analytic staff should be used, (5) a multiyear force and financial plan should project consequences into the future, and (6) open and explicit analysis should form the basis for major decisions.



RDT&E accounts, 2 years; and for most procurement accounts, 3 years (although for SCN, it can be 5 or 6 years, in certain circumstances). This specification means that budget authority must be obligated within those periods, or with only a few exceptions, it is sent back to the U.S. Department of the Treasury (Tyszkiewicz & Daggett, 1998).⁸ There has been recent interest in exploring how these features of the appropriations process affect transparency and oversight, institutional incentives, and the exercise of flexibility, should resource needs change (McGarry, 2022). Importantly, PPBE touches almost everything the DoD does and, thus, forms a critical touchpoint for engagement among stakeholders across the DoD (e.g., Office of the Secretary of Defense, military departments, Joint Staff, combatant commands), in the executive branch (through the Office of Management and Budget), in Congress, and among industry partners.

Study Objectives and Approach

In close partnership with the PPBE Commission, we selected 10 case studies of international defense organizations to explore decision-making in organizations facing challenges like those experienced in the DoD: exercising agility in the face of changing needs and enabling innovation. Three of those case studies are documented here: Australia, Canada, and the United Kingdom. For all 10 case studies, we conducted extensive document reviews and structured discussions with subject-matter experts having experience in the budgeting processes of the examined international defense organizations. Case study research drew primarily on government documentation outlining processes and policies, planning guidance, budget documentation, and published academic and policy research. Although participants in structured discussions varied in accordance with the decision-making structures across case studies, they generally included chief financial officers, representatives from organizations responsible for making programmatic choices, and budget officials. To facilitate consistency, completeness in addressing the commission's highest-priority areas of interest, and cross-case comparisons, we developed a common case study template. This template took specific questions from the commission as several inputs, aligned key questions to PPBE processes and oversight mechanisms, evaluated perceived strengths and challenges of each organization's processes and their applicability to DoD processes, and concluded with lessons learned from each case. To enable development of a more consistent evidentiary base across cases, we also developed a standard interview protocol to guide the structured discussions.

Selected Allied and Partner-Nations Focus

The 2022 National Defense Strategy (NDS) describes a security environment of complex strategic challenges associated with such dynamics as emerging technology, transboundary threats, and competitors posing “new threats to the U.S. homeland and strategic stability” (DoD, 2022). Among these challenges, the NDS notes that “the most comprehensive and serious challenge” is the People's Republic of China (PRC). The NDS points to China's military modernization and exercise of whole-of-government levers to effect “coercive” and “aggressive” approaches to the region and international order (DoD, 2022). While the NDS designates China as the “pacing challenge” for the DoD, it also highlights the threat posed by Russia as an “acute threat” (DoD, 2022). To counter these strategic challenges, the NDS calls for strong relationships among U.S. allies and partner nations (DoD, 2022).

The lower half of Figure 1 illustrates the increasing gap between China's rising military expenditure over time and the relatively flat, lower levels of expenditure by Russia and U.S.

⁸ For a discussion of the availability of funds appropriated to DoD for RDT&E activities, see Section 3131 of Title 10, *United States Code*, Availability of Appropriations.



allies and partner nations: Australia, Canada, and the U.K.

To better understand and operate in the competitive environment, the Commission on PPBE Reform is considering “budgeting methodologies and strategies of near-peer competitors to understand if and how such competitors can address current and future threats more or less successfully than the United States,” along with defense resource planning in allied and partner nations (Pub. L. 117-81, Section 1004(f)(2)(F)). For the allied and partner nations, the commission asked us to analyze the defense resource planning processes of Australia, Canada, and the U.K. Notably, this focus on internal processes as key enablers of military outcomes is well aligned with the NDS’s imperatives of “build[ing] enduring advantage,” “undertaking reforms to accelerate force development, getting the technology we need more quickly, and making investments in the extraordinary people of the Department, who remain our most valuable resource” (DoD, 2022). These imperatives have prompted reflection on the extent to which internal DoD processes, including PPBE, are up to the challenge of enabling rapid and responsive capability development to address the emerging threats. The following sections summarize the key insights and applicability of these insights to the DoD’s PPBE System.

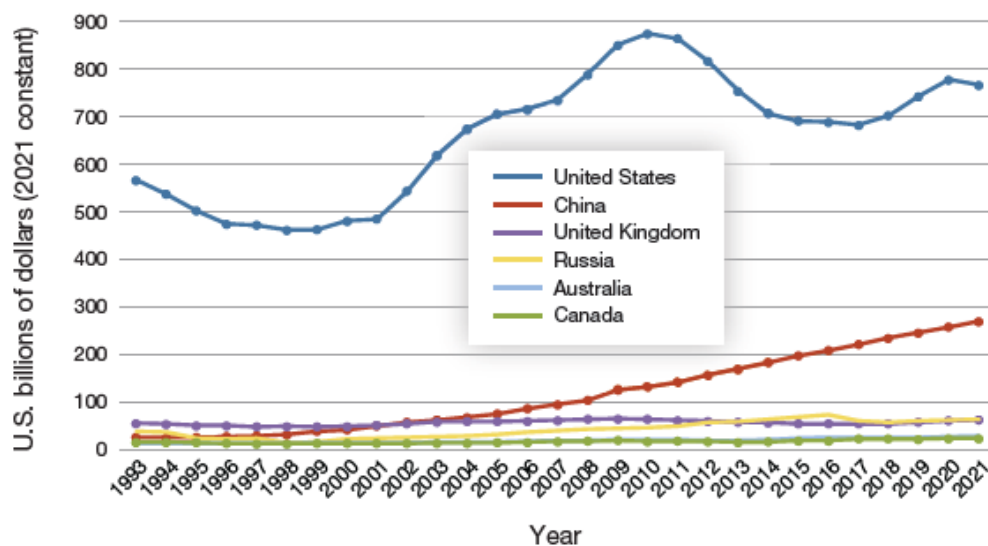


Figure 1. Military Expenditure, by Country
(Features information from Stockholm International Peace Research Institute (SIPRI; n.d.). SIPRI Military Expenditure Database. Data shown are as of March 17, 2023.)

Key Insights

The material presented in this section distills important themes for the commission to understand when trying to compare the U.S. defense resource planning process with that of selected allies and partner nations. The similarities of the Australian, Canadian, and British processes to those of the U.S. PPBE process far exceed the differences and therefore suggest multiple insights that are germane for the United States.

Key Insight 1: Australia, Canada, and the United Kingdom Have a Shared Commitment to Democratic Institutions with the United States and Converge on a Similar Strategic Vision

The United States, Australia, Canada, and the U.K. have similar strategic visions and aim to counter similar strategic threats. This alignment presents opportunities for co-development and broader opportunities to work together toward shared goals, but also it

requires the United States and its allies to develop plans and processes to facilitate more-effective partnership approaches. In addition, each country struggles to balance at least four often-competing priorities: keeping pace with strategic threats, executing longer-term plans, using deliberate processes with sufficient oversight, and encouraging innovation.

Australia's Defence operates in close concert with several allies, especially the United States, and leverages those alliances and partnerships as a central tool of national security. Australia is a member of the Five Eyes (Australia, Canada, New Zealand, U.K., and United States) security agreement, the Quadrilateral Security Dialogue ("the Quad"), and the Australia–United Kingdom–United States (AUKUS) agreement. Australia is a strategically located partner in the Indo-Pacific theater and shares U.S. concerns about China's military rise.

Canada and the United States have a long, collaborative defense relationship. Their militaries have fought alongside one another in several conflicts since World War II. Both countries are members of the North Atlantic Treaty Organization (NATO), and they cooperate extensively through several bilateral defense forums and agreements, including the North American Aerospace Defense Command (NORAD), the Permanent Joint Board on Defense, the Military Cooperation Committee, the Combined Defense Plan, the Tri-Command Framework, the Canada–U.S. Civil Assistance Plan, and the National Technology Industrial Base (Government of Canada, 2014). Canada recognizes its relatively small military size on the world stage and emphasizes cooperation with allies, specifically, the United States and NATO member countries. However, Canada lacks the population and military personnel to sustain large overseas military deployments, and, thus, its 2017 policy limits the size and duration of planned contributions. Nonetheless, the Canadian Armed Forces (CAF) participates throughout the year—again, largely with allies—in operations and joint military exercises, including assurance missions, stability operations, and United Nations missions.⁹

The U.K. is a critical U.S. ally that retains global military responsibilities and capabilities, including nuclear weapons. The U.K. is a member of the AUKUS security pact, the Combined Joint Expeditionary Force with France, the European Intervention Initiative, the Five Eyes security agreement, the Five Power Defence Arrangements (with Australia, Malaysia, New Zealand, and Singapore), the Joint Expeditionary Force (which it leads), NATO, and the Northern Group. It is also a veto-wielding permanent member of the United Nations Security Council. Therefore, the U.K. Ministry of Defence (MoD) interacts frequently and interoperates closely with the U.S. military and intelligence community, and its defense budget and planning decisions are often made in unofficial concert with DoD decisions and priorities.

Key Insight 2: Foreign Military Sales Are an Important Mechanism for Strategic Convergence but Pose Myriad Challenges for Coordination and Resource Planning

Australia, Canada, and the U.K. rely on U.S. Foreign Military Sales (FMS) to promote strategic convergence, interconnectedness, interoperability, and interchangeability. One downside to this reliance is exchange rate volatility, which can require budget adjustments to cover exchange rate adjustments. Accrual-based accounting for life-cycle planning can present additional challenges when adjusting FMS for inflation or exchange rates; these challenges can also require revisions to cost estimates. However, given the strong allied focus of the defense strategies of all these countries, each country places a heavy emphasis on the importance of interoperability and, in some cases, integration—a key consideration in acquisition and force generation. This strategic emphasis poses a further challenge to each

⁹ For a list, see DND (2022b).

country's ability to independently act with flexibility.

Australia's Defence is typically a customer of U.S. systems, often through FMS. Because the development and production of these systems may depend on the DoD's PPBE processes, there are limitations to Australia's ability to become more agile than those U.S. processes will allow—at least with respect to major weapon systems. This constraint is acceptable to Defence in view of the interoperability and capability advantages. In discussions about AUKUS, emerging technologies, innovation, and weapon cooperation, our interviewees indicated that the U.S.–Australia relationship may shift to one in which Australia is not simply a defense materiel customer but more of a partner. Beyond technology cooperation, there is the prospect that greater transparency and coordination across U.S. and Australian PPBE processes could lead to mutual benefits in terms of capability agility, synergies, and efficiencies. Canada also relies on U.S. FMS. Major contracting and FMS for the Canadian Department of National Defence (DND) (and other Canadian federal agencies) are handled by Public Services and Procurement Canada, which centralizes major purchases for the Canadian government. This centralization may cause internal delays in processing FMS. Along with the exchange rate volatility that Australia and the U.K. experience, the Canadian fiscal year does not align with the U.S. fiscal year, which can cause additional problems when planning or accounting for FMS purchases.

In the U.K., inflationary pressures have been exacerbated by a strengthening U.S. dollar, to which the MoD is especially sensitive because of its large number of major U.S. FMS contracts and some fixed-price fuel-swap contracts denominated in dollars.¹⁰ The U.K. defense sector is highly exposed to exchange rate volatility, given the extent of its U.S. imports, primarily aircraft (e.g., F-35Bs, P-8s, AH-64 Apache helicopters, CH-47 Chinook helicopters). Because the MoD budget is expressed in nominal terms and because the MoD often purchases assets from abroad, it is greatly affected by inflation in fuel and other running costs and by the valuation of the pound sterling relative to other currencies (especially the U.S. dollar).¹¹ Consequently, the MoD budget has been hit especially hard by recent inflationary pressures, exchange rate volatility, and the financial costs of Brexit.

Key Insight 3: The Australian, Canadian, and U.K. Political Systems Shape the Roles and Contours of Resource Planning

The political systems in the three allied countries are similar in that the executive branch has the power of the purse, which reduces political friction over appropriations.

The Australian electorate votes for parties, not prime ministers. A prime minister is selected by the party that holds the majority in the new government, and, subsequently, the prime minister appoints senior elected colleagues to ministerial positions, which are comparable to secretaries in the U.S. cabinet. Each minister is therefore an elected official. Under the Minister for Defence, there is both a departmental secretary—who is a career bureaucrat rather than a political appointee—and the Chief of the Defence Force (CDF), who is a military officer.¹² Overall, the legislative and executive branches of the Australian system are more closely linked than they are in the United States.

The two major parties in Australia take a relatively bipartisan approach to defense; hence, a change of government does not necessarily result in any significant change in

¹⁰ The MoD maintains multiple euro and dollar bank accounts and enters into forward-purchase contracts for these currencies to mitigate the risk from changing exchange rates.

¹¹ U.K. subject-matter expert, interview with the authors, October 2022.

¹² The CDF is Australia's senior military officer, the only four-star officer in the ADF. The CDF leads the integrated Australian Department of Defence and ADF as a diarchy with the defence secretary.



defense plans or budget allocations. New governments sometimes direct the department to begin work on a new defense white paper; however, such changes in strategic guidance are typically related more to changes in the geostrategic environment than to politics.¹³

In Canada, members of the lower chamber of parliament, the House of Commons, are elected by voters; the leader of the largest party in that chamber becomes prime minister and selects the cabinet. The executive branch plays the dominant role in Canada's budget preparation, and parliament has relatively limited influence. Parliament performs legislative and oversight functions through its review and approval of the budget (Armit, 2005). When the executive controls a majority of seats in the House of Commons, it is in a very strong position to have its prepared budget approved with minimal or no changes. When the executive controls a plurality of seats but not a majority, it relies on support from the opposition or other, smaller parties to pass budgets and other key legislation. If the ruling government cannot pass its budget through the House of Commons, it is considered to no longer have the confidence of the House, and an election must be called.

In the U.K., the stability of the bicameral parliamentary system relies on the fact that the chief of the executive branch (the prime minister) is an elected member of parliament from the party with a majority in the elected lower chamber (the House of Commons). Members of the upper chamber, the House of Lords, are not elected but appointed. By centuries-old convention, the upper chamber defers to the lower chamber on financial matters. Because the U.K. does not have a codified constitution and instead relies to a significant extent on accumulated convention, there is less inherent antagonism between the branches of government than in the United States. The resulting empowerment of the prime minister can enable more streamlined executive and legislative action, but it also limits the formal checks and balances that characterize the U.S. system.

Parliament must approve the government defense missions and the resources that the MoD requests for those missions. Opposition from the prime minister's own majority in the House of Commons triggers a no-confidence vote and the likely collapse of the government. The alignment of resource allocation with the MoD's mission is therefore a structural feature of the U.K. parliamentary system.

Key Insight 4: Australia, Canada, and the U.K. Have Less Legislative Intervention in Budgeting Processes, Relative to the United States, and No Continuing Resolutions

The Australian, Canadian, and U.K. resource management systems have less partisan interference than in the United States, according to subject-matter experts on these systems.

Compared with the DoD, Australia's Department of Defence receives significantly less PPBE guidance from the Australian legislature. The executive branch—the Minister for Defence, the prime minister, and cabinet colleagues—hold the purse strings. The other members of Parliament and senators can review Australia's PPBE-like functions and direct their questions to either the Minister for Defence or directly to the Australia's Department of Defence through parliamentary liaison officers. Unlike in the United States, the annual budget for existing services and programs in Australia appears in a separate appropriations bill from that for new programs,¹⁴ making it unlikely that existing government services will be blocked and effectively eliminating any need for a continuing resolution.

¹³ The 2022 change in government leadership from the Liberal to the Labour party did not result in any substantial change in priorities or budget for the Australian Department of Defence, nor did it result in a new defense white paper.

¹⁴ For details on the separation of appropriations bills for continuing services and new policies, see Webster (2014).



Canada's government is never at risk of a shutdown because of funding lapses. Parliament can enact interim estimates that authorize spending at proposed levels until the Main Estimates pass through the normal legislative process, or the executive can take other extraordinary measures to continue funding ongoing government functions.

The U.K. parliamentary system offers little or no risk of parliament interfering in the specifics of the MoD's budget or delaying approvals. In any case, the automatic preauthorization of a portion of defense spending based on the previous year's approved expenditure allows the MoD to avoid a U.S.-style situation of political deadlock, budget sequestration, or continuing resolutions. Members of Parliament appear to be less concerned than their U.S. counterparts in Congress with where defense production occurs, perhaps because construction sites are well-established and production does not substantively influence MoD decisions.¹⁵

Key Insight 5: Strategic Planning Mechanisms in Australia, Canada, and the U.K. Harness Defense Spending Priorities and Drive Budget Execution

Australia, Canada, and the U.K. each start their defense resource management processes with strategic planning that tries to identify key priorities for finite funds in defense budgets that are smaller than that of the United States.

Australia's defense budgeting system is guided by a series of strategic planning documents, such as the *2016 Defence White Paper* and *2020 Defence Strategic Update* (Australian Department of Defence, 2016, 2020a; Brangwin & Watt, 2022) that lay out strategic goals, capability priorities, and funding profiles for the following decade. The Portfolio Budget Statement and the Integrated Investment Program (IIP), both of which are derived from mission needs and strategic priorities, reflect the "value to the warfighter" of resource allocations. The Defence Capability Assessment Program (DCAP) ensures that the current and planned force structure is fit for prospective operational scenarios, theater campaign plans, operational concepts, and preparedness directives.

Canada's defense programs are also based on several strategic planning documents: 2017's *Strong, Secure, Engaged*; 2018's *Defence Investment Plan and Defence Plan, 2018–2023*; 2019's updated *Defence Investment Plan*; 2020's *Defence Capabilities Blueprint*; and the latest *Department of National Defence and Canadian Armed Forces Departmental Plan*, which was released in 2022 (DND, 2017, 2018a, 2018b, 2019, 2020, 2022a). Together, these strategic documents provide the basis for defense budgeting decisions.

The MoD's approach to strategic planning begins with its mission as outlined in the Defence Command Paper. The most recent iteration of this white paper, *Defence in a Competitive Age*, was published in March 2021 (MoD, 2021; U.K. Cabinet Office, 2021). The white paper states that the seven primary goals of the MoD and the British Armed Forces are to defend the U.K. and its overseas territories, sustain the country's nuclear deterrence capacity, project the U.K.'s global influence, execute its NATO responsibilities (U.K. House of Commons, Defence Select Committee, 2021), promote national prosperity, contribute to peacekeeping, and support the defense and intelligence-gathering capabilities of the U.K.'s allies and partners (MoD, n.d.). The Treasury aligns fiscal resources to support these missions through comprehensive spending reviews.

Key Insight 6: Jointness in Resource Planning Appears to Be Easier in Australia, Canada, and the U.K. Given the Smaller Size and Structure of Their Militaries

In Australia, the Australian Defence Force (ADF) operates in a relatively more joint

¹⁵ U.K. subject-matter expert, interview with the authors, November 2022.

manner than its U.S. counterpart. Some ADF program costs, such as fuel costs, are centralized.¹⁶ There is a level of joint financial governance; service component Chief Finance Officers (CFOs) report to the departmental CFO and to their service chiefs. These points may be important to the U.S. defense community, given ongoing efforts to enhance jointness across the U.S. military.

In Canada, military service acquisition projects are managed by a DND process that is service-agnostic and ranks projects according to DND priorities. This process ensures that service-centric views do not dominate procurement planning and encourages more collaboration, discussion, and consensus.

With cross-governmental mechanisms and joint funds, such as the United Kingdom Integrated Security Fund (UKISF), the U.K.'s Planning, Budgeting, and Forecasting (PB&F) system can allocate resources to urgent requirements while incentivizing interagency work. Such mechanisms and funding sources allow the MoD to address the root causes of conflict and instability rather than merely reacting to them militarily. These efforts demonstrate ways to balance decentralization with organizational, process, and cultural measures that promote jointness and multidomain integration. They also demonstrate how broader changes to institutional and individual culture can combat the effects of interservice rivalries.

Key Insight 7: Australia, Canada, and the U.K. Place a Greater Emphasis on Budget Predictability and Stability Than on Agility

Australia's Defence is given assurance of sustained funding levels over a 4-year rolling period. The *2016 Defence White Paper* laid out a baseline for defense spending over 10 years. The *2020 Defence Strategic Update* laid out an updated version of this baseline, extending it to 2029–2030. Defence plans its investments out as far as 20 years as whole-of-life investments.¹⁷ Canada's notional DND budget is guaranteed to continue year on year, allowing for better decision-making in out-years. DND's Capital Investment Fund ensures that approved projects will be paid for years or even decades to come, regardless of a change in government.

MoD programs are normally guaranteed funding for 3 to 5 years, with estimates out to 10 years. In contrast, with only a few exceptions, Congress must revisit and vote on DoD's entire budget every year (albeit requiring a 5-year defense plan). Certain U.S. contracts, including for munitions and missiles, must also be renegotiated every year, something that the MoD avoids. These attributes of the systems of Australia, Canada, and the U.K. offer a high degree of budget security but not necessarily flexibility.

Key Insight 8: Despite the Common Emphasis on Stability, Each System Provides Some Budget Flexibility to Address Unanticipated Changes

The Australian Parliament can boost the defense budget in periods of national emergency (e.g., wildfires) or overseas military operations (e.g., Iraq, Timor-Leste) using the no-win/no-loss model for deployments.¹⁸ The government can supplement Defence's allocation to alleviate inflationary pressures. The National Security Committee of Cabinet (NSC) can consider urgent priorities and their funding implications, and the Minister for Defence can intervene to prioritize certain programs or investments. There is flexibility to move current-year funds among groups and military services to meet emerging needs. The CFO can divert funding to meet emerging priorities. The DCAP promotes agility, but it is

¹⁶ Australian Defence official, interview with the authors, November 2022.

¹⁷ Australian Defence officials, interviews with the authors, October and November 2022.

¹⁸ No-win/no-loss funding is appropriated through appropriations bills. It can be appropriated to offset the cost of approved operations and foreign exchange movements.

linked to government updates of strategic guidance, which may not be sufficiently agile.¹⁹ However, there has been an effort to make these updates more frequent and ongoing, and there is an intent for capability processes to be more agile in the future, in cases where reducing operational risk is more important than acquisition risk.²⁰

In the DND, regular supplementary parliamentary spending periods can help close unforeseen funding gaps for emerging requirements and help manage risk. DND officials believe that planning capital investments on an accrual basis while managing year-on-year funding on a cash basis allows for more-flexible funding. DND does not require parliamentary approval—nor must it inform parliament—to transfer funds within a vote from one program to another. DND can carry forward to the next fiscal year up to 5% of total operating expenditures, which it can use to adjust misalignments in spending (Perry, 2015).

For the MoD, multiyear spending reviews make budgeting more rigid than a yearly budget would, but the Treasury and the MoD retain some flexibility when translating the spending reviews into annual budgets and plans. The U.K. also has mechanisms for moving money between accounts and accessing additional funds in a given fiscal year. These mechanisms include a process known as virement for reallocating funds with either Treasury or parliamentary approval. The MoD can make additional funding requests through in-year supplementary estimates sent to parliament. The MoD has access to additional Treasury funds to cover urgent capability requirements (UCRs), and it can use the cross-governmental UKISF or the Deployed Military Activity Pool “to make available resources to fund the initial and short-term costs of unforeseen military activity,” (MoD, 2022) such as responses to natural disasters or support to Ukraine (U.K. Cabinet Office, 2023).

Key Insight 9: Similar Budget Mechanisms Are Used in Australia, Canada, and the U.K.

Australia, Canada, and the U.K. use similar budget mechanisms, including the carryover of funds, movement of funds across portfolios, appropriations with different expirations, and supplementary funds for emerging needs. The use of these mechanisms, however, varies across the cases.

Australia’s Defence has five key cost categories, which are similar to U.S. appropriation categories: workforce, operations, capability acquisition program (including research and development), capability sustainment, and operating costs.²¹ There is limited movement among categories, but there is flexibility for “unders” and “overs,” meaning that funds can be shifted from categories with a surplus to categories with a deficit. Projects are funded and managed on a whole- of-life basis,²² accounting for both capital and operating costs. Under the no-win/no-loss mechanism for deployments,²³ Defence is reimbursed for most operational costs and must return unused funds to the Treasury. Defence absorbs some level of its costs, but the majority is offset by government reimbursement.

Within Australia’s Defence Integrated Investment Program (IIP), both approved government projects and unapproved, fungible programs can be shifted “left” or “right”

¹⁹ Australian Defence official, interview with the authors, October 2022.

²⁰ Australian Defence official, interview with the authors, October 2022.

²¹ In this context, operating relates to the forecasted costs to support defense systems, including training on those systems, whereas operations relates to nonforecasted costs associated with deployed forces.

²² Under the One Defense Capability System (ODCS), approval to acquire new weapon systems requires an estimate of total costs through the system’s projected end of life, including personnel, operating, and sustainment costs.

²³ This is not to be confused with the day-to-day running of the ADF.

(accelerated or delayed) as needs arise.²⁴ To manage the risk of underachievement (or overexpenditure), the IIP is 20% overprogrammed for acquisition in the current financial year. Other types of Australian funding are also fungible in that they can be shifted across the defense portfolio, including across groups and military services. The operating budget for Defence expires at the end of each financial year, but major procurements are handled separately through the IIP and do not expire. Still, the overall acquisition program is expected to hit a target annual expenditure level.

When the Canadian Minister of Finance presents the annual national budget to the House of Commons, there are one or more votes that correspond roughly to different colors of money. Each color of money is assigned an arbitrary, noncontiguous vote number. Common votes include vote 1 for operating expenditures, vote 5 for capital expenditures, vote 10 for grants and contributions, and vote 15 for long-term disability and life insurance plans. The votes can span a portfolio of programs or apply to specific programs. Organizations can transfer funds within a vote from one program to another without parliament's approval (Pu & Smith, 2021). Organizations do need parliament's approval to transfer funds between votes (e.g., from vote 1 to vote 5). Canadian federal agencies can also carry forward a portion of their unspent funds from a previous year, typically up to 5% of operating expenditures and 20% of capital expenditures (Pu & Smith, 2021).

The U.K. uses both accrual-based budgeting (based on when transactions occur rather than when cash receipts or payments are exchanged) and zero-based budgeting (in which all activities and programs must be recosted from zero and justified through a set of criteria for prioritizing projects with the highest value for money). The Treasury controls the MoD's spending using the accrual system.²⁵ The MoD reports its spending monthly to comply with Treasury reporting requirements (MoD, 2019). Like those of every other department, the MoD's budget works on a "spend-it-or-lose-it" basis by which the money allocated each year must be spent or it is returned without compensation.

Key Insight 10: Australia, Canada, and the U.K. Have All Pivoted Toward Supporting Agility and Innovation in the Face of Lengthy Acquisition Cycles

Australia's Defence has been looking for ways to increase agility. One way would extend the no-win/no-loss provision for operations to ordering ordnance and other expendables prior to a conflict so that the ADF would be more prepared for emerging threats. To accelerate innovation, the proposed Australian Strategic Capabilities Accelerator (ASCA) would be required to secure funds for capabilities in which technologies arise faster than capability planning time frames with greater agility, efficiency, and effectiveness.

Like the DoD, Australia's Department of Defence possesses technology facilitators, such as Defence Innovation Hub (DIH), that help integrate emerging technologies with defense priorities. But there are few examples of the successful adoption of new innovations through DIH. And although the goal of ASCA is to help fast-track innovations into service, some observers acknowledge that that agency's success will be highly dependent on broader changes to PPBE-like processes to facilitate agility.

Canada's strategic plan states that the DND should exploit defense innovation as a priority (DND, 2022a). Canada is working with the United States on NORAD modernization as one of its priorities.

Like the DoD, the MoD is experimenting with new ways to encourage innovation,

²⁴ Australian Defence official, interview with the authors, October 2022; Australian Department of Defence (2020b).

²⁵ U.K. subject-matter experts, interviews with the authors, October and November 2022.

including a new dedicated Innovation Fund, which allows the chief scientific adviser to pursue higher-risk projects as part of the main R&D budget. The MoD has also been experimenting with ways to accelerate procurement timelines, including through novel contracting methods for new equipment and through the creation of various accelerators and incubators.

Key Insight 11: Australia, Canada, and the U.K. Have Independent Oversight Functions for Ensuring the Transparency, Audits, or Contestability of Budgeting Processes

Accountability in Australia is provided through several means: the Australian National Audit Office (NAO), the Portfolio Budget Statement, the contestability function, and other reviews. The Australian National Audit Office, as an independent auditor, is similar to the U.S. Government Accountability Office (GAO) and the U.K. National Audit Office. The Portfolio Budget Statement is subject to public and parliamentary scrutiny; although the opposition can rarely change the spending decisions presented in the statement, public grievances can be aired, thereby pressuring the government as elections loom. The contestability function informs oversight but is not oversight itself; rather, contestability advice is integrated into the decision-making of the Defence Investment Committee, the Defence Finance and Resources Committee, and the National Security Committee of Cabinet (NSC). Oversight also exists through independent reviews of acquisition activities and through Senate reviews of defense programs.

Parliamentary oversight—or scrutiny—in Canada is aided by analyses from the Auditor General, the Parliamentary Budget Officer, and, at times, the Library of Parliament. The former two roles are accountable directly to parliament rather than to the executive or a minister. The Auditor General holds office for a 10-year term, issues an annual report to the House of Commons, produces other audits during the year, and appears regularly before parliamentary committees (Barnes, 2021). The Parliamentary Budget Officer holds office for a 7-year term and provides estimates on matters relating to Canada's finances or economy either independently or at the request of a parliamentary committee. The Parliamentary Budget Officer issues an annual report to both chambers of parliament in addition to reports requested by committees or parliamentarians, all of which are meant to raise the quality of debate and promote budget transparency. At the beginning of each fiscal year, the Parliamentary Budget Officer also submits an annual work plan with a list of matters that the office intends to bring to the attention of parliament (Barnes, 2021).

Each year, the MoD is externally vetted by the House of Commons Public Accounts Committee, the NAO, and the Comptroller and Auditor General to ensure that funds are not misused. Audits focus on what the NAO terms the three Es: economy, efficiency, and effectiveness (MoD, 2019b). Within the MoD, evaluation teams undertake internal reviews of individual programs to determine risks and identify other relevant issues. Throughout the year, decision-makers are encouraged to consider value for money and “the effective use of resources” (MoD, 2019b). Nevertheless, cost overruns do occur, and they can be embarrassing for the government.²⁶

The MoD recognizes the need to scale oversight, assurance, and compliance activities to program size and risk to minimize unnecessary bureaucracy and delays. Therefore, there are additional layers of oversight for single-source contracts and major projects. In these and other ways, the U.K. seeks to cultivate a robust but nuanced approach to oversight and assurance, balancing the risk of the misuse of funds or program difficulties and delays (because of insufficient oversight) against the risk of failing to deliver

²⁶ U.K. subject-matter expert, interview with the authors, November 2022.

required capabilities to the warfighter in a timely manner (because of excessive caution and focus on compliance).

Key Insight 12: Despite the Push to Accept Additional Risk, There Is Still a Cultural Aversion to Risk in the Australian, Canadian, and British Budgeting Processes

In Australia, stakeholders seek to spend within limits while adhering to the annual budget, which is intuitively prudent but could also limit agility. The cultural aversion to acquisition risk within Defence lengthens review times and holds up funds that could be spent on other projects. Canada's political structure does not allow Parliament to drastically change funding for departments, including DND, beyond what has been requested. Canada's political culture means that there is typically not much appetite for large increases in DND's spending in any given year. As in DoD, the MoD is experimenting with new ways to encourage innovation, including a new dedicated Innovation Fund. However, these strategies have not alleviated the enduring challenge of a risk-averse MoD culture.

Applicability of Selected Allied and Partner Nation Insights to DoD's PPBE System

The Commission on PPBE Reform is looking for potential lessons from the PPBE-like systems of selected allied and partner nations to improve the DoD's PPBE System. There are notable differences between the United States and the selected allies and partners in terms of political systems, population sizes, industrial bases, workforce sizes, and military expenditures; however, we found that, despite these differences, there are similarities in how all four countries generally approach defense resource management:

- Many decision-makers and stakeholders are involved throughout the complicated defense resource allocation processes.
- Strategic planning is a key input that is used to explicitly connect priorities to how much funding is spent to address military threats.
- Ongoing discussions are held between defense departments and decision-makers who control the "power of the purse" to justify how forces and programs will use the funding.
- Defense departments receive and spend funding according to agreed-on appropriations rules and then use certain mechanisms if plans change to move or carry over funding.
- Oversight is a key mechanism for making sure what is budgeted is appropriately spent.

The United States provides needed capabilities to Australia, Canada, and the U.K. This dependence arises from the capacity of the U.S. industrial base and the technological edge of its systems, but it also arises from the high priority that these countries place on allied interoperability. Given the interdependencies that exist, the Commission on PPBE Reform may want to consider the consequences of potential changes to the DoD's PPBE System for countries with some level of dependence on U.S. FMS.

Although the political systems of the allies and partners described in this report appear to offer easier ways to pass a defense budget with stronger executive branches, the U.S. system of government offers some of its own intended benefits of involving strong voices from both the executive and legislative branches. The diversity of thought can help ensure that both the majority and minority parties have some input in spending priorities. At the same time, this system can cause gridlock yearly through continuing resolutions and potential government shutdowns that allies do not endure. Continuing resolutions have been criticized for the inefficiency that they impose on the DoD; the increased need for advance—



or even crisis—planning; and the rush to spend when one-year funds are, at long last, available. Although the DoD expects and prepares for annual continuing resolutions, the commission may want to consider alternatives for mitigating the consequences of these annual disruptions in resource allocations.

All three countries examined exert some level of oversight over defense spending. In all cases, a balance is needed between the necessary oversight and the necessary flexibility to support innovation in response to emerging priorities. All the cases demonstrated ways in which flexibility is afforded through various mechanisms. Although none is a magic bullet, certain allied mechanisms could help improve DoD practices. Of particular relevance are those mechanisms that provide extra budget surety for major multiyear investments as opposed to reevaluating them every year. For example, the U.K.'s PB&F system benefits from multiannual spending plans, programs, and contracts. The MoD can sign decade-long portfolio management agreements with U.K. firms to provide long-term certainty. The PB&F system also allows for advance funding early in a budget year to ensure continuous government operations, thereby avoiding the possibility—and cost—of a shutdown. Likewise, Australia's defense planning, programming, and budgeting processes provide a high level of certainty for the development and operationalization of major military capabilities. These farsighted processes ensure a strong connection between strategy and resources, reduce prospects for the misuse of funds or inefficiency, and limit the risk of blocked funding from year to year.

The Commission on PPBE Reform will find many similarities across processes used in the United States, Australia, Canada, and the U.K., but one particular similarity that is ingrained in resource planning will be very tough to change: The risk-averse resource planning culture across these countries will need to adapt to allow additional ways to innovate to counter emerging and future threats.

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Planning, Programming, Budgeting, and Execution in Comparative Organizations: Case Studies of Selected Non-DoD Federal Agencies

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Abstract

The U.S. Department of Defense (DoD) Planning, Programming, Budgeting, and Execution (PPBE) System is a key mission enabler for the DoD. As observers consider a dynamic threat environment, increasingly capable adversaries, and rapid technological changes, concern has emerged that the DoD's resource planning processes are too inflexible to meet warfighter needs. In the Fiscal Year (FY) 2022 National Defense Authorization Act, Congress mandated the formation of a commission to (1) examine the effectiveness of the PPBE process and adjacent practices, (2) consider alternatives to maximize the DoD's ability to respond to potential threats, and (3) make recommendations for improvement in order to field the operational capabilities necessary to outpace near-peer competitors and support an integrated budget that is aligned with strategic defense objectives.

To provide process improvement insights, the Commission on PPBE Reform asked RAND to provide an independent analysis of PPBE-like functions in non-DoD federal agencies. Here, the authors present case studies of PPBE-like functions in the Department of Homeland Security (DHS), the Department of Health and Human Services (HHS), the National Aeronautics and Space Administration (NASA), the Office of the Director of National Intelligence (ODNI), the Department of Veterans Affairs (VA), and the Department of Energy's National Nuclear Security Administration (NNSA)

Key Findings

- Other U.S. government agencies looked to the DoD's PPBE System as a model in developing their own systems, which subsequently evolved in accordance with their missions, organizational structures, authorities, staff capacities, available resources, and many other factors.¹
- There are perceived opportunities to strengthen the connection between strategy and budgets, and long-term planning is sometimes limited relative to that done by the DoD.
- A variety of mechanisms enable budget flexibility and agility to meet dynamic mission demands and emerging threats.
- Mechanisms for enabling agility help agencies weather continuing resolutions and other sources of budget turbulence.
- The emphasis on evaluation rather than execution in some non-DoD PPBE-like processes could be instructive for the DoD. Beyond the explicit focus on evaluation in ODNI, DHS, and NNSA, both VA and NNSA have implemented mechanisms to support better analytic inputs to assist with evaluation that could help inform the DoD's PPBE approach.

¹ See McKernan et al. (2024) and Young et al. (2024).



- Implementation of PPBE-like processes at the scale of the DoD is resource-intensive, institutionally challenging, and often infeasible for smaller agencies. For NNSA, improved analytic rigor in planning and budgeting is provided through NNSA's internal Office of Cost Estimating and Program Evaluation (CEPE), which provides independent cost estimates and analyses like those provided by the DoD's Office of Cost Assessment and Program Evaluation (CAPE).
- Consolidated resource management information systems could improve visibility across the federated structures of government agencies.

Introduction

The 2022 National Defense Strategy (NDS) describes a security environment of complex strategic challenges associated with such dynamics as emerging technology, transboundary threats, and competitors posing “new threats to the U.S. homeland and strategic stability.” To meet this challenge, the NDS calls on the DoD (2022) to undertake three activities: integrated deterrence, campaigning, and “build[ing] enduring advantage.” The last category is defined as “undertaking reforms to accelerate force development, getting the technology we need more quickly, and making investments in the extraordinary people of the Department, who remain our most valuable resource.” This imperative has prompted reflection on the extent to which internal DoD processes, including PPBE, are up to the challenge of enabling rapid and responsive capability development to address the emerging threats.

The Planning, Programming, and Budgeting System (PPBS), the precursor to the DoD's PPBE process, took shape in the first decades after World War II and was introduced into the DoD in 1961 by then-Secretary of Defense Robert McNamara.² Drawing on new social science methods, such as program budgeting and systems analysis, the PPBS was designed to provide a structured approach to weigh the cost-effectiveness of potential defense investments. A central assertion of the PPBS's developers was that strategy and costs needed to be considered together.³ As Charles Hitch, Secretary McNamara's first comptroller and a key intellectual leader in the development and implementation of the PPBS, and Roland McKean (1960) noted, “There is no budget size or cost that is correct regardless of the payoff, and there is no need that should be met regardless of cost.”

To make decisions about prioritization and where to take risk in a resource-constrained environment, the DoD needed an analytic basis for making choices. Therefore, the PPBS first introduced the program budget, an *output*-oriented articulation of the resources associated with a given military capability projected out over five years.⁴ The PPBS then introduced an approach for assessing cost-effectiveness, termed systems analysis, which was institutionalized in the Office of Systems Analysis. Since 2009, the institutional successor to the Office of Systems Analysis has been known as CAPE.⁵ At its

² An oft-quoted assertion by Secretary of Defense Robert McNamara, which is pertinent to this discussion, is that “[y]ou cannot make decisions simply by asking yourself whether something might be nice to have. You have to make a judgment on how much is enough.” See Enthoven and Smith (1971); see also Young (2009).

³ Or, as Bernard Brodie stated succinctly, “strategy wears a dollar sign.” See Brodie (1959).

⁴ On the need for an output-oriented budget formulation at the appropriate level to make informed choices, Hitch and McKean (1960) noted that the consumer “cannot judge intelligently how much he should spend on a car if he asks, ‘How much should I devote to fenders, to steering activities, and to carburetion?’ Nor can he improve his decisions much by lumping all living into a single program and asking, ‘How much should I spend on life?’”

⁵ In a discussion of the founding of PPBS, Enthoven (the first director of the Office of Systems Analysis) and Smith (1971) described “the basic ideas that served as the intellectual foundation for PPBS” as follows: (1) decisionmaking should be made on explicit criteria of the national interest, (2) needs and costs should be considered together, (3) alternatives should be explicitly considered, (4) an active analytic staff should be used,



inception, the PPBS was a process for explicitly linking resources to strategy and for setting up a structure for making explicit choices between options, based on transparent analysis of costs and effectiveness. Then, as today, the system introduced friction with other key stakeholders, including Congress and industry partners. Key features of the PPBS have become institutionalized in the DoD's PPBE System, and questions have arisen about whether its processes and structures remain relevant and agile enough to serve their intended purposes (Greenwalt & Patt, 2021).

To set up the discussion of case studies, it will be helpful to outline the key features of the PPBE process and clarify some definitions. Today, consideration of PPBE often broadly encapsulates internal DoD processes, other executive branch functions, and congressional rules governing appropriations. Internal to the DoD, PPBE is an annual process by which the department determines how to align military programs and resources to strategic guidance. The process supports the development of DoD inputs to the President's Budget and to a budgeting program with a five-year time horizon (McGarry, 2020), known as the Future Years Defense Program (FYDP). DoD Directive (DoDD) 7045.14, *The Planning, Programming, Budgeting, and Execution (PPBE) Process*, states that one intent for PPBE "is to provide the DoD with the most effective mix of forces, equipment, manpower, and support attainable within fiscal constraints." PPBE consists of four distinct processes, each with its own outputs and stakeholders. Select objectives of each phase include the following:

- **Planning:** "[I]ntegrate assessments of potential military threats facing the country, over-all national strategy and defense policy, ongoing defense plans and programs, and projected financial resources into an overall statement of policy" (DoD, 2017).
- **Programming:** "[A]nalyze the anticipated effects of present-day decisions on the future force; detail the specific forces and programs proposed over the FYDP period to meet the military requirements identified in the plans and within the financial limits" (Tyszkiewicz & Daggett, 1998).
- **Budgeting:** "[E]nsure appropriate funding and fiscal controls, the phasing of the efforts over the funding period, and the feasibility of execution within the budget year" (Tyszkiewicz & Daggett, 1998); restructure budget categories for submission to Congress according to the appropriation accounts; and prepare justification material for submission to Congress (McGarry, 2020).
- **Execution:** "[D]etermine how well programs and financing have met joint warfighting needs" (DoD, 2017).

Several features of congressional appropriations processes are particularly important to note. First, since FY 1960, Congress has provided budget authority to the DoD through specific appropriations titles (sometimes termed *colors of money*), the largest of which are operation and maintenance (O&M); military personnel; research, development, test, and evaluation (RDT&E); and procurement (Tyszkiewicz & Daggett, 1998). These appropriations titles are further broken down into appropriation accounts, such as Military Personnel, Army or Shipbuilding and Conversion, Navy (SCN). Second, the budget authority provided in one of these accounts is generally available for obligation only within a specified period. In the DoD budget, the period of availability for military personnel and O&M accounts is one year; for RDT&E accounts, two years; and for most procurement accounts, three years (although for SCN, it can be five or six years, in certain circumstances). This specification means that

(5) a multiyear force and financial plan should project consequences into the future, and (6) open and explicit analysis should form the basis for major decisions.



budget authority must be obligated within those periods, or with only a few exceptions, it is sent back to the U.S. Department of the Treasury (Tyszkiewicz & Daggett, 1998).⁶ There has been recent interest in exploring how these features of the appropriations process affect transparency and oversight, institutional incentives, and the exercise of flexibility, should resource needs change (McGarry, 2020). Importantly, PPBE touches almost everything the DoD does and, thus, forms a critical touchpoint for engagement among stakeholders across the DoD (e.g., Office of the Secretary of Defense, military departments, Joint Staff, combatant commands), in the executive branch (through the Office of Management and Budget), in Congress, and among industry partners.

Study Objectives and Approach

In close partnership with the PPBE Commission, we selected six case studies of non-DoD federal agencies to explore decisionmaking in organizations facing challenges like those experienced in the DoD: exercising agility in the face of changing needs and enabling innovation. For all six case studies, we conducted extensive document reviews and structured discussions with subject-matter experts having experience in the budgeting processes of the examined U.S. federal government agencies. Case study research drew primarily on government documentation outlining processes and policies, planning guidance, budget documentation, and published academic and policy research. Although participants in structured discussions varied in accordance with the decisionmaking structures across case studies, they generally included chief financial officers, representatives from organizations responsible for making programmatic choices, and budget officials. To facilitate consistency, completeness in addressing the commission's highest-priority areas of interest, and cross-case comparisons, we developed a common case study template. This template took specific questions from the commission as several inputs, aligned key questions to PPBE processes and oversight mechanisms, evaluated perceived strengths and challenges of each organization's processes and their applicability to DoD processes, and concluded with lessons learned from each case. To enable development of a more consistent evidentiary base across cases, we also developed a standard interview protocol to guide the structured discussions.

Selected Non-DoD Federal Agencies Focus

The idea of dialogue between DoD and non-DoD agencies for lessons in resource planning areas is not new; in 1965, President Lyndon B. Johnson decided to introduce the still-new DoD PPBS across the federal government (Young, 2009). Four of the six cases of non-DoD federal agencies considered by the commission—HHS (known as the U.S. Department of Health, Education, and Welfare in 1965), NASA, VA (known as the Veterans Administration in 1965), and NNSA (functions of which were part of the Atomic Energy Commission in 1965)—were included in this 1965 directive before the experiment ended in 1970. The other two cases of non-DoD U.S. federal agencies—DHS and ODNI—also have PPBE-like functions that resonate with PPBE's origins in the DoD. Although Johnson's mandate was relatively short-lived, all six of these agencies looked to the DoD's PPBE process in the development of their own processes.

These agencies grappled with somewhat similar challenges as the DoD did on issues related to strategic planning, enterprise decisionmaking, and institutional control. Figure 1 compares the discretionary and mandatory budgets of the six agencies with that of the DoD in 2022—showing that the DoD's discretionary budget authority was significantly

⁶ For a discussion of the availability of funds appropriated to the DoD for RDT&E activities, see Section 3131 of Title 10, United States Code, Availability of Appropriations.



higher than those of the six other agencies.⁷ However, HHS's total annual budget authority was more than \$1.6 trillion in 2022, which was more than double the DoD's total 2022 budget authority of roughly \$796 billion. Mandatory HHS funding (primarily for Medicare and Medicaid) constitutes about 90% of the total HHS budget (Office of Management and Budget, n.d.)

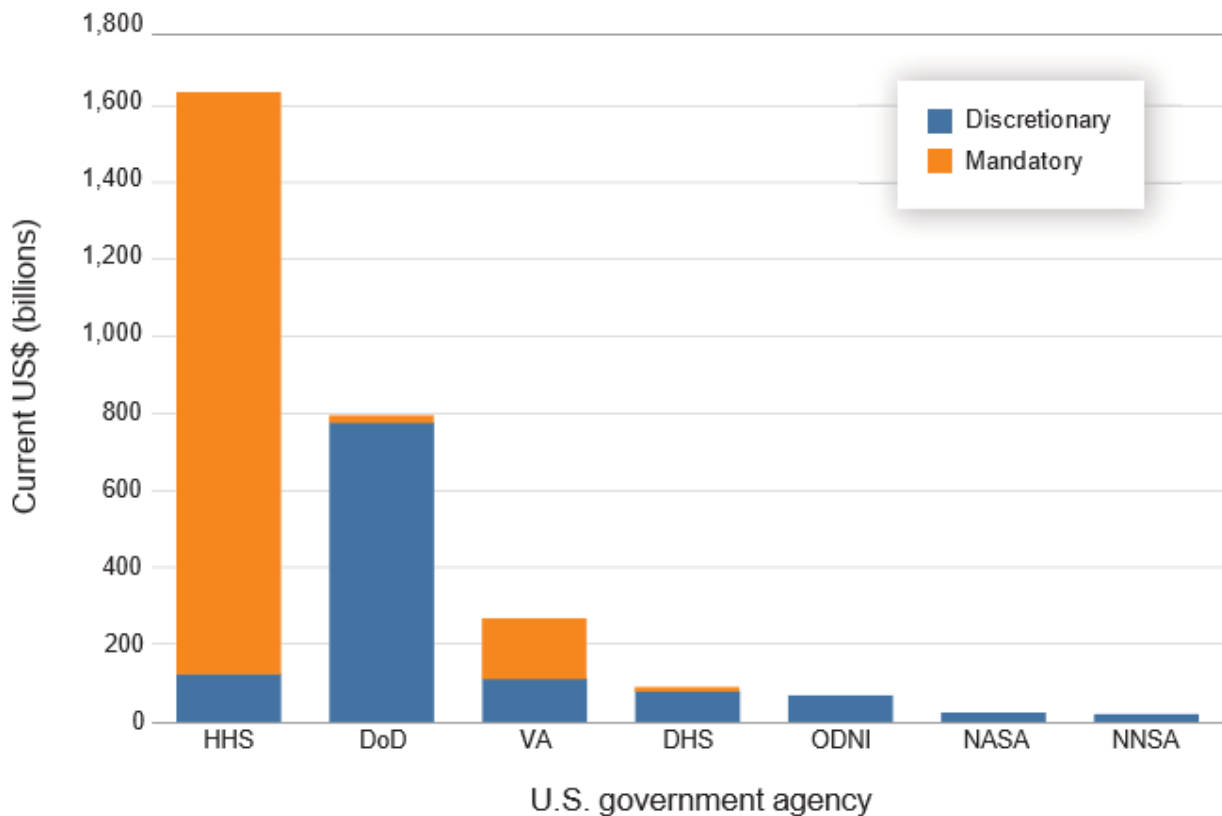


Figure 1. Mandatory and Discretionary Budget Authority, by U.S. Government Agency, 2022
(Office of Management and Budget; Office of the Director of National Intelligence)

NOTE: For ODNI, we show the total budget appropriation for the National Intelligence Program and not discretionary budget authority due to a lack of available data for comparison in the OMB tables. As of FY 2017, ODNI does not receive mandatory funds (Federation of American Scientists, n.d.). We similarly show the total NNSA budget appropriation due to a lack of available data for comparison (Office of Management and Budget, n.d.). As of FY 2022, NNSA did not receive any mandatory funds.

The six non-DoD government agencies selected for analysis were identified as agencies that, by virtue of their missions, grapple with some issues like those that the DoD faced (and continues to face) regarding how to enable innovation, make high-tech investments, and transition technology into the field or remain flexible in response to dynamic mission needs. Although each agency is different from the DoD in important ways,

⁷ "The authority for discretionary spending stems from annual appropriation acts, which are under the control of the House and Senate Appropriations Committees. *Mandatory*—or direct—spending includes spending for entitlement programs and certain other payments to people, businesses, and state and local governments. Mandatory spending is generally governed by statutory criteria; it is not normally set by annual appropriation acts." See Congressional Budget Office (n.d.).

their unique stories also provide some notable insights for the commission.

Key Insights From Selected Non-DoD Federal Agencies Case Studies

The case studies prepared by RAND provided the Commission on PPBE Reform with insights into how other non-DoD U.S. federal government agencies navigate U.S. political institutions and resource planning processes to meet mission needs. The material presented in this discussion, distilled from two separate reports, outlines important themes for the commission to understand when trying to compare the DoD's defense resource planning processes with those of other U.S. government agencies.⁸ Despite significant differences between the DoD and these selected agencies in terms of mission requirements, portfolio, organizational evolution, oversight, and size, among many other factors, these cases suggest several insights that are germane for the DoD, which we present below. The following section on key insights consolidates the strengths, challenges, and lessons outlined in each of the case studies considered. The concluding section on applicability speaks directly to the commission's mandate—and to the potential utility of such insights for the DoD's PPBE System.

Key Insights

Key Insight 1: Other U.S. Government Agencies Looked to the DoD's PPBE System as a Model in Developing Their Own Systems, Which Subsequently Evolved

In 1965, President Johnson drew on the still-nascent PPBS in the DoD as a model for the implementation of analogous systems across the federal government. Although that formal effort ended a few years later, the agencies considered in this report all looked to the DoD's PPBE System as a model for a structured and mature approach to planning and resource allocation decisionmaking—as the names of their budget processes often suggest, such as NASA's PPBE, ODNI's Intelligence Planning, Programming, Budgeting, and Evaluation (IPPBE), and NNSA's PPBE systems. However, budgeting processes have evolved individually in accordance with the agencies' leadership buy-in, missions, organizational structures, authorities provided by Congress, staff capacities, other available resources, and many other factors. For example, while civilian PPBE processes failed to take hold in the Veterans Administration when originally introduced in the 1960s, features of a more structured resource planning process, such as a quadrennial review to drive planning and a five-year financial plan, were proposed as a means of addressing perceived shortcomings of the existing system.

For example, although some vestiges of the PPBE framework—such as its rigorous program evaluation capabilities—remain features of the contemporary HHS budgeting system, the department gradually dismantled much of its PPBS during the 1970s in response to the perception that PPBS did not fit with the U.S. Department of Health, Education, and Welfare's missions (the U.S. Department of Health, Education, and Welfare, or HEW, was renamed to HHS in 1980), organizational structure, or program needs.⁹ HHS's budgeting system has, therefore, diverged significantly from the DoD's since 1980.

ODNI's IPPBE process was specifically modeled on the DoD's PPBE process, with some modifications to ensure that it was suited to ODNI's mission. This adaptation was done both by necessity, to account for the presence of DoD elements in the Intelligence Community (IC), and by design, given that the architects of the IPPBE process were well

⁸ See McKernan et al. (2024) and Young et al. (2024).

⁹ See, for examples, Harlow (1973), Jablonsky and Dirsmitz (1978), Rivlin (1969, Vol. 3, Part V, Section C, pp. 909–922), U.S. Government Printing Office, and GAO (1990).



versed in PPBE and viewed it as the best model for ODNI's complex organizational structure (ODNI subject-matter experts, interviews with the authors, August–September 2022). One notable and deliberate difference between the IPPBE and PPBE processes is ODNI's substitution of *evaluation* for the DoD's execution (ODNI subject-matter experts, interviews with the authors, August–September 2022).

While the standup of NNSA postdated by several decades President Johnson's introduction of PPBE to non-DoD agencies, one of its institutional predecessors, the Atomic Energy Commission, was among the agencies that did experiment in developing resource planning processes modeled on the DoD's PPBE processes. Today, NNSA's PPBE process is indebted to the DoD's PPBE System while tailored to NNSA's unique mission needs. For example, NNSA's PPBE process leverages the original intent of the DoD's PPBE System, albeit with an increased focus on evaluation as the fourth phase of its process. The Future Years Nuclear Security Program (FYNSP), analogous to the DoD's FYDP, underlies NNSA's long-term planning, and NNSA's Office of Cost Estimating and Program Evaluation (CEPE) is deliberately modeled on the DoD's CAPE.

Despite the evolution away from the DoD's PPBE System, the agencies considered still generally follow a budgeting process that is common to most U.S. federal civilian agencies. This process begins with an annual planning cycle and culminates in budget execution and performance evaluation.

Key Insight 2: While Long-Term Planning is Often Limited Relative to That Done by the DoD, There Are Perceived Opportunities to Strengthen Connections Between Strategy and Budgets

While the relative focus on long-term planning varies across cases in accordance with an agency's mission, organizational design, analytic capabilities, and resource constraints, among many other factors, grappling with how to link priorities to budgetary decisionmaking was a theme across all cases.

One difference between the DoD and three of the agencies (DHS, HHS, and ODNI) considered in this report is the DoD's focus on long-term planning processes. We attribute this difference both to the inherently dynamic requirements of DHS's and HHS's mission sets and to the weaker (relative to the DoD) mechanisms for forging forward-looking, cross-departmental plans through a headquarters function in DHS and ODNI. Because HHS programs deliver mostly health care services and grants, the department operates primarily on one-year discretionary funding and restricts budget planning to the annual budget cycle (HHS officials, interviews with the authors, October 2022–January 2023). Consequently, this relatively near-term planning horizon has resulted in an agency that does not focus on long-term budget planning or utilize well-established links between strategic planning and budgeting (HHS officials, interviews with the authors, October 2022–January 2023).

Long-term planning is particularly important for agencies with missions requiring sustained development efforts rather than short-term operational programs. DHS's federated model, in which the components remain responsible for their separate missions and receive direct appropriations, introduces challenges for headquarters in shaping forward-looking cross-component priorities to drive resource decisionmaking—unlike in the DoD, where the Office of the Secretary of Defense disperses the funds, thereby increasing its control. DHS also lacks a Goldwater-Nichols-type mandate to compel jointness, and DHS headquarters lacks the resourcing of the Office of the Secretary of Defense, limiting the ability of DHS headquarters to coordinate and manage its components.

In contrast to DHS, HHS, and ODNI, the other agencies considered (NASA, VA, and NNSA) have long-term planning processes. For example, NASA adheres to five-year



planning guidance and decadal studies to identify future requirements. Both VA and NNSA have processes for long-term planning and linking strategy to budgets, but (like the DoD) there are perceived opportunities to strengthen these connections. In VA, the quadrennial planning process supports the development of a strategic plan, but there are perceived opportunities to strengthen how plans drive resource decisionmaking. For example, VA aligns its annual budget request (albeit not a long-term plan) to specific mission-oriented outputs (e.g., patients treated, outpatient visits), which provides a helpful link between mission priorities and resources. In NNSA, the Future Years Nuclear Security Program (FYNSP) captures plans beyond the budget year, but there are also initiatives underway to strengthen long-term planning (beyond the FYNSP) and facilitate better alignment between plans and programs.

Key Insight 3: A Variety of Mechanisms Enable Budget Flexibility and Agility

Mechanisms have been designed to meet dynamic mission demands, such as the startup of DHS; provide flexible authorities to meet highly variable mission needs, as with DHS's Disaster Relief Fund and CDC's Infectious Disease Rapid Response Reserve Fund; and adapt quickly to emerging public health threats, as with HHS's Public Health Service Evaluation Set-Aside.

We identified several other mechanisms for enabling flexibility and agility, primarily by giving agencies more discretion (than in the DoD) to redirect appropriated funds. HHS and NASA benefit from having fewer restrictions on fungible expenditures, which allows them to shift resources in accordance with changing priorities. The annual Departments of Labor, Health and Human Services, and Education, and Related Agencies (LHHS) Appropriations Act affords HHS considerable flexibility in reprogramming funds: Below a reprogramming threshold of the lesser of \$1 million or 10% of a budget account, HHS is not required to report it to Congress (National Institutes of Health, Office of Management and Assessment, 2020). Congress has granted HHS additional sources of flexibility during budget execution, including the Secretary's One-Percent Transfer General Provision, which allows HHS to transfer up to 1% from any LHHS appropriation account into another account up to 3% of the amount of the receiving account, with a maximum transfer amount of around \$900 million.¹⁰ HHS appears to have wide latitude in how appropriated funds are spent. Similarly, NASA does not appear to receive appropriations in distinct titles, as does the DoD. In part, this is likely due to NASA's narrower mission requirements (e.g., NASA does not procure at the scale of the DoD).

Another mechanism for flexibility is the authority to carry over funding across years. Although DHS's no-year appropriations have been curtailed, DHS still has authority to allow its components to carry over and spend in the next fiscal year up to 50% of prior-year balances in one-year O&S accounts. HHS also has authority to repurpose expiring unobligated balances. The Non-Recurring Expenses Fund (NEF) allows HHS to take expired, unobligated funds and reallocate them to a department-wide capital investment account. HHS has used the NEF extensively to fund IT systems, particularly for cybersecurity purposes, but operating and staff divisions can request funding for other capital expenditures as well. In some instances, Congress further enables agility by employing broader appropriation categories than those used for DoD appropriations; in this way, agency decisionmakers have more flexibility to implement changes to previously communicated funding priorities. For instance, NASA's receipt of appropriations primarily at the mission level allows mission directorates to decide how to allocate funding between

¹⁰ The Office of Refugee Resettlement can take up to 15% of the value of transfer funds, so these funds are often transferred there (HHS official, interview with the authors, January 2023).



projects without having to seek additional congressional approval.

For both VA and NNSA, we identified several budget mechanisms that are useful for enabling flexibility and agility, primarily because they give each agency a degree of discretion to redirect appropriated funds. VA's advance appropriations are particularly notable in this regard, and for NNSA, the lack of designated colors of money and the small number of appropriation accounts (relative to the DoD) provide more discretion to the agency on how to prioritize investments and flex as needed to meet emerging needs.

Another mechanism for flexibility is the authority to carry over funding across years. NNSA's no-year appropriations for its operational budget provides funds that remain available for obligation until expended, without the time pressure associated with funding that must be obligated within a certain time frame. These appropriations enable NNSA to spend such funds as needed and avoids incentivizing a spending rush at the end of a fiscal year. One consideration, however, associated with no-year flexibility is the requirement to maintain sufficient financial controls to manage the complex accounting of executing such appropriations provided over several fiscal years at once. VA also has access to multiyear and no-year appropriations for long-term projects, such as construction and land acquisition, among other functions. VA's advance appropriations provide several useful management levers to the agency. As discussed below, they can help VA weather instability caused by delays in receiving regular appropriations and position the agency for more-stable long-term planning. Finally, similar to the DoD, VA and NNSA can request congressional approval to reprogram resources to accommodate changes above a given threshold, but in NNSA at least, this process was reported to be slow and laborious.

Key Insight 4: Mechanisms for Enabling Agility Help Agencies Weather Continuing Resolutions and Other Sources of Budget Turbulence

Just as budget flexibilities, such as those cited above, can let a manager decide how to prioritize and where to take risks in light of changing mission needs, they can also help an agency manage under continuing resolutions and mitigate the effects of government shutdowns, such as furloughs. Continuing resolutions across the U.S. government remain painful, but an agency's ability to manage them is a function of its portfolio, investments, actions, and other factors.

NASA's two-year expiration timeline for appropriations reportedly provides the agency with a cushion in the likely event that a regular appropriation is delayed. DHS develops requests for grant proposals ahead of anticipated continuing resolutions (GAO, 2021). The ability of DHS components to carry over into the next fiscal year one-year O&S accounts and expend up to 50% of their prior-year lapsed balances could also help DHS mitigate the effects of continuing resolutions, although, as mentioned previously, this is not the main purpose of carryover funding.

A different kind of example for HHS is that its mandatory funding (primarily for Medicare and Medicaid) constitutes about 90% of the HHS budget (Tollestrup et al., 2022). Most mandatory HHS programs, such as Medicare and children's entitlement programs, are budgeted on 10-year schedules outside the annual appropriations process and, thus, are rarely subject to continuing resolutions. Medicaid, however, is still subject to annual congressional oversight (Tollestrup et al., 2022).

Among other benefits, VA's advance appropriations help mitigate challenges associated with constraints on activities during operations under a continuing resolution and uncertainty regarding the timing of a regular appropriation. Similarly, NNSA's no-year appropriations provide the agency with a budgetary cushion (and fewer constraints than those faced under a continuing resolution) in the likely event that a regular appropriation is



delayed.

Key Insight 5: The Emphasis on Evaluation Rather Than Execution in Some Non-DoD PPBE-Like Processes Could Be Instructive for the DoD

ODNI is not alone in substituting evaluation for execution in its budgeting process. DHS has also essentially done so in its PPBE-like process to better understand the results of its spending. To support implementation of the Foundations for Evidence-Based Policymaking Act of 2018, DHS issued a policy on program and organizational evaluations in February 2021 and annual evaluation plans for FYs 2022 and 2023. This line of effort demonstrates an investment by DHS in evaluation activities. DHS's efforts in this area could help inform the DoD's approach to the execution phase.

As was the case for ODNI, NNSA's PPBE process focuses its fourth phase on evaluation rather than execution. DHS has also made recent efforts to bolster evaluation feedback in its PPBE process by mandating organizational evaluations and annual evaluation plans. In the evaluation phase of NNSA's PPBE process, NNSA evaluates progress toward its performance goals. Although this phase does not generate formal documentation, the input is intended to feed back into the planning phase for the following fiscal year. Beyond this explicit focus on evaluation in NNSA, both VA and NNSA have implemented mechanisms to support better analytic inputs to assist with evaluation, primarily in the programming phase of their PPBE processes. For example, VA leverages actuarial models to project future demand and inform budget requests for certain benefits in the budgeting phase; NNSA's new FormEx information system and CEPE function also equip the agencies with consistent and rigorous analytic capabilities.

Key Insight 6: Implementation of PPBE-Like Processes at the Scale of the DoD is Resource-Intensive, Institutionally Challenging, and Often Infeasible for Smaller Agencies—However, Analytical Rigor Has Improved Through NNSA's Implementation of CAPE-Like Capabilities

One area in which a number of the selected non-DoD agencies cannot emulate an exemplary DoD PPBE capability is the DoD's CAPE analytic function. We found that constraints caused by significantly smaller staff and resources shaped the scale of the PPBE-like functions that some examined agencies could execute; in these cases, a CAPE-like function does not exist in comparable size and mission, as this function is resource-intensive to build and maintain and challenging to empower institutionally. As articulated on its website (undated), CAPE's mission is to "provide the Department of Defense with timely, insightful and unbiased analysis on resource allocation and cost estimation problems to deliver the optimum portfolio of military capabilities through efficient and effective use of each taxpayer dollar."

By comparison, the planning, programming, and budgeting for NASA are handled by one NASA organization—the Office of the Chief Financial Officer (OCFO)—and there is a possibility that conflicts of interest might arise. The OCFO's Strategic Investment Division, which develops strategic planning guidance that informs NASA's programming and budgeting phases, is not analogous to CAPE because it is housed within OCFO and, therefore, may not be considered an independent organization when it scrutinizes NASA's budget submissions. Interviewees noted that independent agencies may be able to identify overruns faster than NASA's evaluation-oriented offices could, primarily because of workforce capacity challenges (NASA subject-matter experts, interviews with the authors, September 2022).

ODNI attempted to emulate the analytic rigor of the CAPE function by creating the Systems and Resource Analysis Office (SRA) and tasking it with managing IPPBE



integration and synchronization. The goal was to establish a predictable, transparent, and repeatable method to collect and prioritize critical intelligence requirements and to translate those priorities into resource allocations through the IPPBE process. Between 2009 and 2011, ODNI tested this process, which was later codified. But several years later, concerns arose over the evolution of some documents and the ability of SRA to continue its role. ODNI found it difficult to keep SRA staffed with the capability and capacity to fulfill a CAPE-like function.

We found substantial effort in the NNSA case study to centralize and bolster the rigor of its PPBE processes, including the introduction of the Office of Cost Estimating and Program Evaluation (CEPE), a CAPE-like capability for developing independent cost estimates and analyses of alternatives. NNSA further increased analytical rigor by having its cost analysts report to a single headquarters organization while embedding them in NNSA program offices, thus ensuring the use of standardized costing methodologies and improving transparency and alignment of programs to enterprise-wide priorities.

Key Insight 7: Consolidated Resource Management Information Systems Could Improve Visibility Across the Federated Structures of Government Agencies

We noted efforts (albeit somewhat uneven in practice) in non-DoD agencies to strengthen information systems to enable resource decisionmaking. For example, DHS had an initiative underway to consolidate its PPBE information system to support the development of its five-year funding plan: capturing performance management data has facilitated automation in reporting. NNSA's new FormEX similarly reflects an effort to modernize the IT infrastructure on which PPBE decisions rely. As a budget information management system, FormEX is intended to bolster transparency and information-sharing by providing a common budget structure to facilitate insight into plans, gaps, potential redundancies, and potential execution risks.

As these cases suggest—and as the motivation for the DoD's efforts (as of 2024) to develop Advana reflects¹¹—there are potential opportunities to leverage IT and data analytics to better meet complex decisionmaking needs and foster stronger transparency and communication across stakeholder communities.

Applicability of Key Insights to the DoD's PPBE System

The Commission on PPBE Reform is looking for potential lessons from the PPBE-like processes of non-DoD federal agencies. While those agencies' budgeting processes were originally modeled after the DoD's PPBE System, they have been adapted over time to align with the unique missions of each agency. Despite the movement away from the DoD's PPBS model, the agencies still use similar PPBE processes. Because of these similarities, there would be no benefit from the DoD adopting any of these systems wholesale. However, there is value in exploring the ways in which Congress provides each agency with flexibility so that the DoD can ask for similar kinds of flexibility to support more innovation, make funding more predictable over multiple years, and obtain relief from various pain points in the system. These pain points include continuing resolutions, rigid appropriation categories, and appropriations for line items instead of portfolios. The commission could further explore the flexibility mechanisms identified below, organized by agency.

DHS funds are typically budgeted annually, but some programs receive multiyear or no-year appropriations. Congress sometimes appropriates multiyear funds to major acquisition programs to foster a stable production and contracting environment. A key example of no-year money is the Disaster Relief Fund, which is meant to give FEMA the

¹¹ For more on Advana, see Commission on Planning, Programming, Budgeting, and Execution Reform (2023).



flexibility to respond quickly to emerging disaster relief and recovery needs. As another example, DHS officials mentioned how the border security, fencing, infrastructure, and technology appropriation gave DHS the ability to carry over significant amounts of funds related to this mission area. DHS officials noted that funds are no longer appropriated to this account and that the use of no-year appropriations was significantly curtailed with the implementation of the common appropriations structure (DHS officials, interview with the authors, November 2022).¹² Congress also authorizes DHS components to carry one-year O&S accounts forward into the next fiscal year and to expend up to 50% of the prior-year lapsed balance amounts. Beyond the base budget, DHS often receives supplemental funds for emergent requirements, the number of which varies from year to year.

HHS has access to emergency supplemental funding and several flexible-spending accounts, such as the NEF, which allows HHS to reallocate expired, unobligated funds to capital investments. These flexibility mechanisms are often given multiyear or no-year funding. HHS does not use a common appropriations structure, so budget justifications focus heavily on missions and needs. This focus allows discussions between the OPDIVs and the SBC's department-level leadership to concentrate on aligning program budgets and missions with the HHS Secretary's priorities.

NASA requests and is allocated funding differently than the DoD. Because NASA's funds are appropriated to mission directorates primarily at the mission, theme, and project levels, NASA has some flexibility to align project funding to meet changing priorities or real-world circumstances. NASA's FY 2023 congressional justification does not request, nor is it funded with, appropriations split into categories, such as RDT&E, procurement, and O&M in the same manner as the DoD. Therefore, NASA does not appear to encounter the same types of restrictions as the DoD with respect to using specific funding for specific activities (e.g., using RDT&E only during the design and development stages of a program). Moreover, all of NASA's appropriations, except for construction, have two-year durations. NASA has obligation goals of 90–95% in the first year of two-year funds, which allow for some funding to be expended in the second year, typically at the start of the fiscal year. Because continuing resolutions are a real possibility, this carryover funding can mitigate any shortfalls that might result at the start of a fiscal year—and, thus, act as a cushion for continuing resolutions.

ODNI funds may be reprogrammed under five conditions: (1) when funds are transferred to a high-priority intelligence activity in support of an emergent need, (2) when funds are not moved to a reserve for contingencies of the DNI or the Central Intelligence Agency, (3) when funds are cumulatively less than \$150 million and less than 5% of the annual accounts available to a department or agency, (4) when the action does not terminate an acquisition program, and (5) when the congressional notification period is satisfied. Congress must be notified of above-the-threshold reprogramming actions (i.e., those that exceed \$150 million or 5%) within 30 days or within 15 days for matters of urgent national security concern. Below-the-threshold reprogramming actions do not require congressional notification. However, ODNI does notify Congress of below-the-threshold actions that may be of congressional interest (Office of the Director of National Intelligence, 2018).

Despite having significant differences with the DoD, VA and NNSA have some notable similarities with the DoD in terms of missions and investment portfolios. First, the DoD's PPBE System served as the initial model for the resource planning processes

¹² For more information on the border security, fencing, infrastructure, and technology appropriation, see Painter and Singer (2020).



institutionalized in both VA and NNSA. VA, like the DoD, provides medical care, oversees infrastructure construction, sustains a large footprint of real property, and conducts efforts to modernize IT infrastructure. NNSA, like the DoD, has requirements informed by the demands of emerging threats and a dynamic strategic environment, which necessitate a posture that enables innovation and the leveraging of new technology.

However, there are also important differences that affect the applicability of lessons from VA and NNSA to the DoD. As was true when comparing all of the case studies of comparative non-DoD organizations with the DoD, the DoD stands alone in terms of the global roles that U.S. defense spending enables, the breadth and complexity of its missions, and the overall size of its budget. Both VA and NNSA have more-focused mission sets and significantly smaller discretionary budgets than those of the DoD. Another key difference is the overall constitution of non-DoD agencies' budgets compared with the DoD's portfolio. VA—and HHS—has a large percentage of its overall budget in mandatory spending, relative to the DoD's budget. About 40% of the VA budget is discretionary spending, and much of this funding is relatively inflexible because it supports medical care. This means that resource planning to support its primary mission depends more on actuarial modeling in VA than in DoD. This difference in planning and programming approaches reflects VA's unique mission and budget portfolio.

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Planning, Programming, Budgeting, and Execution in Comparative Organizations: Case Studies of China and Russia

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Abstract

The U.S. Department of Defense's (DoD's) Planning, Programming, Budgeting, and Execution (PPBE) System was originally developed in the 1960s as a structured approach for planning long-term resource development, assessing program cost-effectiveness, and aligning resources to strategies. Yet changes to the strategic environment, the industrial base, and the nature of military capabilities have raised the question of whether existing U.S. defense budgeting processes remain well aligned with national security needs.

The U.S. Congress called for the establishment of a commission on PPBE reform. As part of its data collection efforts, the commission asked RAND to conduct case studies of budgeting processes across sixteen comparative organizations: ten international defense organizations and six U.S. federal government agencies.

In this paper, RAND researchers conduct case studies of the defense budgeting processes of China and Russia. Within data availability constraints, researchers conducted extensive document reviews and, to the extent possible, structured discussions with subject-matter experts with knowledge of internal decision-making processes and governance structures for each case study. Each case study was assigned a unique team with appropriate regional, language, or organizational expertise. The analysis was also supplemented by experts in the U.S. PPBE process.

Key Findings¹

- China and Russia make top-down decisions about priorities and risks but face limitations in implementation
- China and Russia make long-term plans but have mechanisms for changing course in accordance with changing priorities
- Especially in China, political leaders provide stable and sustained long-term support for military modernization priorities
- China and Russia have weak mechanisms for avoiding graft or ensuring transparency, efficiency, effectiveness, and quality control in PPBE-like processes
- Reforms in China and Russia have been designed to increase oversight of

¹ There is additional information on this topic in the full document: *Planning, Programming, Budgeting, and Execution in Comparative Organizations: Volume 1, Case Studies of China and Russia* (McKernan et al., 2024).



Introduction

In light of a dynamic threat environment, increasingly capable adversaries, and rapid technological changes, there has been increasing concern that the U.S. Department of Defense's (DoD's) resource planning processes are too slow and inflexible to meet warfighter needs.² The DoD's Planning, Programming, Budgeting, and Execution (PPBE) system was originally developed in the 1960s as a structured approach for planning long-term resource development, assessing program cost-effectiveness, and aligning resources to strategies. Yet changes to the strategic environment, the industrial base, and the nature of military capabilities have raised the question of whether the DoD's budgeting processes are still well aligned to national security needs.

To consider the effectiveness of current resource planning processes for meeting national security needs and to explore potential policy options to strengthen those processes, Congress called for the establishment of a commission on PPBE reform in Section 1004 of the National Defense Authorization Act for Fiscal Year (FY) 2022.³ The Commission on PPBE Reform took shape as a legislative commission in 2022, consisting of 14 appointed commissioners, each drawing on deep and varied professional expertise in the DoD, Congress, and the private sector. In support of this work, the commission collected data, conducted analyses, and developed a broad array of inputs from external organizations, including federally funded research and development centers, to develop targeted insights of particular interest to the commission. The commission asked the RAND National Defense Research Institute to contribute to this work by conducting case studies of 16 comparative organizations: ten international defense organizations and six other U.S. federal government agencies.

The Planning, Programming, and Budgeting System (PPBS), the precursor to the DoD's PPBE process, took shape in the first decades after World War II and was introduced into the DoD in 1961 by then-Secretary of Defense Robert McNamara.⁴ Drawing on new social science methods, such as program budgeting and systems analysis, the PPBS was designed to provide a structured approach to weigh the cost-effectiveness of potential defense investments. A central assertion of the PPBS's developers was that strategy and costs needed to be considered together.⁵ As Charles Hitch, Secretary McNamara's first comptroller and a key intellectual leader in the development and implementation of the PPBS, and Roland McKean (1960) noted, "There is no budget size or cost that is correct regardless of the payoff, and there is no need that should be met regardless of cost."

To make decisions about prioritization and where to take risk in a resource-constrained environment, the DoD needed an analytic basis for making choices. Therefore, the PPBS first introduced the program budget, an *output*-oriented articulation of the

² See, for example, Section 809 Panel (2018, pp. 12–13); McGarry (2022, p. 1); and Greenwalt and Patt (2021, pp. 9–10).

³ Public Law 117-81. National Defense Authorization Act (NDAA) for Fiscal Year 2022. (2021, December 27). Section 1004(f) of this Act is of particular relevance to our research approach: "Compare the planning, programming, budgeting, and execution process of the Department of Defense, including the development and production of documents including the Defense Planning Guidance (described in section 113(g) of Title 10, United States Code), the Program Objective Memorandum, and the Budget Estimate Submission, with similar processes of private industry, other Federal agencies, and other countries."

⁴ An oft-quoted assertion by Secretary of Defense Robert McNamara, which is pertinent to this discussion, is that "[y]ou cannot make decisions simply by asking yourself whether something might be nice to have. You have to make a judgment on how much is enough" (Enthoven & Smith, 1971; Young, 2009).

⁵ Or, as Bernard Brodie stated succinctly, "strategy wears a dollar sign" (Brodie, 1959).



resources associated with a given military capability projected out over five years.⁶ The PPBS then introduced an approach for assessing cost-effectiveness, termed systems analysis, which was institutionalized in the Office of Systems Analysis. Since 2009, the institutional successor to the Office of Systems Analysis has been known as Cost Assessment and Program Evaluation (CAPE).⁷ At its inception, the PPBS was a process for explicitly linking resources to strategy and for setting up a structure for making explicit choices between options, based on transparent analysis of costs and effectiveness. Then, as today, the system introduced friction with other key stakeholders, including Congress and industry partners. Key features of the PPBS have become institutionalized in the DoD's PPBE System, and questions have arisen about whether its processes and structures remain relevant and agile enough to serve their intended purposes (Greenwalt & Patt, 2021).

To set up the discussion of case studies, it will be helpful to outline the key features of the PPBE process and clarify some definitions. Today, consideration of PPBE often broadly encapsulates internal DoD processes, other executive branch functions, and congressional rules governing appropriations. Internal to the DoD, PPBE is an annual process by which the department determines how to align military programs and resources to strategic guidance. The process supports the development of DoD inputs to the President's Budget and to a budgeting program with a five-year time horizon (McGarry, 2020), known as the Future Years Defense Program (FYDP). Department of Defense Directive (DoDD) 7045.14, *The Planning, Programming, Budgeting, and Execution (PPBE) Process*, states that one intent for PPBE "is to provide the DoD with the most effective mix of forces, equipment, manpower, and support attainable within fiscal constraints." PPBE consists of four distinct processes, each with its own outputs and stakeholders. Select objectives of each phase include the following:

- **Planning:** "[I]ntegrate assessments of potential military threats facing the country, over-all national strategy and defense policy, ongoing defense plans and programs, and projected financial resources into an overall statement of policy" (DoD, 2017).
- **Programming:** "[A]nalyze the anticipated effects of present-day decisions on the future force; detail the specific forces and programs proposed over the FYDP period to meet the military requirements identified in the plans and within the financial limits" (Tyszkiewicz & Daggett, 1998).
- **Budgeting:** "[E]nsure appropriate funding and fiscal controls, the phasing of the efforts over the funding period, and the feasibility of execution within the budget year" (Tyszkiewicz & Daggett, 1998); restructure budget categories for submission to Congress according to the appropriation accounts; and prepare justification material for submission to Congress (McGarry, 2020).
- **Execution:** "[D]etermine how well programs and financing have met joint warfighting needs" (DoD, 2017).

Several features of congressional appropriations processes are particularly important

⁶ On the need for an output-oriented budget formulation at the appropriate level to make informed choices, Hitch and McKean (1960) noted that the consumer "cannot judge intelligently how much he should spend on a car if he asks, 'How much should I devote to fenders, to steering activities, and to carburetion?' Nor can he improve his decisions much by lumping all living into a single program and asking, 'How much should I spend on life?'"

⁷ In a discussion of the founding of PPBS, Enthoven (the first director of the Office of Systems Analysis) and Smith (1971) described "the basic ideas that served as the intellectual foundation for PPBS" as follows: (1) decision making should be made on explicit criteria of the national interest, (2) needs and costs should be considered together, (3) alternatives should be explicitly considered, (4) an active analytic staff should be used, (5) a multiyear force and financial plan should project consequences into the future, and (6) open and explicit analysis should form the basis for major decisions.

to note. First, since FY 1960, Congress has provided budget authority to the DoD through specific appropriations titles (sometimes termed *colors of money*), the largest of which are operation and maintenance (O&M); military personnel; research, development, test, and evaluation (RDT&E); and procurement (Tyszkiewicz & Daggett, 1998). These appropriations titles are further broken down into appropriation accounts, such as Military Personnel, Army, or Shipbuilding and Conversion, Navy (SCN). Second, the budget authority provided in one of these accounts is generally available for obligation only within a specified period. In the DoD budget, the period of availability for military personnel and O&M accounts is one year; for RDT&E accounts, two years; and for most procurement accounts, three years (although for SCN, it can be five or six years, in certain circumstances). This specification means that budget authority must be obligated within those periods, or, with only a few exceptions, it is sent back to the U.S. Department of the Treasury (Tyszkiewicz & Daggett, 1998).⁸ There has been recent interest in exploring how these features of the appropriations process affect transparency and oversight, institutional incentives, and the exercise of flexibility, should resource needs change (McGarry, 2020). Importantly, PPBE touches almost everything the DoD does and, thus, forms a critical touchpoint for engagement among stakeholders across the DoD (e.g., Office of the Secretary of Defense, military departments, Joint Staff, combatant commands), in the executive branch (through the Office of Management and Budget), in Congress, and among industry partners.

Study Objectives and Approach

In close partnership with the PPBE Commission, we selected ten case studies of international defense organizations to explore decision making in organizations facing challenges like those experienced in the DoD: exercising agility in the face of changing needs and enabling innovation. Two of those case studies are documented here: China and Russia.

For all ten case studies, we conducted extensive document reviews and structured discussions with subject matter experts having experience in the budgeting processes of the examined international defense organizations. Case study research drew primarily on government documentation outlining processes and policies, planning guidance, budget documentation, and published academic and policy research. For the near-peer competitor cases, the assigned experts had the language skills and methodological training to facilitate working with primary sources in Chinese or Russian. In general, the analysis was also supplemented by experts in the U.S. PPBE process, as applicable. Although participants in structured discussions varied in accordance with the decision-making structures across case studies, they generally included chief financial officers, representatives from organizations responsible for making programmatic choices, and budget officials. While these inputs reflected the research approach generally across case studies, Russia and China case studies presented unique challenges of data availability and access to interview subjects with experience in government roles.

To facilitate consistency, completeness in addressing the commission's highest-priority areas of interest, and cross-case comparisons, we developed a common case study template. This template took specific questions from the commission as several inputs, aligned key questions to PPBE processes and oversight mechanisms, evaluated perceived strengths and challenges of each organization's processes and their applicability to DoD processes, and concluded with lessons learned from each case. To enable development of a more consistent evidentiary base across cases, we also developed a standard interview

⁸ For a discussion of the availability of funds appropriated to the DoD for RDT&E activities, see Section 3131 of Title 10, *United States Code*, Availability of Appropriations.



protocol to guide the structured discussions.

Near-Peer Competitors Focus

The 2022 National Defense Strategy (NDS) describes a security environment of complex strategic challenges associated with such dynamics as emerging technology, transboundary threats, and competitors posing “new threats to the U.S. homeland and to strategic stability” (DoD, 2022). Among these challenges, the NDS notes that “[t]he most comprehensive and serious challenge” is the People’s Republic of China (PRC). The NDS points to China’s military modernization and exercise of whole of government levers to effect “coercive” and “aggressive” approaches to the region and international order (DoD, 2022). Although the NDS designates China as the “pacing challenge” for the DoD, it also highlights the threat posed by Russia as an “acute threat” (DoD, 2022).

To better understand and operate in the competitive environment, the Commission on PPBE Reform is considering “budgeting methodologies and strategies of near-peer competitors to understand if and how such competitors can address current and future threats more or less successfully than the United States” (Public Law 117–81, 2021, Section 1004(f)(2)(F)). Notably, this focus on internal processes as key enablers of military outcomes is well aligned to the NDS’s imperative to “build enduring advantage,” “undertak[e] reforms to accelerate force development, [get] the technology we need more quickly, and mak[e] investments in the extraordinary people of the Department, who remain our most valuable resource” (DoD, 2022). This imperative has prompted reflection on the extent to which internal DoD processes, including PPBE, are up to the challenge of enabling rapid and responsive capability development to address the emerging threats.

China

China’s rise from a technologically backward and poorly equipped military in the 1970s to the U.S. pacing challenge in 2022 has made it a case study of particular interest to DoD policymakers with regard to the apparent drivers of relative comparative advantage. China’s military modernization is especially remarkable given the speed with which it has occurred.

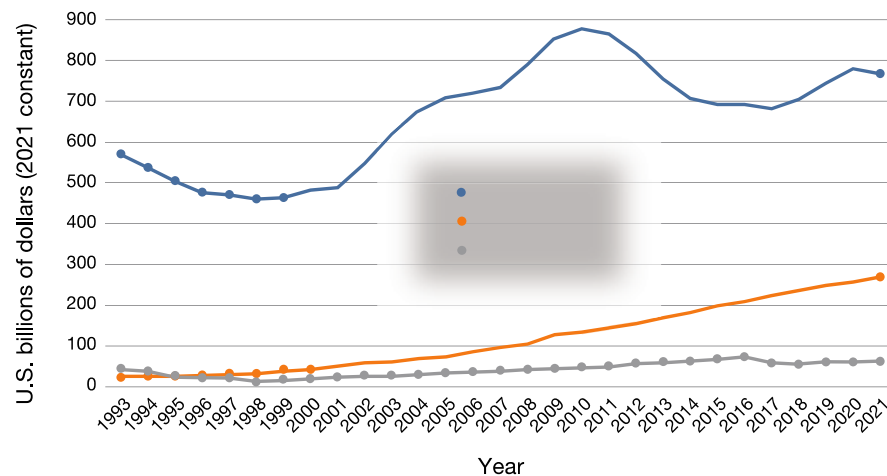
In 1979, Beijing abandoned Maoist economic policies in favor of more pragmatic, market friendly reforms. In the 1980s, the country prioritized rapid economic growth, and military modernization progressed slowly. However, over the following decade, the defense budget soared. From 2000 to 2016, China’s military budget increased annually by about 10%, although this growth has slowed to about 5%–7% per year (DIA, 2019).

Figure 1 illustrates the steady rise in China’s military expenditure over time; however, estimating the actual size of China’s defense budget has remained difficult because of Beijing’s lack of transparency and the country’s incomplete transition to a market economy. According to government sources, China’s defense budget was \$230 billion in 2022, second only to that of the United States (Zhao, 2022). Years of major budget increases have yielded an increasingly lethal and capable People’s Liberation Army (PLA). As we describe in detail in the full report (McKernan et al., 2024) the story of China’s recent military successes is difficult to disentangle from the country’s broader story of economic development, the sheer scale of increased investment in the military, workforce development, the development of advanced manufacturing and industrial capabilities, and other transformative social and economic factors. This is a case, it might be argued, for which the ruling leaders of the Chinese Community Party (CCP) have made substantial and sustained investment in



building enduring advantage.⁹

What has enabled China's achievements in the science and technological innovation underlying military modernization? Analysts have pointed to several contributing factors.



SOURCE: Features information from SIPRI, "SIPRI Military Expenditure Database," homepage, undated. Data shown are as of March 17, 2023.

Figure 1. Military Expenditures, by Country, 1993–2021

China's technological innovations build on the advantages of the country's industrial base. China has a large manufacturing capacity, ample mineral resources, and a strong science and technology sector (Weinbaum et al., 2022). China's science and technology workforce has grown dramatically, and government spending on research and development has grown at a compounding annual rate of 15% since 2010 (Ashby et al., 2021). An analysis of China's innovation-related capabilities has noted steady improvements over time, owing to the combined effects of a more educated workforce, strong manufacturing capacity, investments in infrastructure to support scientific and technological research and development, technology transfer, and gains from civil-military technological collaboration (Cheung, 2022). Technology transfer in China focuses in part on U.S. and Western technologies that are transferred or stolen by China's PLA, state-owned enterprises (SOEs), or other enterprises, which has helped decrease the time needed to build capabilities. Indeed, part of what has enabled China's rapid achievements is intellectual property theft from the West, including the siphoning of U.S. scientific research (Weinbaum et al., 2022).

China's military budgeting practices could also play a role in its military's successes in research and development and technological innovation. Beijing's emphasis on long-term strategic planning and the ability to allocate resources to projects deemed nationally important could contribute to the country's sustained investments in priority technologies. However, given the uneven successes in China's technological pursuits, the role of budget practices likely remains secondary to more critical factors related to the maturity of relevant industrial sectors.

Russia

Russia is 30 years past a painful transition from a Soviet planned economy to a

⁹ For a broader look at factors associated with a country's competitive posture, see the *Societal Foundations of National Competitiveness* (Mazarr, 2022).

partially market-based economy. Although Russia has largely left its Soviet planning model in the past, it has carried forward certain ideas and legacies of centralized economic control. For example, in Russia, competition between defense firms is not viewed as an inherently good thing that could spur innovation and increase productivity. Instead, it is viewed as a mechanism that dilutes available funds. State ownership is viewed as protection from international markets and sanctions and as a mechanism to keep unproductive companies afloat.

Russia can be fiscally conservative at the federal level, avoiding deficits and engaging in little foreign borrowing, and its defense acquisition plans are often closely tied to military strategy and defense needs. However, opacity in multiple parts of Russia's PPBE-like process, even within Russia—compounded by insufficient oversight—often perpetuates corruption and generates outputs of varying quality from the defense industry.

Russian leaders realize that their defense budget is limited and that they are outspent by their rivals; they speak often about their desire for a modern, capable military (Tass, 2021). Although there have been attempts to reduce systemic graft and corruption in the past decade, the war in Ukraine has revealed these efforts to be insufficient (Anderson, 2016; Janes, 2012). The desire for a well-oiled defense industrial base often collides with the excessive concentration of power in Russia's executive branch and the informal practices that make business possible in modern Russia.

An understanding of Russia's defense industrial base is essential for understanding Russia's military resource decision making. Russia's defense industrial base comprises approximately 800 companies or entities with a workforce of nearly 3 million, consolidated under partial or majority state ownership (Janes, 2022). Consolidation began under a federal program known as Reform and Development of the Defense Industrial Complex, 2002–2006, which was motivated by a desire to vertically integrate various design, development, and manufacturing entities with a focus on distinct domains, in contrast to Soviet-era organizational structures (Janes, 2022; Cooper 1993). After 2007, Russia consolidated most of its defense firms under state control to protect them on the global market, create efficiencies in Russia, and ensure more-direct oversight to account for funds and reduce graft.

Although consolidating firms under state control has generated efficiencies, the consolidation and protectionist policies have also stymied innovation, given the lack of domestic competition. Furthermore, corruption has long plagued Russia's defense industry and its government more broadly. In 2012, Russian and Western analysts estimated that 20%–40% of annual funding from the State Defense Order (SDO) for military procurement was lost because of corruption, inflated prices for military goods, or the use of earmarked allocations for other purposes (Anderson, 2016; Military Prosecutor, 2012). These findings led to various reforms: imposing larger fines and criminal penalties on individuals and organizations, moving responsibility for the SDO to the Russian Ministry of Defense (MoD), and paying defense industry entities through restricted accounts at state-owned banks (Anderson, 2016).

However, as evidenced by the 2022 war in Ukraine, corruption persists in Russia's defense industrial base. Official accounts from the United States and unofficial reports from Ukrainian and Russian social media have revealed a Russian Army that lacks appropriate equipment, logistics, and even first-aid kits (Cranny-Evans, 2022; Russian Military's; Schneider, 2022; Lee, 2022). Observers have documented Russian equipment without its necessary defensive components, including missing or hollowed-out explosive reactive armor on T-80 battle tanks (Shinkman, 2022). Transparency International, a nonprofit



research, monitoring, and advocacy organization, attributes the high incidence of corruption in Russia's defense industrial base to a lack of external, transparent oversight of PPBE-like functions—specifically, oversight over the functions of defense policy, budgeting, and acquisition (Transparency, 2022).

Key Insights

The material presented in this section distills important themes for the commission to understand when trying to illuminate aspects of the competitive environment and better understand the resource planning process of strategic competitors and points of comparison and divergence from the United States, while recognizing profound differences in governance structures, political cultures, and strategic orientations.

Key Insight 1: China and Russia Make Top-Down Decisions About Priorities and Risks but Face Limitations in Implementation

Senior leaders in these countries have the authority to make top-down decisions, but realizing returns on those decisions is contingent on key social, economic, and other factors. In China, modernization in such areas as jet engines, semiconductors, and hypersonics has not yielded consistent outcomes; other determinative factors are long-term investment stability, innovation enablers, and a workforce with relevant expertise.

Russia's invasion of Ukraine has shown that Russia can rapidly pivot to fulfill different military procurement needs, albeit under extreme pressure. In November 2022, Russia suspended SAP-2027 and announced that it would commit a significantly larger SDO to the war. However, Russia's new mobilization laws, which were meant to respond to wartime needs more rapidly, confronted limitations in industrial capacity, supply chain reliability, and the ability to call up required manpower even through conscription.

Key Insight 2: China and Russia Make Long-Term Plans but Have Mechanisms for Changing Course in Accordance with Changing Priorities

In China and Russia, centralized decision making can reduce the friction associated with course corrections, although the need to make hard choices is likely lower in China than in Russia because of China's economic growth over recent decades.

Key Insight 3: Especially in China, Political Leaders Provide Stable and Sustained Long-Term Support for Military Modernization Priorities

The lack of political opposition, the high degree of alignment between CMC and senior CCP leaders, and the sheer scale of military investment over decades have facilitated the stable planning and long-term investments that are essential for making progress toward complex modernization priorities. The synchronization of defense plans with budgets has offered long-term benefits to China's military modernization. In contrast, Russia has a 10-year SAP supported by a three-year budget—a combination that, in theory, balances stability with flexibility for the MoD and the defense industry. But in reality, the SAP is aspirational and has been rapidly jettisoned without political or legal blowback, leaving companies in a vulnerable position over the long term.

Key Insight 4: China and Russia Have Weak Mechanisms for Avoiding Graft or Ensuring Transparency, Efficiency, Effectiveness, and Quality Control in PPBE-Like Processes

The power dynamics and the structures of decision making in these countries provide limited guardrails for ensuring efficiency, effectiveness, or oversight of investments. Oversight is essential to control corruption and ensure proper budget execution. However, in China, there is weak oversight and the potential for corruption, misuse of funds, and waste.



China's budgeting processes are hampered by clientelism (bribery), patronage (favoritism), and other forms of corruption that pervade the defense industries. Powerful SOEs continue to operate in a highly inefficient and wasteful manner, partly because of the political power they exert. Similarly, in Russia, execution of defense spending is subject to corruption within the MoD, cronyism throughout the defense industrial base, and a general lack of serious anticorruption measures.

Key Insight 5: Reforms in China and Russia Have Been Designed to Increase Oversight of Resource Allocation Processes

In recent years, both countries have recognized the inefficiencies and the limited avenues for competing voices in their top-down budget processes. Both countries have looked to other international models, including that of the United States, for lessons on the development and implementation of budget reforms.

Chinese officials have sought to imitate some practices that are commonly used in Western countries to improve their government's ability to execute budgets. In accordance with centrally directed reforms to all branches of the government, the PLA has carried out multiple rounds of reforms in its budgeting and financial system. Moreover, Chinese leaders have long recognized that the military's budget system, like that of the government overall, suffers from severe problems related to corruption and weak accountability, owing in part to the country's adherence to outdated centralized budgetary practices in which most economic decisions are made by high-level government authorities instead of market participants. Russia's budget has been based on best practices and recommendations from the IMF and OECD, such as the use of a three-year or medium-term expenditure framework. In addition, the Ministry of Economic Development and the Ministry of Finance produce macroeconomic and socioeconomic forecasts, respectively, and allocate funding annually within reasonable constraints.

The Russian government's spending practices are fiscally conservative in that it does not engage in excessive debt spending or foreign borrowing, and it maintains a sovereign wealth fund to manage shocks or unforeseen events. Although Russia's budget process has been developed with best practices in mind, budget execution is done with few safeguards, little oversight, and meager quality control.

Applicability of These Insights to the DoD's PPBE System

Although the 2022 NDS calls out China and Russia as posing particular challenges to the United States and the international order, the nature of the challenges posed are distinct and situationally dependent. China and Russia have unique histories, economic conditions, industrial capacities, and military capabilities; thus, they pose unique challenges to the United States. Societal fundamentals for building military capability are critical factors in determining the success of military modernization; therefore, it is unclear how much success can be meaningfully attributed to resource planning processes. Additional critical inputs to success include the following:

- workforce capacity, capabilities, and productivity
- scale and focus of defense investment over time
- industrial capacity and capability
- industrial policy
- innovation policy.

China and Russia are also both extraordinarily different from the United States in political culture, governance structure, values, and strategic orientation. China and Russia have demonstrated that strong central authority (without opposition) can provide long-term



planning that aligns resources to priorities and redirects resources to meet changing needs, but there are constraints and trade-offs that come with a top-down approach. A top-down approach can hamper innovation and yield weak mechanisms for oversight and quality control of budget execution.

Given this context, the lessons for U.S. PPBE reform efforts cannot be directly applicable. In addition, there is immense information asymmetry regarding what little we understand and know from open-source reporting on China's and Russia's budgetary processes versus the abundance of critiques in open-source reporting on the U.S. PPBE process. The risk is that China's and Russia's processes may sound more ideal because of a lack of publicly available information about execution. Despite these differences, the case studies suggest several considerations that are relevant for the United States.

The applicability of lessons, mostly from China, will invariably be constrained by the differences between the political systems of the United States and China. The DoD will not likely find any simple way of replicating China's advantages by imitation, given the stark differences between the governmental systems of the United States and China. However, finding analogous measures to achieve similar effects could be worthwhile. In particular, two types of measures could have beneficial effects on DoD budgeting practices: (1) finding ways to ensure sustained, consistent funding for priority projects over many years and (2) delegating more authority and granting greater flexibility to project and program managers—without compromising accountability—so that they can make changes to stay in alignment with guidance as technologies and programs advance.

Russia can be fiscally conservative at the federal level, avoiding deficits and engaging in little foreign borrowing, and its defense acquisition plans are often closely tied to military strategy and defense needs. However, opacity in multiple parts of Russia's PPBE-like process—compounded by insufficient oversight—often perpetuates corruption and generates outputs of varying quality from the defense industry. Although there have been attempts to reduce systemic graft and corruption in the past decade, the war in Ukraine has revealed these efforts to be insufficient. Furthermore, the desire for a well-oiled defense industrial base often collides with the excessive concentration of power in Russia's executive branch and the informal practices that make business possible in modern Russia. Russia's PPBE-like process does not allow sufficient oversight to ensure that it works effectively or produces uniformly high-quality products.

Despite the frequent public discussion in the United States that oversight adds time to the DoD's PPBE process, it is clear from the experiences of China and Russia that oversight is a critical element that ultimately helps lead to successful capabilities for use during operations and, therefore, should not be haphazardly traded away for speed during resource allocation.

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PANEL 10. HOW SYSTEMS ENGINEERING ENABLES ACQUISITION INNOVATION

Wednesday, May 8, 2024	
2:15 p.m. – 3:30 p.m.	<p>Chair: Dr. Dinesh Verma, Professor; Executive Director, Systems Engineering Research Center (SERC) and the Acquisition Innovation Research Center (AIRC), Stevens Institute of Technology</p> <p><i>Acquisition with Digital Engineering</i> Tom McDermott, Stevens</p> <p><i>Enabling Systems Engineering Technical Review (SETR) Modernization Across the Department of Defense (DoD)</i> Kelly Alexander, OUSD R&E</p> <p><i>Leveraging Generative AI to Create, Modify, and Query MBSE Models</i> Ryan Longshore, Naval Postgraduate School</p>

Dr. Dinesh Verma— Dinesh Verma served as the Founding Dean of the School of Systems and Enterprises at Stevens Institute of Technology from 2007 through 2017. He currently serves as the Executive Director of the Systems Engineering Research Center (SERC), a US Department of Defense sponsored University Affiliated Research Center (UARC) focused on systems engineering research. During his fifteen years at Stevens he has successfully proposed research and academic programs exceeding \$175m in value. He has a courtesy appointment as a Visiting Professor in the Department of Biochemistry in the School of Medicine at Georgetown University. Verma served as Scientific Advisor to the Director of the Embedded Systems Institute in Eindhoven, Holland from 2003 through 2008. Prior to this role, he served as Technical Director at Lockheed Martin Undersea Systems, in Manassas, Virginia, in the area of adapted systems and supportability engineering processes, methods and tools for complex system development.

Before joining Lockheed Martin, Verma worked as a Research Scientist at Virginia Tech and managed the University's Systems Engineering Design Laboratory. While at Virginia Tech and afterwards, Verma continues to serve numerous companies in a consulting capacity. He served as an Invited Lecturer from 1995 through 2000 at the University of Exeter, United Kingdom. His professional and research activities emphasize systems engineering and design with a focus on conceptual design evaluation, preliminary design and system architecture, design decision-making, life cycle costing, and supportability engineering. In addition to his publications, Verma has received three patents in the areas of life-cycle costing and fuzzy logic techniques for evaluating design concepts.

Dr. Verma has authored over 100 technical papers, book reviews, technical monographs, and co-authored three textbooks: Maintainability: A Key to Effective Serviceability and Maintenance Management (Wiley, 1995), Economic Decision Analysis (Prentice Hall, 1998), Space Systems Engineering (McGraw Hill, 2015). He was honored with an Honorary Doctorate Degree (Honoris Causa) in Technology and Design from Linnaeus University (Sweden) in January 2007; and with an Honorary Master of Engineering Degree (Honoris Causa) from Stevens Institute of Technology in September 2008.



Acquisition with Digital Engineering

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Philomena Zimmerman—is a research scientist and fellow with the Acquisition Innovation Research Center (AIRC) at Stevens Institute of Technology in Hoboken, NJ. She was previously the Director for Engineering Tools and Environments within the Department of Defense (DoD) Office of the Deputy Director for Engineering. During her career, Zimmerman has also served in leadership positions within the Army's Future Combat System program, Program Executive Office Integration, and Defense Modeling and Simulation Office, and with NAVAIR. [pzimmerm@stevens.edu]

Abstract

Acquisition with Digital Engineering (DE) support, a.k.a. DE-enabled acquisition, cannot succeed as an engineering initiative pushed by engineers. It must be pulled into acquisition and sustainment by acquisition and sustainment functionals and fully integrated across all of their activities, including those that are not seen as technical. DE pilot efforts have demonstrated that it is fully possible to conduct government acquisition planning, contractor source selection, and engineering and manufacturing development in a shared Digital Engineering and Acquisition Ecosystem. This research conducted by the Acquisition Innovation Research Center (AIRC) developed a fundamental perspective and a set of recommendations for acquisition with DE. Research Issue Digital engineering is as fundamental a paradigm shift as the pathways in the Adaptive Acquisition Framework (AAF), affecting all pathways and supporting functions and enabling broad benefits in the transformation to Digital Acquisition. Digital engineering implementation and benefits involve and affect all acquisition functions—not just engineering and technical management.

Keywords: digital engineering, systems engineering, contracting, acquisition system

Introduction

In June 2018, the Under Secretary of Defense for Research and Engineering published the DoD Digital Engineering (DE) Strategy (Under Secretary of Defense for Research and Engineering, 2018). Since then, the DoD's engineering and technical communities have acknowledged and are adopting DE as a transformative, value-added approach to improving weapon system development, capability integration, testing, and sustainment. However, for successful DE implementation in acquisition and sustainment, the broader benefits and the realization of complete Digital Acquisition, must involve all acquisition functions—not just technical ones.

In other words, acquisition with DE support, a.k.a. DE-enabled acquisition, cannot succeed as an engineering initiative pushed by engineers. It must be pulled into acquisition and sustainment by acquisition and sustainment functionals and fully integrated across all of their activities, including those that are not seen as technical. An AIRC report, *Acquisition with Digital Engineering*, explored some of the methods, processes, and tools in the acquisition and sustainment functions beyond engineering that need to implement DE and realize its benefits, ultimately to our warfighters and taxpayers (McDermott et al., 2023).



DE pilot efforts have demonstrated that it is fully possible to conduct government acquisition planning, contractor source selection, and engineering and manufacturing development in a shared Digital Engineering and Acquisition Ecosystem (DEAE; Blackburn et al., 2019, 2020, 2021). This requires government management and provisioning of program data and models as appropriate authoritative sources of truth (ASOT) and a collaborative digital environment with defined government and contractor access, workflows, and digital artifact “views.” A concurrent research task conducted by SERC/AIRC and OUSD(R&E) found a significant number of pain points that are creating a slow adoption of DE in DoD program offices (McDermott & Benjamin, 2022; McDermott & Mesmer, 2023). These include a lack of the ways and means to drive adoption; a lack of fully integrated DEAE reference implementations; lack of modernized engineering and technical management processes; and poor understanding of the value and benefit of DE across all acquisition and non-engineering functions.

Consistent with the Federal Acquisition Regulation (FAR) and the Defense Federal Acquisition Regulation Supplement (DFARS), the digital artifacts that result from DE implementation can be viewed legitimately as technical data and computer software (McDermott & Mesmer, 2023). However, there are a few issues in simply specifying in a contract the delivery of these artifacts. Taking delivery of these artifacts versus their actual use are very different in terms of value and detail necessary in specification. In other words, viewing DE as a set of digitized artifacts using the same acquisition and sustainment intent historically applied to paper and document artifacts may not ensure the quality and information exchange needed, thus defeating the value of a DE-enabled Defense Acquisition System (DAS), on the journey to digital transformation of the DAS.

The programmatic value of DE and associated artifacts come from the government and contractor aligned teams conducting their respective development, analysis, decision-making, and certification activities from a common set of data and models (known collectively as the ASOT), continuously, in an appropriately shared government and contractor DEAE. These data and models must be managed and curated in the associated DEAE across the full life cycle of the weapon system, appropriate for the subsequent acquisition activities necessary to bring the product to realization. This could include Needs Statements, Mission Engineering, Requirements, Budgeting, Acquisition, Test, Operation, Sustainment, and Disposal phases.

The policy basis for DE-enabled acquisition must fully communicate the intent and benefits of DE methods and results from computational activities, to be used in other non-technical activities. Engineering activities (supported by DE) in policy remain overly focused within the Major Capability Acquisition (MCA) pathway. DE-enabled activities should be fundamental to any acquisition function in any Adaptive Acquisition Pathway. As with the pathways in general, it is not intuitive to move from DE support from MCA to any other pathway. It should be articulated for non-MCA-focused staff, how to transfer fundamental DE-enabled acquisition process knowledge from MCA to their pathways of choice.

The DoD is at an intersection in its ability to utilize industry-accepted, standard DE practices to improve defense acquisition and sustainment. All acquisition and sustainment functions—not just engineering and technical management disciplines—need to engage through a shared demand signal to the DE practitioner community. These research results lay out this fundamental perspective and identify several recommended areas of activity.

Research Results

The acquisition and sustainment communities have an opportunity to shape DE methods and reap benefits of DE-enabled acquisition and sustainment through active



engagement and demand signals. Without a clear demand signal from the acquisition and sustainment user community, it is impossible for the DE practitioners to know how DE will be used by acquisition and sustainment, and how to prioritize the order of method development to benefit acquisition and sustainment. The who is clearly the acquisition and sustainment communities writ large; however, the what, when, where, and how needs to be further developed by the acquisition and sustainment functional communities along with their demand signals.

This research conducted a review of DoD issuances and other available guidance for DE-related contract artifacts and flows, as well as general acquisition policy and guidance (McDermott & Benjamin, 2022). Most of the available policy and guidance reflects the impact of DE on contracting in the regulatory domain of technical data and models, or as sets of recommended engineering processes. There is a general lack of related guidance that acknowledges the much broader changes that should be realized in fully digital processes and workflows. These can be characterized as (i) a general “shift left” to conduct program definition, development, and test activities earlier—some possibly even into government pre-acquisition activities, (ii) an exchange of digital development artifacts into manufacturing (commonly known as “digital thread”), and (iii) long-term life-cycle maintenance of digital models and environments (“digital twins,” et al.) to inform and improve logistics, sustainment, and even feedback into requirements and mission engineering decision-making for related products.

Digital Engineering as a technical and management approach is “an integrated digital approach that uses authoritative sources of systems’ data and models, along with other information, as a continuum across disciplines to support life cycle activities from concept through disposal” (Office of the Deputy Assistant Secretary of Defense [Systems Engineering], 2017). Today the acquisition and sustainment communities are in the initial stages of their DE transformation and need additional research and guidance to define the workflows and processes to contract for, use, and sustain fully digital model-based artifacts and the associated digital environments. The acquisition and sustainment communities, from practitioners to decision-makers, based on current policy, guidance, and observed practice, still retain a document-centric view of engineering technical and management data, as periodically delivered artifacts. The benefit of DE application comes from government/contractor collaboration around and through models (vs. document generation and review) in environments that continuously allow the use of models and associated data to generate results from, and for computational analysis and review. Program offices do not have adequate guidance on how to enable effective use of DE methods, tools and associated products when making materiel development, or sustainment decisions anywhere in a system life cycle.

Additionally, the vision in the DoD Data Strategy (conceived separately from DE) of “a data-centric organization that uses data at speed and scale for operational advantage and increased efficiency” (Under Secretary of Defense for Research and Engineering, 2018) is not yet sufficiently captured into engineering or acquisition and sustainment policy and guidance. Program offices need additional guidance in various areas that can effectively define their workflow and enable data-supported decisions within the engineering, acquisition, and sustainment activities.

Initial example acquisition artifacts are being exchanged through various pilot projects, and in a small set of acquisition programs of record, but these are not the norm. There are statutory requirements for delivery of technical data and computer software. These easily support exchange of data and models between government and contractor, but not the widespread use needed for the continuum of product life-cycle operations.



Additionally, some statutory requirements generally echo existing standards for written documents, which are static entities and do not meet the goal of the DoD Digital Engineering Strategy—to collaborate around, with, and through data and models.

The decision process that drives contracting and contracting language should not just define what the technical data requirements are for data/models and delivered computer software. The decision process should reflect how the government and contractor teams make best use of data and models “for operational advantage and increased efficiency” within the context of acquisition and sustainment activities.

The complete value of DE implementation is realized with collaborative knowledge exchange among practitioners of varying activities, and results in improved agility in design, shorter lead times, increased confidence in the end product, and improved product life-cycle sustainability. A related SERC project on DE benefits and measures clearly articulates this value. DE does not necessarily result in cost savings but will improve program timelines and quality if implemented and measured as an integrated process across all engineering, management, and related acquisition disciplines.

Acquisition Functional Roles

Each of the current seven managed acquisition workforce areas (DAU, n.d.), at a minimum, have a role to play in the DE transformation of acquisition and sustainment practices, to benefit from the continuum of digital artifact availability and use.¹ Below are some of the new or modernized acquisition and sustainment processes that are recommended to be addressed in the digital transformation of the DAS, as an example of the scale and need beginning with implementation of DE within the DAS:

- Life-Cycle Logistics: ensuring that authoritative data and models and their use are included in the system Life-Cycle Sustainment Plan (LCSP), life-cycle cost analyses, and the government/contractor product support analyses and strategy and made available to the logistics and supply domain.
- Engineering and Technical Management: developing the collective ASOT and associated DEAE per the life-cycle management plan, as documented in the program Digital Engineering Implementation Plan (DEIP), as a main part of the Systems Engineering Plan (SEP).
- Program Management: planning and budgeting for data and models across the full life cycle, defining and managing program office requirements that are consistent with the use and expected benefits of DE, selecting acquisition pathways and defining appropriate DE model-based review processes, staffing the program office with sufficient digitally skilled program office personnel in appropriate functions, defining data exchange requirements for data and models across the spectrum of their use, defining and tracking DE activities in earned value management systems (EVMS) as well as Integrated Master Plan (IMP) and Integrated Master Schedule (IMS), defining a DE measurement plan and inspecting program digital artifacts delivery for completeness and consistency.
- Test and Evaluation: defining and planning the verification and validation (V&V) requirements and operational assessment with and of models, using data from live events to update models and the collective ASOT, capturing appropriate digital test artifacts in the ASOT, developing the digital Test and Evaluation Master Plan (TEMP).

¹ The current seven managed acquisition workforce functional areas are Auditing, Business Financial Management/Cost Estimating, Contracting, Engineering and Technical Management, Life Cycle Logistics, Program Management, and Test and Evaluation (DAU, n.d.).



- Business Financial Management/Cost Estimating: DE data and models integrated into cost modeling, updating cost estimation models to reflect the relative resource (time, budget, and personnel) costs, cost avoidance and potential savings of DE in the complete, executed life cycle of a system, including but not limited to development, production, and sustainment.
- Contracting: incorporating DE processes, data and model exchanges, and digital review processes into the Statement of Work (SOW), defining data and model exchange and delivery requirements, defining program DEAE requirements.
- Auditing: ensuring appropriate management of program digital artifacts so curation is possible.

Recommendations

Life-cycle management activities for models, in total, should extend beyond the acquired system to equally cover the authoritative data and models, their development environments, and especially, non-engineering uses. In the system life cycle, the government must be prepared (at the appropriate time and defined in the Acquisition Strategy and Acquisition Plan) to manage and further develop data and models as an organic enterprise resource, to be reused, recast, or modified if appropriate. These activities need to be developed and approved in the LCSP, SEP, and TEMP, as well as planned into program requirements, SOW, and IMS/IMP. **Thus, digital artifacts are more than just product deliverables; they must be contractually required in a way that ensures they convey complete and common understandings, for a continuum of use, not only between the DoD and the contractors but across other functions and the product lifecycle and beyond.** From this research, additional broad recommendations were developed (McDermott et al., 2023). As a next step, this team is moving from broad to specific recommendations, with a specific pilot implementation using one or more ongoing acquisition programs at various life-cycle stages. Specific recommendations follow:

1. Services should develop appropriate enterprise strategies for governance and support of the system ASOT and DEAE and define, develop, and train to, appropriate templates for Acquisition Plans. Data and models and other components of product ASOT, as well as the DEAE, should be identified and planned in the agency's Acquisition Plan as defined in FAR Part 7. Since data and models and the associated DEAE are associated with the system, a system basis should be used for planning (expand beyond an individual contract or order). The research team did not find any examples of Acquisition Plan language for acquisition with DE.
2. Services should define appropriate product support strategies and LCSP templates for the ASOT and DEAE at the enterprise level. Digital data and models are products and should be represented in the system Product Support Management Plan as defined in DoDI 5000.91 and the system LCSP (DoD, 2021). The LCSP outline version 3.0 section 4.6.3 "Digital Product Support" provides high-level guidance for both digital product data and the DEAE. The research team did not find any examples of program LCSP language for acquisition with DE.
3. A mature Digital Engineering and Acquisition Ecosystem framework will allow program offices and associated personnel to use their practice and expertise to determine what activities they need to do in, and with, the DEAE. NASA-HDBK-1004 has a comprehensive description of the components and operation of a DEAE framework, but no equivalent description exists in DoD guidance (NASA, 2020). The actual DEAE implementation will vary by acquisition pathway and program objectives. The SE Modernization project found a lack of mature DEAE reference implementations were



inhibiting government adoption and that the DoD should invest in development of DEAE concepts of operations and reference tool and use patterns (McDermott et al., 2023).

4. The research team recommends that, consistent with existing standards as much as practical, a set of Data Exchange Exemplar Reference Implementations be developed to aid in maturing data constructs, data exchange mechanisms, security architectures, and configuration management provisions to realize the vision noted in the Systems Engineering Modernization report (McDermott & Mesmer, 2023). Data constructs, data exchange mechanisms, security architectures and configuration management processes are tied together, and are referenced, directed, and encouraged from disconnected organizations, policies, guidance, and other issuances. The DEAE is an Enterprise Information System and is thus covered by the DoDI 5000.82 *Acquisition of Information Technology and Associated Requirements for the Acquisition of Digital Capabilities* guidebook (DoD, 2023b). The DoD Chief Information Officer (CIO) office is a major player in data exchange policies and guidance. This office is tasked to support other areas as well and may not understand the full nature of the acquisition and sustainment communities. Meanwhile, within the shift to DE-enabled acquisition, much of the transformation is still manual interpretation of disparate data and analyses.
5. The research team recommends long-term evolution of the SEP and TEMP to digital resources as noted in the SE Modernization Report (McDermott et al., 2023). Programs should define acquisition with DE across all requirements of the SEP in any AAF pathway, and not as a separate appendix. As the SEP is generally referenced as the authoritative guidance for DE, the DoD SEP Outline Version 4.1 (DoD, 2023a) should be regularly updated to reflect evolving practice and lessons learned for acquisition with DE. At this point the SEP outline defines a separate Digital Engineering Implementation Plan as an Appendix to the program SEP covering the DE architecture and digital tool chain. In the long-term, a fully digital SEP is recommended that defines ASOT governance and DEAE implementation by reference to the appropriate digital environments.
6. Very few acquisition and sustainment activities are underway which are deemed to be digital in nature. In order to populate a DEAE and establish an ASOT that is 1) usable by government and contractor teams, 2) across all activities within a program life cycle, 3) as a matter of common and best practice rather than something new to be attempted, the research team recommends that an inclusive review of DIDs, CRDLs, from sample program office contracts, as well as issuances be reviewed and suggestions for revisions developed, in order to enable modifications of, and computational use of the artifact, in a continuum across the relevant acquisition activities.
7. The research team recommends that policies and guidance on the AAF site be reviewed and suggestions offered to increase the strength of digital transformation and connectivity. The AAF represents an evolutionary change in acquisition thinking. In reviewing the issuances on the DAU's AAF website it is evident that there is language in the collection that implies a digital transformation within the technical functional acquisition activities. However, this DE-enabled continuum is not linked from data sender to receiver, through the policy and guidance.
8. The research team recommends workflow guidance for DE-enabled acquisition and sustainment for program management offices and staff be drafted, as a means to close this gap in the transformation guidance and continue with the acquisition activities evolution in the AAF. There is a knowledge gap with the lack of the top-down, supporting digitalized-view from the Program Manager (PM). Neither the *Guide to Program Management Business Processes* (DAU, 2022a) nor the *Guide to Program Management*



Knowledge, Skills and Practices (DAU, 2022b) in the current DAU Acquisition Guidebooks discuss any aspects of the ongoing DoD digital transformation and its impact on management of acquisition programs.

9. The research team recommends that benefits of digital transformation be developed for each pathway, and for each decision point within each pathway, targeting the “why” of digital transformation and away from directed change. Furthermore, the research team recommends that programs quantitatively measure their engineering progress using DE tools. It is typical to claim the need to invoke technical and process advancements, because it is required. In reality, this is not always true. In the time since Digital Engineering Strategy, DoD Data Strategy, and AAF have been released, research has been conducted and published related to measuring value of different areas of digital transformation, and DE. Digital Engineering will make many engineering activities explicitly and continuously measurable that were previously only assessed at program milestone reviews.
10. The research team recommends that a strategy, and overarching roadmap for digital transformation of the acquisition, and eventually sustainment processes be developed to aid in decision-making process for what and when to digitalize, separately, and similarly for the sustainment system. Digital transformation is a complex task. The acquisition and sustainment processes are also complex. For the engineering community, the release of the Digital Engineering Strategy, containing the “what” that needs to be done led the shift toward digitally based engineering to support design and development.

Summary

Digital engineering is as fundamental a paradigm shift as the pathways in the Adaptive Acquisition Framework (AAF), affecting all pathways and supporting functions and enabling broad benefits in the transformation to Digital Acquisition. Digital engineering implementation and benefits involve and affect all acquisition functions—not just engineering. Acquisition with DE support cannot succeed as an engineering initiative pushed by engineers. It must be pulled into acquisition and sustainment by acquisition and sustainment functionals and fully integrated across all of their activities, including those that are not seen as technical.

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Enabling Systems Engineering Technical Review (SETR) Modernization Across the Department of Defense (DoD)

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Abstract

The current SE technical processes and the technical management process remain relevant at the macro level; however, there is a lack of guidance regarding the governance of shared data and models and an understanding of agile and continuous data and model development approaches and their impact on the Systems Engineering Technical Review (SETR) process. Continuation of status quo document-centric methods will unnecessarily delay acquisition program decisions and impact the ability to implement future modifications and technology insertions. Additionally, continuation of the current document-centric methods will not allow the integration of ongoing important initiatives, such as MOSA, SW Modernization and Agile program development methods. This study will review the current SETR practices and how the digital transformation can improve the process, resulting in better and more agile decision-making. The intended outcomes/results of the study include guidance for



implementing model-based SETR processes, exemplars for governance and oversight of model-based artifacts, recommended approach to Agile and continuous data and model development to support the SETR, model-based SEP/SETR processes that enable agile continuous data and model development and recommended SE digital artifacts usage and management.

Background: SERC SE Modernization Research Study Findings

In 2023, the Systems Engineering Research Center (SERC) completed a research study to support the Office of the Under Secretary of Defense for Research and Engineering (OUSD[R&E])’s investigation on how to modernize Department of Defense (DoD) Systems Engineering policy and practices, with an emphasis on equipping the workforce for the digital transformation (McDermott, 2023). The same year, *INCOSSE Vision 2035* was released that discusses the increasing complexity of systems as the rationale for automated and efficient workflows and predicts that “by 2035, systems engineering will leverage the digital transformation in its tools and methods and will be largely model-based” (INCOSSE, 2023).

Figure 1 identifies the primary findings of the SERC report. A key recommendation from SERC is that OSD must work to “achieve seamless and efficient data flows to improve acquisition decision, and further advises the DoD to modernize the current Systems Engineering Technical Review (SETR) processes so that acquisition programs can trace lifecycle workflows “from data to decision artifacts and from decision artifacts back to data” (McDermott, 2023). A critical aspect of SETR Modernization is to transition from the current document-centric to a model-centric approach that supports milestone decisions with authoritative sources of truth.



Figure 1. (Alexander & McDermott, 2023)

As a follow-on to the SERC study, the OUSD(R&E) is spearheading a study that will determine a recommended set of SETR processes and the associated digital artifacts to support a data-driven and model-based approach. The OUSD(R&E) is leveraging SERC ongoing research in Ontology, Agile Development, and model-based artifacts such as the SEP (Service level) and the TEMP (OSD DTEA-led). Additionally, ongoing forums and activities across the DoD are producing “emerging knowledge” to support transition to a digital environment. Emerging knowledge includes lessons learned and processes that are best practices and continue to mature before becoming official guidance. The government and industry led forums include the Digital Engineering Model and Simulation (DEMS) Community of Practice, Modular Open Systems Working Group (MOSWG), Software Modernization Working Group, OMG Model Based Acquisition Working Group, and R&M

MBSE Working Group, where cross service and industry community of stakeholders share and discuss their current practices, challenges, and pain points.

These ongoing activities are progressing, but there is no overarching approach that the stakeholders can use to manage the digital environment and infrastructure required to transition to the modern SETR. This study is focused on the following research questions: (1) How do we implement the digital transformation into the current systems engineering technical review (SETR) process? (2) What are the key artifacts that should be model-based? (3) How do we share and manage model-based artifacts and the associated data during the SETR process? Responses to these questions are aligned to the overall SE Modernization program, as discussed later in this paper.

Objectives of SETR Modernization

The objective of the SETR Modernization research is to transition the current document-centric approach to a knowledge-based approach that relies on data and models to support better and more timely decisions along with a more efficient SE workflow. To make this happen, the DoD workforce will need the appropriate policy, guidance, and means to work in a digital environment. The outcomes of this research will rely on ongoing activities that are developing emerging content to support best practices and lessons learned and determine ways to successfully achieve this transition. Table 1 summarizes ongoing activities that are developing emerging content that is expected to provide input to the intended outcomes.

Table 1. Outcomes and Emerging Content Alignment

INTENDED OUTCOME	Ongoing Activities with Emerging Content
Guidance for implementing model-based SETR processes	SE Modernization Service Modernization/Transformation
Exemplars for governance and oversight of model-based artifacts	MBTEMP, MBSEP, OMG MBAcq WG, DEM&S COP
Recommended approach to Agile and continuous data and model development to support the SETR	MCDERMOTT Roadmap Research Activities
Recommended digital artifacts usage and management during the SETR	SERC Roadmap Research Activities, Service Use Cases, Industry Collaboration

The Traditional SETR Process

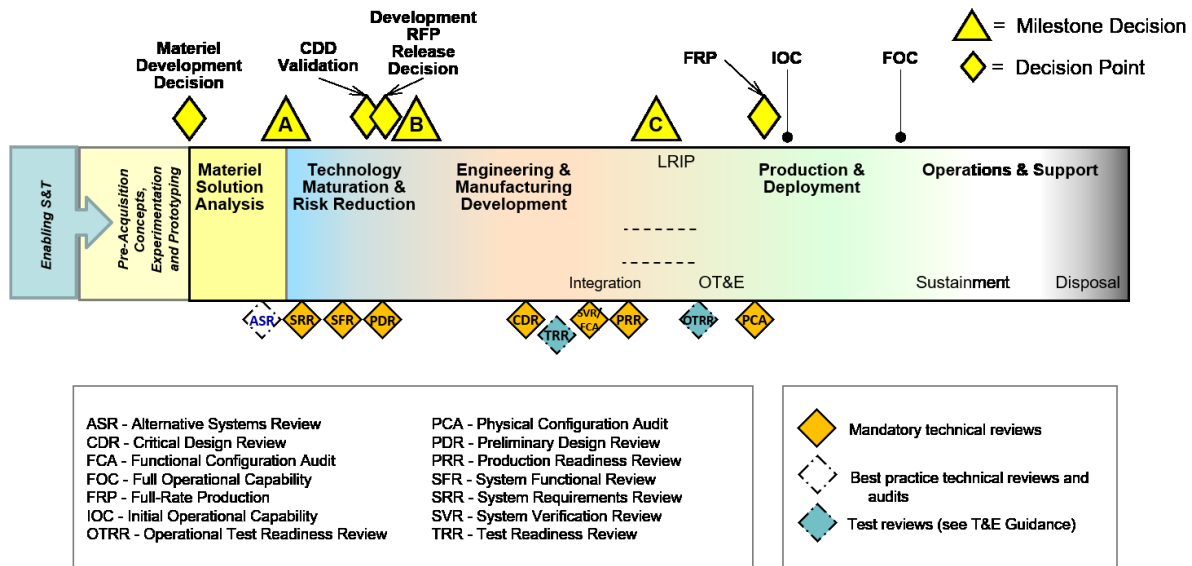
The current SETR process is governed separately by each of the DoD services. SETRs are tailored by the services to adapt to a specific solution, acquisition pathway, and other factors such as technical maturity and risk management. Each of the DoD services governs the current SETR process separately. SETRs provide independent forums designed to establish technical baselines, evaluate technical maturity, and assess technical risks. The services tailor SETRs to adapt to a specific solution, acquisition pathway, and other factors, such as technical maturity and risk management. The following graphic shows a potential sequence of SETR events (in the grey triangles) for a Major Capability



Acquisition (MCA) as depicted in DoD 5000 (www.dau.aaf.org). At each technical review, the PM will, to the extent practicable, use information from the digital authoritative source of truth to assess key risks, issues, opportunities, and mitigation plans to understand cost, schedule, and performance implications. At a minimum, DoD Major Defense Acquisition Programs (MDAP) must complete the following technical reviews and audits, unless waived through the Systems Engineering Plan (SEP) approval process: Systems Requirements Review (SRR; or Systems Functional Review [SFR]), Preliminary Design Review (PDR), Critical Design Review (CDR), Systems Verification Review (SVR; or Functional Configuration Audit [FCA]), Production Readiness Review (PRR), and Physical Configuration Audit (PCA).

Systems engineering decisions often rely on manually interpreting a wide range of separate data and analyses. One challenge is systems engineering's dependence on numerous data sources, static models, and document-centric decision artifacts to support decision-making across the systems engineering lifecycle (SELC). While tailoring of these documents is recommended, over 20 documents can be used to support the SRR. The study will consider a model-centric approach that leverages relevant data, information, and knowledge to visualize and communicate decision rationale to stakeholders during technical engineering reviews and milestone decisions. This will rely on understanding the key information that is essential to inform the decisions and enable programs to minimize redundancy and ambiguity.

A listing of the current major technical reviews across the acquisition lifecycle can be found in [DoDI 5000.88, Section 3.5a](#). Figure 2 shows a potential sequence of SETR events (in the orange triangles) for a Major Capability Acquisition as depicted in DoD 5000 (www.dau.aaf.org).



Notes:
- Derived from DoDI 5000.85, Major Capability Acquisition Model

Figure 2. (DOD 5000)

For the purposes of this research, the following NAVAIR description of SETR will be used:



“The SETR events are designed to enable an independent assessment of the emerging design against the overall objective of promoting a well-managed development effort leading to a system that meets programmatic requirements while providing the system performance required supporting mission needs” (NAVAIR, 2015).

As the traditional SETR transitions, the SERC study concluded that the current systems engineering processes, while still valid, need to adapt to the digital transformation. The traditional document-centric methods are becoming a hindrance to efficient decision-making and the implementation of future modifications and technology insertions.

The lack of guidance on the governance of shared data and models, as well as the understanding of agile and continuous data and model development approaches, is impacting the SETR process. To fully leverage the benefits of digital transformation, it is crucial to integrate important initiatives such as the Modular Open Systems Approach (MOSA), Software (SW) Modernization, and Agile program development methods. This integration will require a shift from document-centric methods to a more dynamic, data-centric approach that allows for continuous updates and real-time collaboration.

As data-driven methods and digital artifacts become more mature, there is a pressing need to update practices and methodology (SETR Workflow) to represent the digital transformation. This change will not only streamline the SETR process but also enhance the overall efficiency and effectiveness of systems engineering. OSD led SE Modernization effort will continue to emphasize the implementation of the DE transformation into SE practices and policies with the immediate focus on SETR Modernization.

SE Modernization: Implementing Digital Transformation into SE Practices & Policy

The motivation for SEMOD stems from the need to integrate across independent guidance provided down to the DoD SE and acquisition communities related to Digital Engineering, MOSA, Mission Engineering, and Software Engineering/ Agile/DevOps across the multiple pathways of the Adaptive Acquisition Framework. The SERC/government research team found that there is a lack of an integrated approach to implementation of SE Focus Areas that is creating a delay in full implementation of the Digital Transformation, which is necessary to ensure the relevant guidance, skills, and training are available to deliver a robust, disciplined approach to weapon systems acquisition (Alexander & McDermott, 2023).

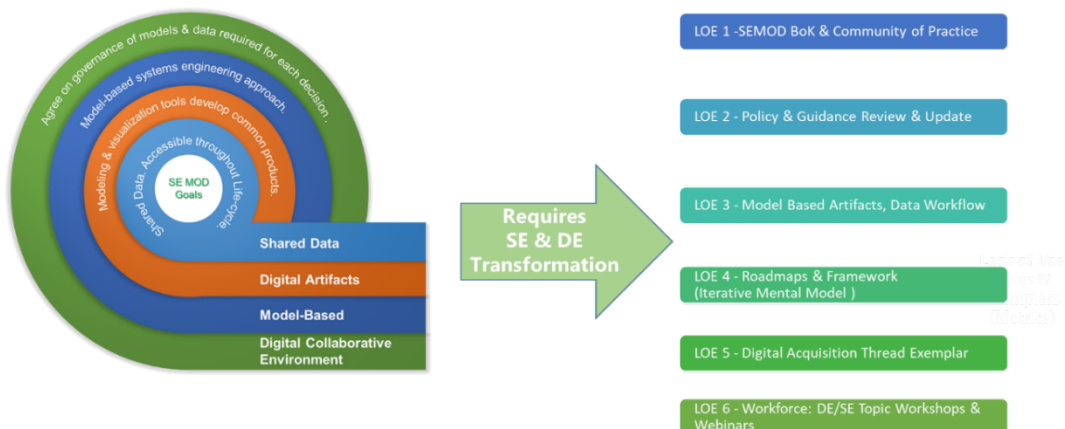


Figure 3.

The OSD led SE Modernization project established the high-level strategic goals shown in Figure 3 that shaped these follow-on efforts. Line of Effort (LOE) 3, “Model Based Artifacts and Digital/Data Workflow,” is most closely aligned with this study; however, the outcomes will also contribute to each of the other LOEs. As SE workflow and practices evolve, the intent is to share the emerging knowledge through webinars, conferences, and workshops.

“The vision of SE Modernization is to use data and models to create a more agile and responsive acquisition system that can quickly and effectively meet the needs of the warfighter” (SERC, 2022). With these goals in mind, SERC research recommended a new mental model for integrating SE, DE and Acquisition. “The value of SE Modernization will be realized in more seamless and efficient transfer of data and models from underlying performance drivers through models to decisions, as well as ease of drilling back down from decisions to data.” And, “New SE lifecycle processes must evolve that address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle” (SERC, 2023).

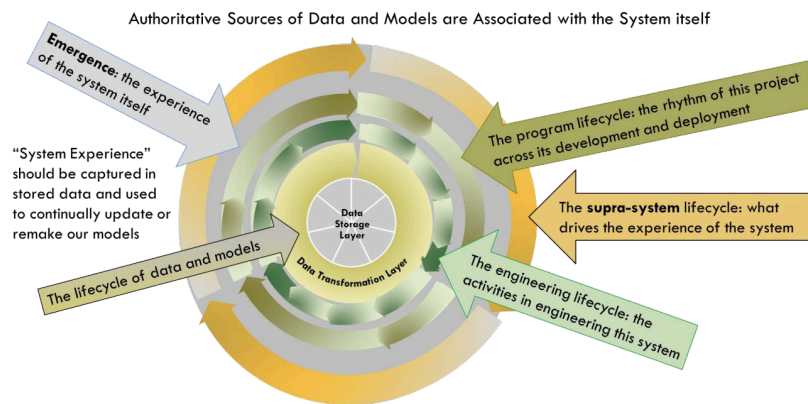


Figure 4. (McDermott, 2023)

Finally, the research found that a true representation of the model-based SE lifecycle is a complex integration of four distinct lifecycles (Figure 4):

1. **System Lifecycle:** This pertains to the lifecycle of the system itself, including any offspring it produces.
2. **Engineering Lifecycle:** This involves the processes conducted within the lifespan of the system from an engineering perspective.
3. **Program/Project Lifecycle:** This refers to the management and execution of programs or projects related to the system.
4. **Supra-System Lifecycle:** This reflects the experiences of the system in its operational context, particularly in relation to other systems it interacts with. A Supra-System is a larger system that integrates or contains other systems.

Each of these lifecycles is individually relevant and must evolve to address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle.

Aligning Digital Transformation Principles to the SETR

Recognizing the Supra-System model and its complexity, the new SE lifecycle processes must evolve to address shared and authoritatively managed sets of digital data

and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle (McDermott, 2023). Each of the DoD Services are leveraging digital engineering by first transitioning to Model-Based Systems Engineering (MBSE) to develop and manage system design; however, these efforts are stove-piped and do not allow seamless transition of data and models throughout the lifecycle. As the Services shift from document-centric to data and knowledge-centric activities, the goal is to provide continuous access to authoritative data and models.



Figure 5.

In 2018, the OUSD R&E published the DE Strategy with the intent to “Formalize the development, integration, and use of models to inform enterprise and program decision-making.” The DE Strategy established five goals, with the first goal focused on establishing the formal planning, development, and use of models as an integral part of performing engineering activities as a continuum across the lifecycle. As Shown in Figure 5, multiple ongoing activities are developing methodology and practices that implement the DE Strategy. The DE strategy concluded that such ubiquitous use of models will result in a continuous end-to-end digital representation of the system of interest to support consistent analysis and decision making for programs and across the enterprise” (OUSD[R&E], 2018).

Aligning Research Questions to Emerging Knowledge

With this goal in mind, the following is a discussion of each of the research questions and DE related activities that may contribute toward the DE Strategy goal. Answers to the following questions will provide OSD with information to support development of guidance to modernize the SETR process and artifacts.

Question 1: How do we implement the digital transformation into the current SETR process?

Several activities are working toward this goal by developing enterprise level strategies that will provide their community of stakeholders with access to the tools necessary to establish model-based development processes. For example, in 2023, the Department of the Navy (DoN) Chief Engineer (CHENG) office and DON CIO collaborated to release a joint memo, *Department of Navy Enterprise Service Designation for Naval Integrated Modeling Environment (IME)*, to ensure Enterprise level resourcing to properly manage, sustain and evolve its capabilities to meet the Naval engineering workforce needs with a focus on systems modeling tools to support MBSE. While this is a major move in the

right direction, the governance, processes, tools and resourcing to ensure the workforce has the level of needed skills continue to mature. Similar progress is being made in the other Services: In 2021, the Air Force established their Digital Transformation Strategy that is developing an integrated environment with authoritative sources of truth, while the under secretary of the Army plans to release an Army Digital Engineering Strategy memo this year. Each of these activities will contribute to understanding the SE transition to the digital transformation. The Services participate in the forums mentioned in this research to share best practices and lessons learned.

Questions 2 and 3 are combined for further discussion: What are the key artifacts that should be model-based? How do we share and manage model-based artifacts and the associated data during the SETR process?

As the Services and program leads continue maturing their processes and SE workflow in a digital environment, the answer to this question will become clear. SERC recommended the following roadmap (Figure 6) comprised of recent and ongoing research to build a body of knowledge and understand more digital artifacts and data. A full description of the roadmap is available in the SERC 2023 report (McDermott, 2023).

The answer is wrapped up in a more comprehensive discussion regarding the digital transformation that includes policy, infrastructure, and data governance. Many of the key elements required to make this happen are considered “emerging knowledge” that is useful but not authoritative. Communities of practice, bodies of knowledge, stakeholder conferences and other important forums are being used to share information. While not an exhaustive list, some of this emerging knowledge is included in the SE Modernization Roadmap (McDermott, 2023). The line of activities on the “Collaboration around Digital Contracts and Artifacts” and “Controlling the Digital Acquisition Lifecycle” will have tremendous benefit toward identifying and gaining understanding of managing and developing digital artifacts.

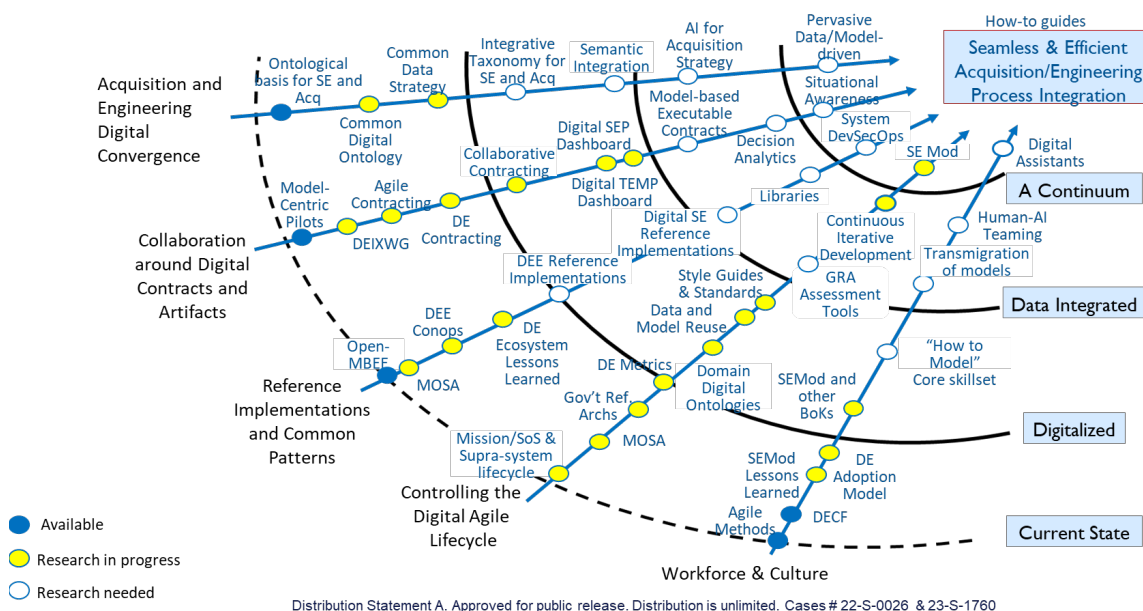


Figure 6. (McDermott, 2023)

Conclusion and Next Steps

There is continuing urgency to mature approaches to manage and share data and models across the Supra-System lifecycle as defined in this research. The need to transition to a digital environment is included in the 2019 National Defense Authorization Act (NDAA 2019) that challenged the Services to ensure “access to digital technical data.” In 2020, the DoD released the Digital Data Strategy that highlighted “Enterprise-Wide Data Access and Availability” with the understanding that the DoD data must be made available for use by all authorized individuals and non-person entities through appropriate mechanisms” as one of eight guiding principles (DoD, 2020).

The digital transformation is a continuous process that requires constant learning, adaptation, and alignment with evolving technologies and business goals. As this study continues over the next 2 years, the reliance on data and model use will become the norm for system development across DoD acquisition. This study is one of many efforts that is working toward ensuring successful implementation of the digital transformation. The words of Dr. Roper from 2020 still ring true: “This “digital trinity” — digital engineering and management, agile software, and open architecture — is the true successor to stealth: the next big paradigm shift for military 2 tech dominance. Rather than just building better systems, it builds systems better — opening doors to faster design, seamless assembly, and easier upgrades” (Roper, 2020).

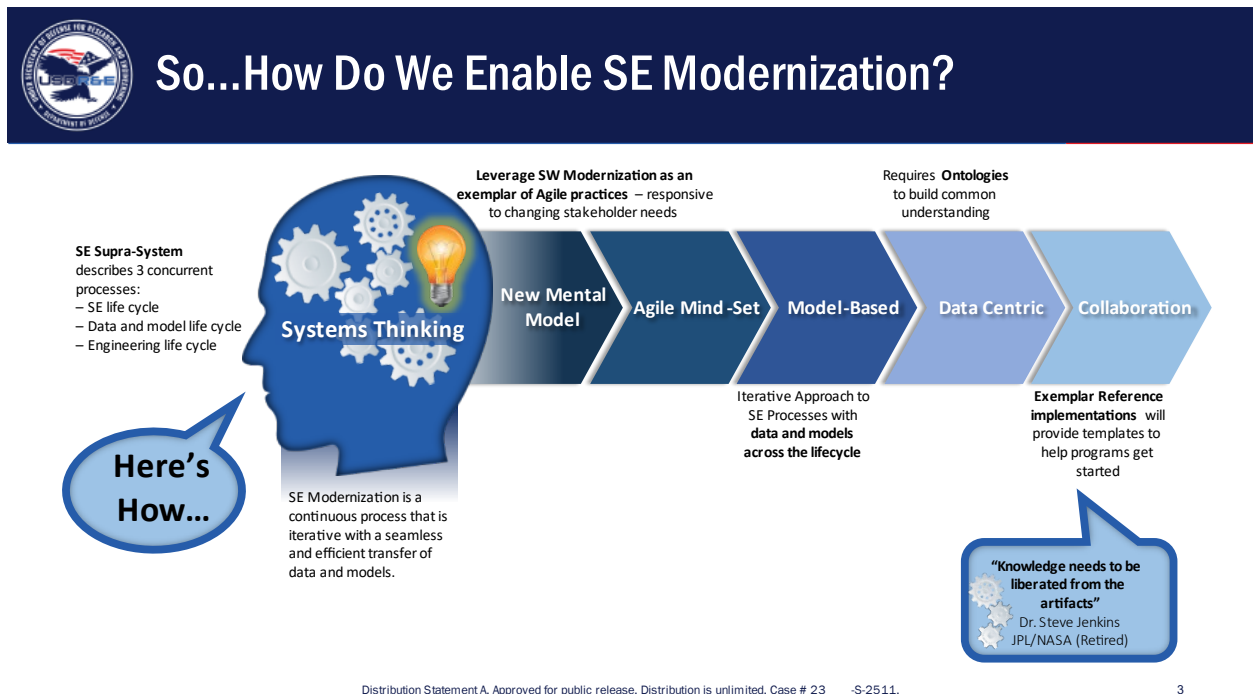


Figure 7. (Alexander & McDermott, 2023)

Finally, the SE Modernization effort has laid the framework for the DoD to meet the challenges involved in the digital transformation with respect to SETR and the overall SE role in system development. The key to SE Modernization (Figure 7) is reliant on (1) understanding the Supra System and the associated mental model and (2) developing an agile mindset that is based on model-based data-centric collaborations that enhance

decision-making. The answer to the fundamental question – “How Do We Enable SE Modernization?” – is still evolving.

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Leveraging Generative AI to Create, Modify, and Query MBSE Models

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Abstract

Generative AI tools, such as large language models (LLMs), offer a variety of ways to gain efficiencies and improve systems engineering processes from requirements generation and management through design analysis and formal testing. Large acquisition programs may be particularly well poised to take advantage of LLMs to help manage the complexities of system and system of systems acquisitions. However, generative AI tools are prone to a variety of errors.

Our research explores the ability of current LLMs to generate, modify, and query Systems Modeling Language (SysML) v2 models. Techniques such as Retrieval-Augmented Generation (RAG) are utilized to add domain-specific knowledge to an LLM and improve model accuracy. A preliminary case study is presented where the number of prompts to generate the models is minimized. We also discuss the limitations of LLMs and future systems engineering research related to LLMs.



Introduction

Applications of artificial intelligence (AI) have the potential to change many fields including systems engineering. Large language models (LLMs) may enable systems engineers to build, modify, and query systems models through plain language prompts, reducing the need for domain-specific modeling knowledge. Systems Modeling Language version 1 (SysML v1) is a graphical language to describe a system and its interaction with its environment. The use of graphical diagrams requires a multi-modal LLM to interact with a SysML v1.x model. However, the introduction of textual notation into SysML version 2 (SysML v2) enables more unimodal LLMs to interact with a systems model.

This paper explores the use of ChatGPT 3.5, ChatGPT 4, and a custom GPT, Senior System Engineer – Systems Modeler (SSE-SM), to create, modify, and query SysML v2 models from natural language prompts. This paper also identifies methods to reduce the number of prompts required to create models, including Retrieval-Augmented Generation (RAG). This paper also identifies some limitations of LLMs when applied to systems modeling and suggests areas of future research.

Background and Related Research

Model Based Systems Engineering

The International Council on Systems Engineering (INCOSE) defines MBSE as “a formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases” (INCOSE, 2007). Traditionally, systems engineering was performed using a document-based approach. However, the growing complexity of systems and systems of systems necessitates a need to “capture, analyze, share, and manage the information associated with the complete specification of a product” (Friedenthal et al., 2009). Capturing this information in a model enables the system to be viewed by multiple stakeholders from their respective viewpoints, streamlines collaboration between systems and domain-specific engineers, enables tracing of requirements through design and verification/validation activities, and provides a formal way to identify, analyze, and track system changes/defects as a solution is developed (Carroll & Malins, 2016).

Systems Modeling Language (SysML)

To implement a MBSE methodology, Systems Modeling Language (SysML) v1.0 was developed and adopted in 2006 with formal publication in 2007 by the Object Management Group (OMG). Formally released in 2019, SysML v1.6 is the latest release of the SysML v1.x standard. SysML v1.x is an extension of the Unified Modeling Language (UML) 2 standard containing some, but not all, elements of UML 2 and some new SysML specific elements (OMG, n.d.). SysML v1.x is a graphical language consisting of nine diagram types where each diagram represents a view of the underlying model elements.



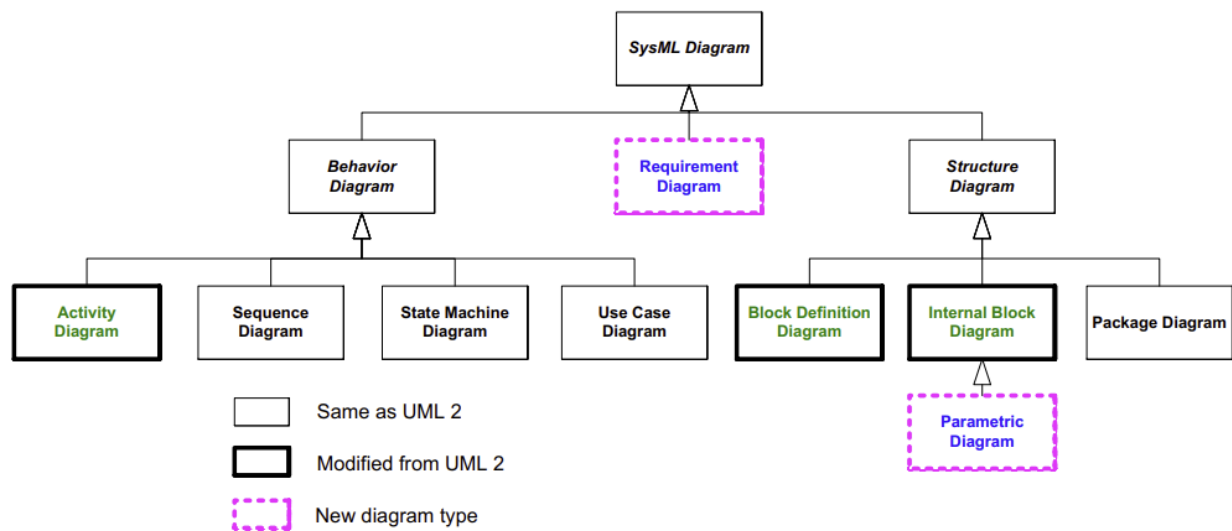


Figure 1. SysML v1.x Diagram Taxonomy (OMG, 2017)

While SysML v1 has been widely adopted across government, industry, and academia, many weaknesses were noted that led to the development of SysML v2. In an article introducing SysML v2, Friedenthal and Seidewitz (2020) state the objectives of SysML v2 are to improve:

- Precision and expressiveness of the language
- Consistency across language concepts
- Usability for model developers and model consumers
- Interoperability between systems modeling tools and other model-based engineering tools
- Extensibility to support modeling of domain-specific concepts (Friedenthal & Seidewitz, 2020)

Key SysML v2 enhancements address many of the limitations of SysML v1 (Stachecki, 2024):

- New metamodel grounded in formal semantics not constrained by UML
- Addition of textual notation
- Addition of a standardized API: There were several vendors for SysML v1 tools. However, each vendor implemented the standard differently, which led to very limited, and often, no interoperability between MBSE tools.

SysML v2 also utilizes the concept of standard views instead of diagrams to view the model. In addition to two new views, all diagram types of SysML v1 can be replicated as standard views in SysML v2 (Figure 22).

can be installed and run locally (hardware dependent) using tools such as LM Studio (Arya, 2024).

LLMs vary in their size and number of parameters. The number of parameters often, but not always, leads to a trade-off between speed and accuracy. A 7B LLM has 7 billion parameters while a 13B LLM has 13 billion parameters. Some proprietary LLMs utilize 175B or more parameters (Yao et al., 2024). A 13B model will likely out-perform a 7B model on general knowledge tasks, but the 7B model may perform better in domain-specific tasks it is specifically trained to complete. Introducing new information can enhance accuracy, and when models need finetuning or retraining, updating smaller models is typically more practical and faster (Huertas, 2023). Smaller models also require less computing power for inference and often respond much quicker than larger models.

Improving Responses from LLMs

LLMs are only as good as the datasets they are trained on. To improve responses to domain-specific requests, it is often necessary to provide additional context to a model through one of the following methods:

- RAG utilizes an external data to augment the LLM's knowledge without changing the underlying LLM's parameters (weights; Nucci, 2024). RAG can be particularly useful for fields where new knowledge is generated regularly or when information is proprietary/private and the user desires to not make it a permanent part of the LLMs training set (Nucci, 2024).
- Finetuning slightly adjusts an LLM's internal parameters by teaching the LLM specialized knowledge (Nucci, 2024). Nucci stresses only a small number of parameters are adjusted, which results in the significant time savings of finetuning vice re-training the entire model.
- Prompt Engineering
 - Zero-shot prompts are requests that challenge an LLM to perform a task correctly on its first try, even though it hasn't been directly trained for that specific task (Oleszak, 2024). They are often used for simple tasks that only require general knowledge or when domain-specific knowledge was included in the training set or provided via RAG or finetuning.
 - For more complex tasks that require multi-step reasoning or when an LLM is not aware of domain-specific knowledge, few-shot prompts may be used to teach an LLM through examples (Oleszak, 2024). Few-shot learning may be used to format code correctly by providing code syntax examples.

It's also possible to combine the methods above. OpenAI allows users to create Custom GPTs where specific instructions can be provided along with an area to upload files containing domain-specific knowledge (OpenAI, 2023). This combination of RAG and prompt engineering may enable a user to reduce the number of prompts required to complete complex tasks the model was not specifically trained on.

Methodology

While the following methodology can be utilized with a variety of LLMs, the following ChatGPT variants were utilized for the case studies in the next section: ChatGPT-3.5, ChatGPT-4, and a custom GPT: Senior Systems Engineer – Systems Modeler (SSE-SM).

Model Creation Process

Models are created using the process in [Figure 33](#):



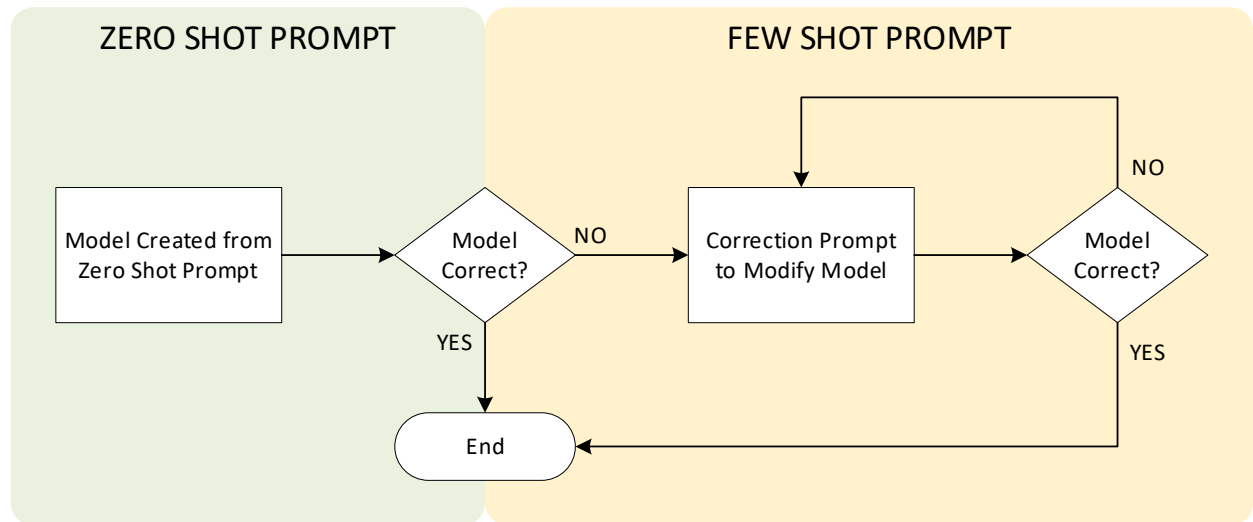


Figure 3. Zero or Few-Shot Prompting Process

The first step in the process is a prompt instructing the LLM to create a SysML v2 textual model from a list of requirements or system description. This is the zero-shot case. After the LLM returns a model, the model is analyzed for correctness. The process is completed if the model is correct. If the model is not correct, it is modified by a corrective prompt, and analyzed again for correctness. The process repeats until a correct model is output by the LLM.

The SysML v2 specification was utilized to check generated models for accuracy. Graphical models were built using the PlantUML plugin in Eclipse (<https://github.com/Systems-Modeling/SysML-v2-Release/tree/master/install/eclipse>).

Senior Systems Engineer - Systems Modeler (SSE-SM)

SSE-SM is a custom GPT based on ChatGPT-4 with the following documents from the SysML v2 Github repository added to incorporate RAG:

- SysML v2.0 Specification
- Introduction to the SysML v2 Language: Textual Notation
- Introduction to the SysML v2 Language: Graphical Notation

A SysML v2 textual template and examples of requirements and parts packages were also uploaded to SSE-SM. The following instructions were uploaded to the instructions part of the custom GPT user interface.

As an expert level systems engineer, this GPT excels at querying, modifying, and developing systems models in the SysML version 2 modeling language. This GPT will respond with SysML v2 text based models when prompted.

This GPT recognizes key differences between SysML v1 and v2. For example, in SysML v2, there are no blocks. Blocks are a SysML v1 concept. In SysML v2, components are represented as parts.

The documentation, template, examples, and custom instructions uploaded to SSE-SM were developed using the prompts in the ChatGPT-3.5 and ChatGPT-4 as guidance.

Case Study: Bicycle System Model

The goal of this case study is to determine the feasibility of using an LLM to build, modify, and query a SysML v2 model from natural language prompts only. While a much more complex model could have been developed, a structural model focused on a requirement, parts, and interconnections of the parts of a bicycle offers a useful example while also offering the opportunity to add complexity in future research.

Creating the SysML v2 Model

The following prompt was utilized to build the SysML v2 textual model:

Create a SysML v2 textual model of a bicycle consisting of the following parts: a frame, handlebars connected to the frame, a seat post connected to a frame, a front axle connected to the frame, a rear axle connected to the frame, a front wheel connected to the front axle, a rear wheel connected to the rear axle, front brakes connected to the front wheel and frame, rear brakes connected to the rear wheel and frame, and a drivetrain connected to the frame and rear wheel.

The key parts of this prompt are:

- *Create*: The term *create* signals the LLM that a specific item needs to be created.
- *SysML v2*: Prompts that stated SysML, but not a version, generated a textual model that confused SysML v1.x and v2 concepts (blocks and parts). When using ChatGPT-4 if a SysML v2 was not specified, ChatGPT-4 called Dall-E to create a visual diagram.
- *Textual*: Prompts that did not state *textual* often gave responses on how to create a model, but no code.
- *Connected*: The term connected signals the LLM that a specific relationship needs to be created
- The parts list is given as a list of interconnections. Splitting the prompt into a parts list and interconnection list did not improve results. For brevity, the parts list and their interconnections were combined.

ChatGPT-3.5

The following are samples from the zero-shot prompt. The model did identify all parts, but the syntax was incorrect (e.g., missing semi-colons at the end of each line). The model also identified parts and typed parts (e.g., part handlebars: Handlebars) but did not define all parts prior to using them.

After a few more prompts, some of the model syntax (semi-colons) was corrected and parts were defined correctly. However, the LLM was not able to connect parts correctly. While there may be a set of prompts to fully develop the model correctly, after multiple attempts to correct the model using several different prompt structures and instructions, we decided to try different LLMs.

ChatGPT-3.5 zero prompt model sample:

```
package BicycleSystem {  
  
  part bicycle: Bicycle {  
    frame,  
    handlebars,  
    seatPost,  
    frontAxle,  
    rearAxle,  
    frontWheel,  
    rearWheel,  
  }
```



```

    frontBrakes,
    rearBrakes,
    drivetrain
}

part frame: Frame

part handlebars: Handlebars {
    connectedTo(frame)
}

part seatPost: SeatPost {
    connectedTo(frame)
}
// END OF SAMPLE CODE
}

```



Figure 4. ChatGPT-3.5 Zero Prompt Model Graphical Notation

ChatGPT-4

The model identified all the parts from the prompt, properly defined the parts, but did not make the connections correctly. However, when given the following two prompts were given as examples, ChatGPT-4 was able to properly make the connections.

Prompt 1:

Connections should be formatted like the following two examples:

connect handlebars to bicycleFrame;

connect seatPost to bicycleFrame;

Prompt 2:

There should be no and statements in connections. For example, 'connect frontBrakes to frontWheel and bicycleFrame;' should be:

connect frontBrakes to frontWheel;

connect frontBrakes to bicycleFrame;

We confirmed that valid SysML v2 models could be built by ChatGPT-4 using a few-shot prompting method. The following text is sample code from the zero-shot model. The graphical version of the corrected model is shown in **Figure 55**.

ChatGPT-4 zero prompt model sample:

```

package BicycleSystem {
// SAMPLE CODE BEGINS
    part def Brakes {
    }

    part def Drivetrain {
    }

    part def Bicycle {
        part frame: Frame;

```

```

part handlebars: Handlebars;
part seatPost: SeatPost;
part frontAxle: FrontAxle;
part rearAxle: RearAxle;
part frontWheel: Wheel;
part rearWheel: Wheel;
part frontBrakes: Brakes;
part rearBrakes: Brakes;
part drivetrain: Drivetrain;

// Connections
connect frame -> handlebars;
connect frame -> seatPost;
connect frame -> frontAxle;
connect frame -> rearAxle;
connect frontAxle -> frontWheel;
connect rearAxle -> rearWheel;
connect frame -> frontBrakes -> frontWheel;
connect frame -> rearBrakes -> rearWheel;
connect frame -> drivetrain -> rearWheel;
}
}

```



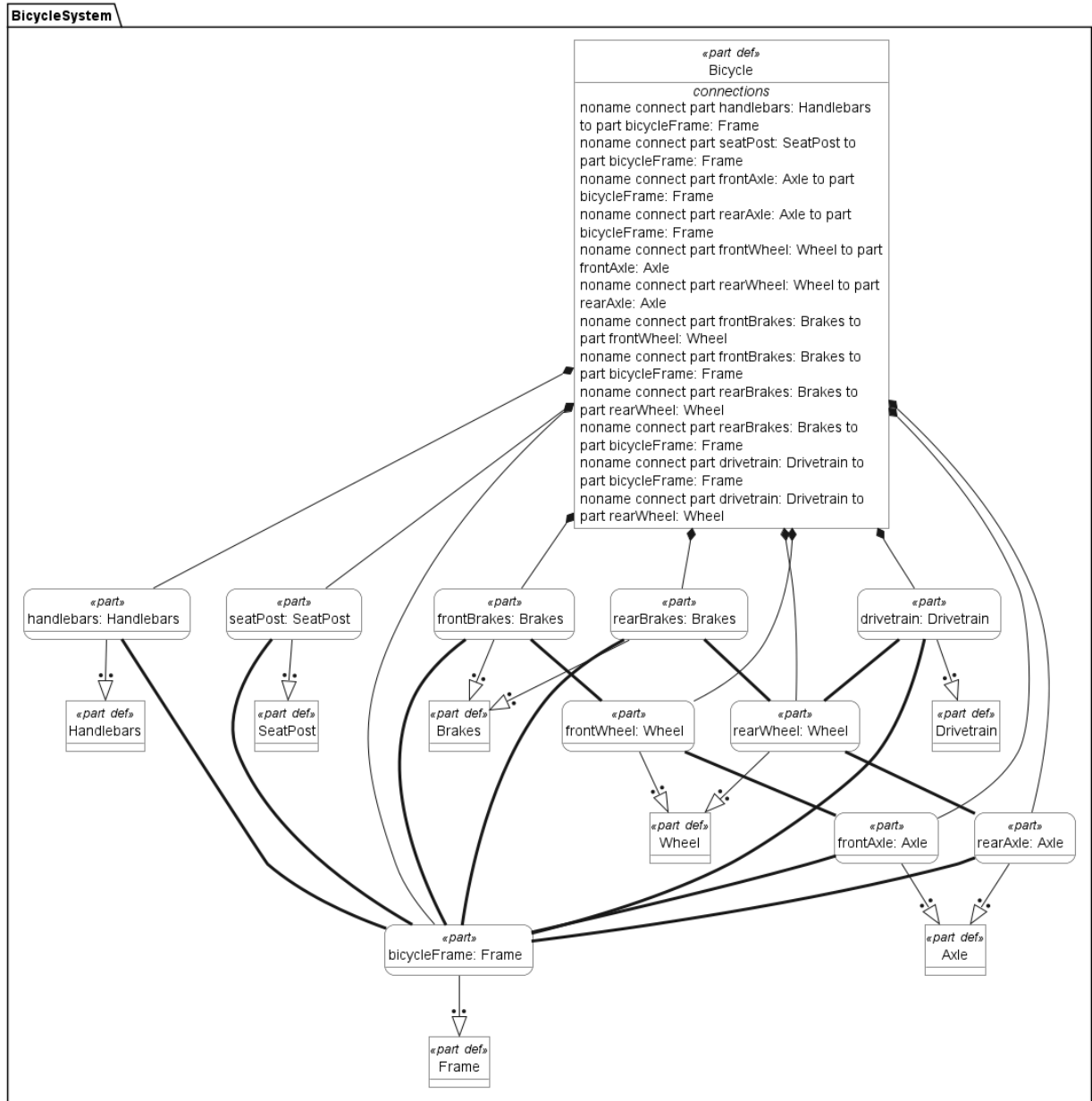


Figure 5. ChatGPT-4 Model after Examples Provided (Few-Shot Prompt)

SSE-SM

SSE-SM was developed using the few-shot prompt example instructions from the ChatGPT-4 prompts and providing additional knowledge via RAG (see under heading “Senior Systems Engineer - Systems Modeler (SSE-SM)” for full details). By building a correct model, we confirmed that SSE-SM can build a fully valid model with one prompt. While the initial prompt was enough to create a valid model, due to the inclusion of additional knowledge, this is not a zero-shot prompt.

The graphical version of the corrected model is shown in **Figure 5**.

SSE-SM zero prompt model:

```
package Bicycle {
  part def BicycleFrame {
    doc /* The main structure of the bicycle to which other parts are connected. */
  }

  part def Handlebars {
    doc /* The steering mechanism of the bicycle, connected to the BicycleFrame. */
  }

  part def SeatPost {
    doc /* Supports the seat and connects to the BicycleFrame. */
  }

  part def Axle {
    doc /* Supports the wheels and allows them to rotate. */
  }

  part def Wheel {
    doc /* Allows the bicycle to roll and includes a tire and a rim. */
  }

  part def Brake {
    doc /* The mechanism used to slow down or stop the bicycle. */
  }

  part def Drivetrain {
    doc /* Transfers power from the cyclist to the rear wheel. */
  }

  part Bicycle {
    part bicycleFrame : BicycleFrame;
    part handlebars : Handlebars;
    part seatPost : SeatPost;
    part frontAxle : Axle;
    part rearAxle : Axle;
    part frontWheel : Wheel;
    part rearWheel : Wheel;
    part frontBrakes : Brake;
    part rearBrakes : Brake;
    part drivetrain : Drivetrain;

    // Connections
    connect handlebars to bicycleFrame;
    connect seatPost to bicycleFrame;
    connect frontAxle to bicycleFrame;
    connect rearAxle to bicycleFrame;
    connect frontWheel to frontAxle;
    connect rearWheel to rearAxle;
    connect frontBrakes to frontWheel;
    connect frontBrakes to bicycleFrame;
    connect rearBrakes to rearWheel;
    connect rearBrakes to bicycleFrame;
    connect drivetrain to bicycleFrame;
    connect drivetrain to rearWheel;
  }
}
```



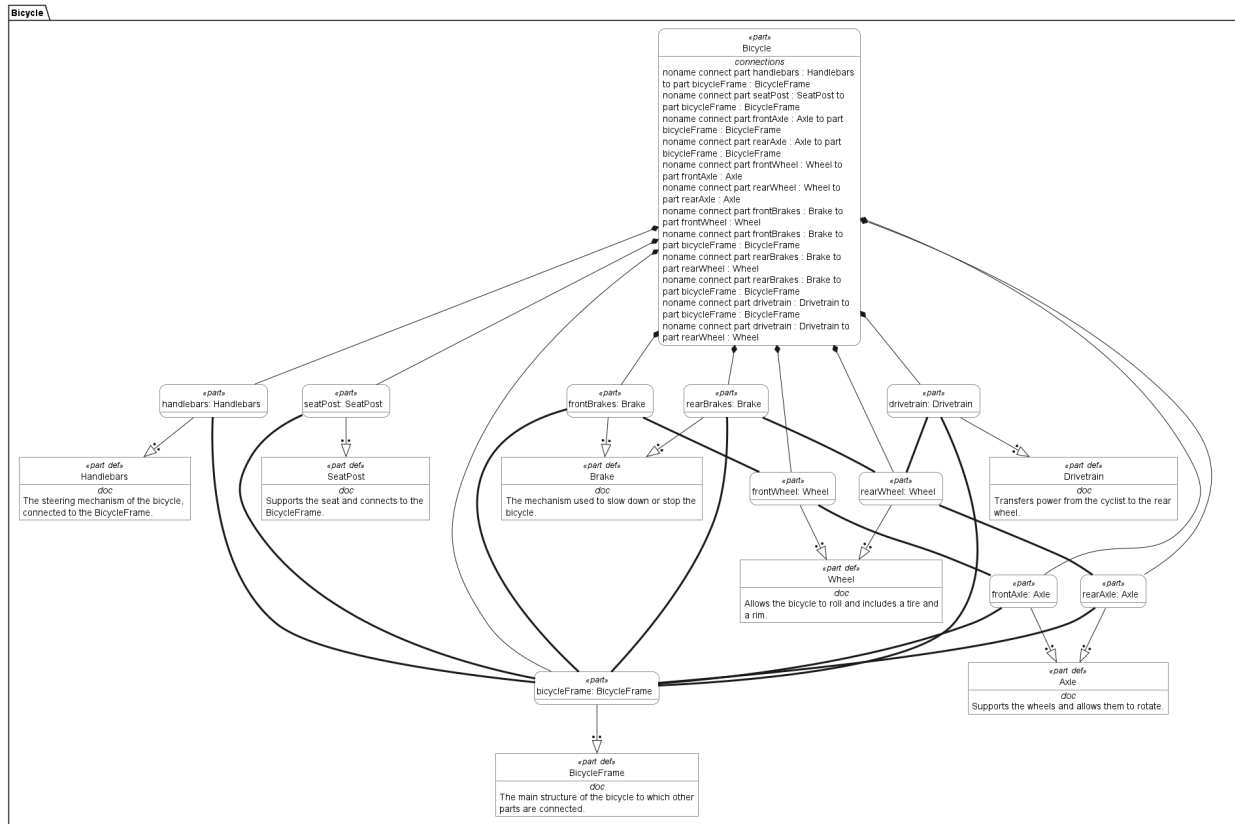


Figure 6. SSE-SM Model First Prompt

Modifying the SysML v2 Model

The SysML v2 model was modified to add a left and right pedal to the drivetrain; and add a user maximum weight requirement of 300 pounds using the following prompts. The [SysML v2 Model] in the prompts is the bicycle model created by SSE-SM.

Prompt 1:

Modify the following SysML v2 model to add a left pedal to the drivetrain and a right pedal to the drivetrain: [SysML v2 Model]

Prompt 2:

Modify the model to include the following requirement: "The bike shall support a user weighing 300 pounds or less."

ChatGPT-3.5

When adding the two pedals to the model, ChatGPT-3.5 defined a left and right pedal, added two parts called leftPedal and rightPedal to the model, and connected the pedals to the drivetrain as shown in the snippet below. While technically correct, there are more efficient ways to effect this modification.

```
package Bicycle {

    // Code Snippet Removed for Brevity

    part def LeftPedal {
        doc /* The left pedal of the bicycle. */
    }
}
```

```

part def RightPedal {
  doc /* The right pedal of the bicycle. */
}

part Bicycle {

  // Code Snippet Removed for Brevity

  part leftPedal : LeftPedal;
  part rightPedal : RightPedal;

  // Code Snippet Removed for Brevity

  connect leftPedal to drivetrain; // Connect left pedal to drivetrain
  connect rightPedal to drivetrain; // Connect right pedal to drivetrain
}
}

```

When adding the requirement to the model, ChatGPT-3.5 modeled it as a constraint and not a requirement.

```

part def BicycleFrame {
  doc /* The main structure of the bicycle to which other parts are connected. */
  constraint maxUserWeight: Real[1] { max <= 300 } // Constraint for maximum user weight
}

```

ChatGPT-4

When adding the two pedals to the model, ChatGPT-4 defined a pedal, added two parts called leftPedal and rightPedal to the model, and connected the pedals to the drivetrain as shown in the snippet below.

```

package Bicycle {

  // Code Snippet Removed for Brevity

  part def Pedal {
    doc /* A part of the drivetrain, mounted on the crank to allow the cyclist to power the bicycle. */
  }

  part def Drivetrain {
    doc /* Transfers power from the cyclist to the rear wheel. */
    part leftPedal : Pedal;
    part rightPedal : Pedal;
  }

  part Bicycle {

    // Code Snippet Removed for Brevity

    // Additional connections for pedals
    connect drivetrain.leftPedal to drivetrain;
    connect drivetrain.rightPedal to drivetrain;
  }
}

```

When adding the requirement to the model, ChatGPT-4 modeled it as a requirement.

```

requirement def WeightCapacity {
  doc /* The bike shall support a user weighing 300 pounds or less. */
}

```



SSE-SM

When adding the two pedals to the model, SSE-SM defined a pedal, added two parts called leftPedal and rightPedal to the model, and connected the pedals to the drivetrain as shown in the snippet below.

```
package Bicycle {  
  
    // Code Snippet Removed for Brevity  
  
    part def Drivetrain {  
        doc /* Transfers power from the cyclist to the rear wheel. */  
        part leftPedal : LeftPedal;  
        part rightPedal : RightPedal;  
    }  
  
    part def LeftPedal {  
        doc /* The pedal on the left side of the drivetrain. */  
    }  
  
    part def RightPedal {  
        doc /* The pedal on the right side of the drivetrain. */  
    }  
  
    part Bicycle {  
  
        // Code Snippet Removed for Brevity  
  
        // Adding pedal connections  
        connect drivetrain.leftPedal to drivetrain;  
        connect drivetrain.rightPedal to drivetrain;  
    }  
}
```

When adding the requirement, SSE-SM added a requirement definition and also numbered the requirement.

```
requirement def <'1'> UserWeightSupport {  
    doc /* The bike shall support a user weighing 300 pounds or less. */  
}
```

Model Query

The bicycle SysML v2 model was queried to determine if the LLMs could recall information from the model and infer information from the model that was not explicitly defined in the model.

For simple recall, the LLMs were asked how many brakes the bicycle contained. All LLMs correctly identified two brakes, front and rear.

The LLMs were asked “Will the bicycle be able to stop if the rear brakes fail?” All LLMs correctly identified the bicycle would be able to stop using the front brakes.

The LLMs were asked “Will the bicycle be able to stop if the front brakes fail?” All LLMs correctly identified the bicycle would be able to stop using the rear brakes.

The LLMs were asked “Will the bicycle be able to stop if both brakes fail?” All LLMs identified this would be a failure of the braking system and gave alternate options for stopping the bicycle. All LLMs also identified that the braking system was a critical system for the bike and recommended regular inspection and maintenance.



Results, Discussion, and Limitations

In each case, the LLMs were able to identify all parts from the prompt describing the bicycle system. However, when it came to creating a SysML v2 textual model from the prompt, the models performed differently (Table 1). Using the few-shot learning prompts from the ChatGPT-4 model as a guide and adding SysML v2 knowledge, the SSE-SM was able to correctly model the bicycle on the first attempt.

The LLMs were all able to add pedals to the model although they utilized different methods to do so. ChatGPT-3.5 added the requirement as a constraint while the other two LLMs correctly added the requirement as a requirement.

Table 1. LLM Comparison

Criteria	Correct Response?		
	ChatGPT-3.5	ChatGPT-4	SSE-SM
Model Creation			
The LLM identified all parts	Yes	Yes	Yes
The LLM defined all parts	No	Yes	Yes
The LLM identified all connections	No	Yes	Yes
The LLM modeled all connections	No	Yes – required few-shot prompts	Yes
The LLM developed model was able to be graphically displayed	No	Yes – required few-shot prompts	Yes
Model Modification			
The LLM modified the model by adding pedals	Yes	Yes	Yes
The LLM modified the model by adding the weight requirement	No	Yes	Yes
Model Query			
The LLM identified the number of braking systems	Yes	Yes	Yes
The LLM reasoned the bicycle would be able to stop if only the front brakes failed	Yes	Yes	Yes
The LLM reasoned the bicycle would be able to stop if only the rear brakes failed	Yes	Yes	Yes
The LLM reasoned the bicycle would not be able to stop using the brakes if both brakes failed	Yes	Yes	Yes

In addition to the widely acknowledged limitations of LLMs (e.g. incorrect answers based on “hallucinations,” replicability of results), the case study in this paper exhibited several limitations:

- A simple model not representative of a complex system was used for demonstration of capability. It is not known if the LLMs tested will perform as well or better when behavioral and/or more complex structural models are required. To overcome this limitation, future research could focus on building models that are more inclusive of the SysML v2 textual notation.
- SysML v2 is not widely adopted. This led to a limited amount of information available for RAG. Future research could focus on developing more SysML v2 example models for LLM training, finetuning, and RAG.

Future Work

There are many opportunities to build upon the research and case study presented in this paper:

- **Systems Modeling Benchmark:** Develop a benchmark to quantify LLM’s capabilities to perform system modeling functions. SysEngBench (Bell et al., in press) is a recently introduced systems engineering benchmark for LLMs and is a good candidate for further contributions in the areas of system modeling.
- **SysML v2 Model Library:** A corpus of SysML v2 model examples is likely required to increase the capability of LLMs to perform systems modeling functions via RAG or finetuning. These new models should be more inclusive of the SysML v2 language and provide different, but correct, methods to model the same system.
- **Systems Modeling Domain-Specific LM:** Where LLMs have a broad understanding of language, a domain-specific model narrows its scope in the pursuit of deep expertise in a certain area. Domain-specific LMs could be LLMs, but Small Language Models (SLMs) may also be a feasible option. SLMs require much less memory and compute to infer responses and may be run on a variety of devices. Locally ran LMs are also desirable for work with sensitive data.
- **Emergent Property Discovery:** Explore the ability of LLMs to discover emergent properties in Systems of Systems via a System of Systems model.
- **Model Conversion:** Explore the ability of LLMs to convert SysML v1.x models to SysML v2. While mass conversion of models will likely require specialized tools, LLMs may be able to assist in building these tools.
- **AI Assistance Cost Factors:** As AI disrupts software and systems development, cost models used by the DoD will need to be updated. Madachy et al. (in press) introduced six new cost factors that may apply to a variety of cost estimation techniques. Capturing time savings from using general and domain-specific LLMs in systems modeling can help inform new AI related-cost factors.

Conclusion

LLMs have shown an ability to generate SysML v2 models with increasing capability as an LLM becomes aware of domain-specific knowledge. As SysML v2 becomes widely adopted, systems engineering domain-specific LLMs are a promising method to reduce the knowledge gap and training required to build, modify, and query systems models using plain language prompts. However, more research is required to ensure the accuracy and reliability of LLMs applied to systems modeling is acceptable. As we continue to explore the use of LLMs in systems modeling, a variety of applications will undoubtedly shape the future of AI and systems engineering.



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PANEL 11. MANAGING PROGRAMS FOR SPEED

Wednesday, May 8, 2024	
3:45 p.m. – 5:00 p.m.	<p>Chair: David H. Lewis, VADM, USN, (Ret), Senior Vice President, Maritime, Leidos</p> <p><i>Navigating the Labyrinth: Unraveling Schedule Complexity</i> Raymond Franck, US Airforce Academy</p> <p><i>Timeboxed Earned Schedule Approach (TESA): An Innovative Framework to Program Schedule Management for Programs within OTAs</i> Michael Oliver, MITRE</p> <p><i>Leading Practices Iterative Cycles Enable Rapid Delivery of Complex, Innovative Products</i> Brian Smith, GAO</p>

David H. Lewis, VADM USN, (Ret)—before joining Leidos, Lewis served as the Naval Postgraduate School Chair of Acquisition and in the United States Navy in operational, engineering, and acquisition related billets. Upon selection to flag rank in 2009, he served as vice commander of the Naval Sea Systems Command, followed by four years as Program Executive Officer (Ships), where he directed the delivery of 18 ships and procurement of an additional 51 ships. From 2014-2017, he served as commander of the Space and Naval Warfare Systems Command, where he led a global workforce of 10,300 civilian and military personnel who designed, developed and deployed advanced communications and information capabilities for the Navy. His final assignment was Director for the Defense Contract Management Agency.

Lewis graduated from the University of Nebraska in 1979 and was commissioned through the Naval Reserve Officers Training Corps program. He also holds a Master of Science in Computer Science from the Naval Postgraduate School.



Navigating the Labyrinth: Unraveling Schedule Complexity

Charles Pickar—retired from the Naval Postgraduate School (NPS) faculty, where he taught project management, defense acquisition, and systems engineering. Before joining NPS, he led the Applied Systems Engineering Program Area at the Johns Hopkins University Applied Physics Laboratory. He is also a retired Army officer with extensive experience in the U.S. defense industry, including Director and VP levels at Lockheed Martin, Northrop Grumman, and SAIC. He also served as Chair of the Systems Education Technical Committee of the IEEE Systems Council. His research and published work focus on applying systems engineering and system dynamics analytical approaches to defense acquisition problems. [ckpickar@gmail.com]

Raymond Franck—retired from the NPS faculty in 2012. He retired from the Air Force in 2000 in the grade of Brigadier General. His active-duty career included operational tours, staff positions, leadership assignments and, finally, head of the Department of Economics and Geography, United States Air Force Academy. His published work includes journal articles, book chapters, and research reports on military innovation and defense acquisition management. [cfranck215@aol.com]

Abstract

This paper continues our efforts to help advance the state of the art for estimating defense acquisition program schedules. Accurate schedule estimates provide valuable benchmarks for program managers and reliable dates for the availability of new systems for warfighters. But credible (much less accurate) schedule estimates are difficult, at best. This is due to many factors, including programs' inherent complexities and the likelihood of unfavorable developments outside the control of program management. Recognizing this difficulty, our inquiries center on improving the art of estimating schedules, and also making program schedules more resilient with respect to those difficulties. Accordingly, we also focus on the role of Systems Dynamics in program execution (illustrated with case studies) and on improving management information through prediction markets. Despite the difficulties, we remain convinced that improvements are possible.

Introduction and Overview

We have identified three significant areas of interest in our continuing inquiries into the art and science of managing acquisition schedules. First, credible, available prior to program start (*ex ante*); second, during program execution (*in media res*); and finally, lessons learned from completed programs (*ex post*).

However, even the best ex-ante schedule estimates do not fully prepare program management for the difficulties ahead. In this paper, we focus on project dynamics and the difficulty (arguably impossibility) of foreseeing what unforeseen events (some external to the program itself) can affect acquisition schedules.

A central theme of our previous papers (e.g., Franck et al., 2017) is understanding project dynamics in schedule execution in weapon system development projects. Scheduling is a unique and challenging problem requiring mathematical and human perspectives.

A system is complex if it has many elements, interactions, and variables, and if it is difficult to predict its behavior and outcomes. A system is dynamic if it changes over time and if its changes depend on its current state and history. Projects and weapon system development programs are systems. Typically, such programs are dynamic, complex, interrelated, and changing systems. Project dynamics refer to those internal and external factors that can influence the course of a development project throughout its life cycle. These factors can be unpredictable and constantly evolving, posing significant challenges to maintaining a project schedule. According to conventional wisdom, project management can



plan and execute projects by identifying and controlling the cause-and-effect relationships among various factors inside the system. However, this approach is inadequate in dealing with the uncertainties and interdependencies within the system and during the project life cycle. Since most people are prone to linear thinking, they have difficulty with systemic and nonlinear thinking, especially when faced with complex and dynamic situations that involve multiple variables, uncertainties, time delays, and trade-offs (in abundance in weapon system development projects; Dörner, 1996). Dörner also notes that people often fail to recognize the interrelated and long-term effects of their decisions, leading to unintended and sometimes disastrous outcomes (Dörner, 1996, p.45). The fact is that 50% of technology projects fail to meet their cost and schedule objectives (Flyvbjerg & Budzier, 2015).

Closely related to the idea of dynamics is the value of using data analysis for schedule planning and execution. Data analysis of past projects can provide insight into the problems experienced in other developments. Data can provide insights into the project's progress, resource allocation, and potential roadblocks, allowing project managers to make informed decisions. Data can also help to give indicators of the project's progress against the schedule, allowing for timely interventions and adjustments. Data can help identify problem areas and opportunities for improvement, leading to more efficient project execution. In past papers, we have used data to better understand trends in schedule execution, as well as provide insight into the causes of schedule delays. To identify the causes of schedule execution dynamics, collecting and analyzing data related to these factors, such as historical, current, or forecast data, is necessary. A significant data source for qualitative and quantitative analysis of previous studies was the Selected Acquisition Report (SAR). We reference some past data-focused studies on the determinants of schedule delays (Pickar, 2018). We had also hoped to make greater use of Selected Acquisition Reports for this study, but the lack of data for the two case studies in this paper prevented their use.¹

So, while reasonable *ex-ante* schedule estimates are helpful, they are insufficient to successfully complete the program. Many problems in today's defense acquisition world occur because managers fail to recognize that the various tasks in the program are not isolated problems; they interact within their own system through personnel and activities and with multiple stakeholders, environments, and events that can influence and change project outcomes. Therefore, project managers need to adopt a more dynamic and adaptive mindset to anticipate and respond to the dynamics of complex projects. In short, project managers must acknowledge defense projects' dynamic nature.

Knowledge of program dynamics can conceptually equip program managers to cope with and mitigate the ill effects of unpredicted developments. Such knowledge can provide a basis for making weapon systems development programs more resilient to untoward developments. Moreover, the quantity (and quality) of information available to program management can significantly increase resilience in program execution.

In this context, recent developments in data analytics can provide valuable information for getting acquisition programs through their generally turbulent stages. It's also vital that data quality includes the situational contexts from which it is filtered through hierarchies and widely distributed. Therefore, including local knowledge in the program's

¹ In past research, we used two main sections of the SAR: the Executive Summary and the Schedule Change Explanations. The F-35 Executive Summary changes very little from reporting period to reporting period. The Schedule changes provide information of what changes, but do not always provide the reasons for the schedule changes.

management information system is essential. One way to do that is through “prediction markets.”²

In this paper, we consider the art of managing defense acquisition programs as complicated and incompletely understood systems through the lens of system dynamics—which we illustrate through case studies. We also consider improving the quality of information available to decision-makers through “prediction markets” regarding upcoming program events and milestones.

System Dynamics and Rework in Schedules

Scheduling is about allocating resources, tasks, and time to achieve a desired outcome in a project. It is a crucial aspect of project management, affecting the project's quality, cost, and scope. However, scheduling is neither straightforward nor simple, as it involves many uncertainties, complexities, and interdependencies. Moreover, scheduling is not only a technical or mathematical problem but also a human and social one, as it involves the behavior, motivation, and interaction of the project manager, team, and stakeholders.

In a previous paper, we introduced the concept of rework (Franck et al., 2017). **Error! Reference source not found.** shows the rework cycle (Richardson, & Pugh, 1981; Cooper, 1993a). Rework is correcting or modifying work that has already been completed. It is common in many projects and can significantly impact project outcomes in terms of cost, schedule, and performance.

The rework cycle is a feedback loop that describes the negative and positive effects of rework on project dynamics. The rework cycle is a critical aspect of system dynamics studied extensively in project management. The rework cycle is characterized by feedback effects that can be negative, controlling, or positive, re-enforcing, often “vicious circles.” The rework cycle can also lead to knock-on or domino effects within or between work phases and between projects. Software engineering and development is prone to rework due to errors, changes, and learning in the software development process (Abdel-Hamid & Madnick, 1982, 1983). Rework can affect the cost, schedule, and performance of software projects and the developers' and users' satisfaction and motivation.

Figure 1. The Rework Cycle (adapted from (Cooper, 1993a))

Rework is a common and pervasive phenomenon in project management. It occurs when a task or process must be redone or corrected because it was not done correctly or

² Prediction markets are described below.

completely the first time. Rework can have negative consequences for a system's cost, schedule, and performance, as well as for the satisfaction and motivation of the stakeholders involved. It can also create delays, waste, errors, and rework cycles, worsening the system's behavior and outcomes.

Rework is influenced by various dynamics, such as the complexity and uncertainty of the task or the process, the quality and availability of the inputs and resources, the skills and experience of the workers, the communication and coordination among the participants, the feedback and control mechanisms, the standards and expectations, and the external environment and disturbances. Rework can also vary in nature, extent, and impact, depending on the type, stage, and scope of the task or the process, as well as the detection and correction time and method (Love et al., 2002).

There is a general agreement that rework involves the need to redo or correct a task or a process that was not done correctly or completely the first time. However, the criteria and standards to determine what is correct or complete can vary depending on the context and the stakeholders' perspective. For example, a task or a process can be considered correct or complete from a technical or functional point of view but not from a customer or user point of view, or vice versa. Similarly, a task or a process can be considered correct or complete at a given time but not later due to changes in the requirements, specifications, or expectations.

Our past research agenda has included examination of the reasons for schedule delays. We have used qualitative and quantitative techniques to identify the causes of schedule delays (extracting the data from the Selected Acquisition Reports). Of course, these studies depend on the PM reported reasons for the delays. These studies yielded the following broad categories of causes.

Table 1. Schedule Delay Factors. (Pickar, 2018, p. 82).

Schedule Delay Factor	# instances
Administrative changes to the schedule, including updates to APB, ADM changes as well as changes resulting from Nunn-McCurdy processes and program restructuring	460
Technical	291
Testing delays	283
Delay in availability of key capabilities/facilities (launch vehicle/testing facilities/IOT&E units)	3
Budget/funding delays	52
Delays attributed to the contractor	50
Delays because of rework	16
External events such as inflation, earthquakes, labor strikes, etc. (<i>force majeure</i>)	4
Delays due to contracting/contract negotiation/award delays	29
Actuals (updating previously reported dates to actual occurrence)	172

The number of instances of rework cited is of note. This study examined 20 years of Selected Acquisition Reports (SAR). The delay causes were extracted from the SARs' reported schedule explanations. The low number of reported cases of rework could come



from two reasons. The first is that the contractor may not have reported specific instances of rework instead of the result of the rework (e.g., contractor delays or the catch-all category of administrative problems) to the government program office. The second reason could be a lack of understanding of the factors causing rework and the resulting problems caused by rework.

A systems approach to project management provides project management organizations insight into the systemic causes and consequences of rework, enabling them to make more informed decisions and implement effective strategies for its prevention or mitigation. This concept highlights the importance of a holistic and dynamic perspective when analyzing and managing rework, recognizing its role in shaping the behavior and performance of weapon system development. The case studies provide examples of the impacts of rework.

Case Study: F-35 Weight and Other Rework Problems

The F-35 program is the most extensive and expensive military procurement project in history, with an estimated total cost of over \$1.5 trillion. This weapon system development is a classic example of a complex dynamic system. The F-35 program has faced numerous programmatic and engineering challenges. One of the most critical and persistent problems was the aircraft's weight, which threatened to compromise its performance, stealth, and safety. In a previous study, we introduced the weight problem from a different perspective (Pickar et al., 2019). This case study examines macro-level F-35 schedule issues from the system dynamics perspective.

Schedule Problems

The F-35 program has experienced significant schedule problems since its inception. The original schedule for the system development and demonstration phase was to complete the initial operational test and evaluation by 2012 and to achieve the initial operational capability by 2013. However, the schedule has been repeatedly revised and extended due to various technical, operational, and political factors. Factors affecting the schedule include the technical complexity of the aircraft and uncertainty associated with the operational and political environment. From a technology perspective, the F-35 is a highly complex and sophisticated system incorporating advanced technologies such as stealth, sensor fusion, and network-centric warfare. It must also meet the diverse and demanding requirements of the different variants and customers. The F-35's technical complexity has resulted in numerous design changes, software issues, testing challenges, and reliability problems, which have caused delays and rework in the development and production processes.

Operational uncertainty reflects the dynamic complexity and uncertain tactical environment the aircraft operates in, as well as the constantly evolving threats, missions, and scenarios project management must address daily. The F-35 also must adapt to the changing needs and expectations of domestic and international customers, who may have changing operational priorities, preferences, and constraints. The operational uncertainty of the F-35 has resulted in frequent requirement changes, specification revisions, and performance trade-offs, which have increased the scope and complexity of the development and production processes. More specific schedule delay issues are associated with TR-3 upgrades, simulator development, and Block 4 modernization. All these issues are potential rework problems.

Rework is a cycle of corrective actions or changes within a project involving feedback effects, knock-on effects, and implications for project management (Rahmandad & Hu, 2010). Rework issues in the F-35 development are omnipresent. These include seemingly



simple problems, such as the prime contractor installing a valve backward, as recounted in this script excerpt from the CBS *60 Minutes* program, broadcast on February 16, 2014. The scene is a morning staff meeting between the F-35 Program Executive Officer (PEO), LtGen Chris Bogdan, and his staff (Walsh & Martin, 2014).

CBS 60 Minutes, 02/16/2014

“Lt. Gen. Chris Bogdan is the man in charge of the F-35 and every morning starts with problems that have to be dealt with ASAP. This morning it’s a valve that’s been installed backwards and has to be replaced.

Chris Bogdan: How long does it take?

Answer: It’s about a seven-day operation.

Chris Bogdan: OK. And now you know what I’m going to say next.

Answer: Yes sir.

Chris Bogdan: What am I going to say next?

Answer: You’re going to say, “We’re not going to pay for it.”

Chris Bogdan: That’s right. We’re not going to pay for it.

Chris Bogdan: Long gone is the time where we will continue to pay for

No one would fault the PEO for focusing on the costs associated with the rework necessary to fix the valve issue. However, while cost is a consideration, the schedule implications of this rework issue were equally important. We learned that the rework associated with this effort added approximately six months to that development phase. The impact of the ripples caused by the rework, the other activities that needed to stop while this fix was installed, and the downstream delays throughout the development are unknown. In system dynamics, this phenomenon is called firefighting³ (Novak & Levine, 2010).

From a schedule perspective, the central issue is whether the project management office (PMO) considered schedule impacts when this issue surfaced. The PMO was focused on cost, which is unsurprising as cost is the most critical consideration for DoD PMs. Here is where the action-reaction-counteraction heuristic can help to identify downstream problems.

The F-35 Weight Problem

The F-35’s weight problem can be traced back to its inception, when the program aimed to develop a common platform for three variants: the F-35A for conventional takeoff and landing (CTOL), the F-35B for short takeoff and vertical landing (STOVL), and the F-35C for carrier-based operations. The common platform was intended to reduce

³ Firefighting is a term used in system dynamics to describe a situation where a problem is temporarily solved by applying a quick fix, but the underlying cause is not addressed, and the problem reappears or worsens over time. Firefighting often leads to a vicious cycle of increasing complexity, unintended consequences, and escalating costs. An example of firefighting is using overtime or hiring temporary workers to meet a surge in demand but neglecting to improve the production process or capacity. Firefighting can be avoided or reduced by applying a systems thinking mindset, which is essential for avoiding firefighting and achieving long-term goals.

development and production costs and increase interoperability among the partner countries. However, the common platform also imposed significant design constraints and trade-offs, especially for the F-35B, which required a complex and heavy lift system to enable vertical landing.

According to a report by the Government Accountability Office (GAO), the F-35 program faced a “mismatch between aircraft weight and available engine thrust” since its early stages, and the F-35B was the most affected variant (GAO et al., 2005). The report stated that the F-35B had a low weight margin of 2%, meaning that any increase in weight would hurt its performance and requirements. The report also noted that weight reduction efforts necessitated an 18-month delay (GAO et al., 2005).

The F-35 weight problem emerged in the early 2000s when the aircraft was still in the concept demonstration phase (Tirpak, 2006). The initial weight target for the F-35 was 30,000 pounds, but by 2003, the aircraft had grown to 35,000 pounds, and by 2004, to 36,000 pounds. The weight problem severely affected the F-35’s performance, stealth, and safety. A heavier aircraft requires more fuel and thrust, reducing its range, maneuverability, and payload. It would also generate more heat and radar signatures, compromising its stealth and survivability. Moreover, a heavier aircraft would pose more significant risks of structural failure, especially for the STOVL and CV variants, which had to endure harsher landing conditions.

The Weight Solution

The Pentagon and Lockheed Martin recognized the F-35 weight problem as a significant threat to the program’s success and viability. In 2004, the Pentagon initiated a comprehensive review of the F-35 program, known as the Joint Estimating Team (JET; Pappalardo, 2006). The JET concluded that the F-35 needed to shed at least 2,000 pounds to meet its performance and stealth goals. The JET recommended management and engineering changes to improve the program’s oversight, accountability, and efficiency.

In response to the JET’s findings, Lockheed Martin launched a weight reduction campaign known as the Weight Attack Team (WAT), which involved hundreds of engineers and managers from across the company and its subcontractors. The WAT adopted a rigorous and systematic approach to identify and eliminate unnecessary or excessive weight from every part and system of the F-35. The WAT used various tools and techniques, such as computer modeling, simulation, testing, and prototyping, to evaluate each design decision’s weight, cost, and performance trade-offs. The WAT also implemented a culture of weight consciousness and discipline, encouraging innovation, collaboration, and communication among the F-35 team members (Pappalardo, 2006).

The WAT’s efforts seem to have paid off, as the F-35 shed about 2,700 pounds by 2006, exceeding the JET’s target. The weight reduction was achieved by making numerous changes to the F-35’s design, such as using lighter materials, optimizing the shape and size of the components, simplifying the wiring and plumbing, and eliminating or consolidating some of the features and functions.

Notwithstanding the success of the WAT efforts, the F-35 program continues to address the weight problem through various measures, such as weight reduction initiatives, engine upgrades, and operational adjustments. The F-35’s weight problem is a complex and persistent issue that has affected its performance, cost, and competitiveness. However, the weight problem remains a significant challenge and a source of controversy for the F-35 program. The schedule impacts of the weight issue are still being felt.



The SAWT-driven changes to the design and assembly of the aircraft are estimated at \$4.8 billion. This is part of a \$6.2 billion replanning to accommodate the additional design cycle required to make the improvements. The replanning caused an 18-month schedule delay in F-35 deliveries (Pappalardo, 2006). The work to reduce the weight of the F-35B also improved the designs for the other variants. However, much of the already completed engineering and manufacturing work had to be redone, causing years to be added to the schedule.

Case Study: Peace Shield

The Gulf War of 1990–1991 exposed the vulnerability of Saudi Arabia’s air defense system, which was largely dependent on the U.S.-led coalition forces. The war highlighted the need for a robust and coordinated air defense system that could cover the vast and diverse terrain of Saudi Arabia. The Saudi government pursued a long-term strategic partnership with the United States to upgrade and modernize its air defense system. The United States agreed to provide Saudi Arabia with the latest technology, expertise, training, and maintenance support. The original Peace Shield Program (Peace Shield) was a large-scale air defense system project to design, develop, and test ground-air defense systems for the Saudi Air Force (Sciolino, 1985). The program aimed to modernize and integrate the existing Saudi air defense network with new radars, command and control centers, communication systems, and missile batteries. The overall program was initiated in 1984 and completed in 1996, costing more than \$9 billion (Kausal IV, 1996).

Boeing was awarded the original Command, Control, Communications, and Intelligence (C3I) Peace Shield FMS contract in 1985. The C3I contract was expected to be completed in 1992, with the entire network planned to be fully operational by 1994. However, software integration problems caused significant delivery delays. Among other issues, Boeing significantly underestimated the cost and schedule of the project. In November 1989, the U.S. Air Force issued a cure notice to Boeing with a deadline of December 1989. Initially, the Air Force accepted Boeing’s proposed solution. However, delays continued, with the completion estimate pushed into August 1994 (the original contract’s completion date was April 1991). Boeing’s original delivery schedule of 39 months had extended to 92 months. The Air Force terminated the Boeing contract for default in 1991 (Kausal IV, 1996).

In May of 1991, Pugh-Roberts/PA Consulting (PA) provided proposal support for Hughes to bid on the former Boeing part of the Peace Shield program. PA already had extensive experience in developing program management-based system dynamics models. Key personnel of the PA organization had written about the concept of rework in 1993 (Cooper, 1993a, 1993b, 1993c; Lyneis et al., 2001). Working closely with Hughes’s managers, the PA team modified a model they had previously built to support what would turn out to be the winning bid. The model showed that with careful management, staffing, and execution, Hughes could deliver in 54 months. While the Air Force FMS Program Office was skeptical of the Hughes 54-month timeline based on their experience with Boeing, the Air Force awarded Hughes Aircraft a contract of \$837 million in July 1991 (Kausal IV, 1996). The contract required Hughes to deliver the processing, displays, and communications equipment throughout Saudi Arabia and provide various equipment and software in 54 months (Forecast International, 2003).

During the execution of the contract, Pugh Roberts/PA Consulting advised Hughes during the program execution using the system dynamics model developed for the proposal. The model was based on the rework cycle and provided planning and execution support during the contract performance period (Lyneis et al., 2001). A central aspect of the model



was the software development, which would be “lifted” (reused) from a previous program. The reuse significantly reduced schedule risk.

Given the program’s history to that point, the Air Force offered significant cost and schedule incentives. The contract had a cost and schedule incentive that offered a \$50 million bonus for a three-month early delivery and a \$50 million penalty for a late delivery (Kausal IV, 1996). Hughes decided to provide 40% of that \$50 million contract incentive to incentivize employees (Kausal IV, 1996). The execution was flawless, and Peace Shield was delivered six months and 13 days ahead of schedule and below cost, a clear win for the Kingdom of Saudi Arabia, the U.S. Air Force, Hughes, and their employees.

The program was successful for three essential reasons. First, a Hughes unique “teaming” process provided more oversight and more frequent reviews. This oversight process was simulated in the system dynamics model. Although there was a short-term disruption in the work, the process yielded increases in quality, thus resulting in less rework (Lyneis et al., 2001). The second reason was staffing. Usually, staff doing those tasks would be reassigned as soon as tasks are finished. Instead, the typical “roll-off” of staff, especially software engineering staff, was slowed. This provided a personnel buffer to deal with rework issues that would otherwise add significant time to the schedule. The final reason was the overall approach to the project. From the beginning, Hughes worked with PA to plan and execute Peace Shield in a systems fashion, using system dynamics simulations to test various approaches. This system approach provided visibility from start to finish and allowed managers to anticipate problems before they became overwhelming.

This section examined the criticality of understanding project dynamics in schedule execution in weapon system development projects. The F-35 and Peace Shield case studies provided examples of the importance of realizing that a weapon system development project is a system and that there are feedback effects at work in our programs with rework and its impact on project cost, schedule, and performance of the system being predominant. The F-35 and the Peace Shield case studies also highlight the challenges of recognizing the complex and dynamic forces in our weapon system developments. Finally, a systems approach to project management provides valuable insights into the systemic causes and consequences of rework, enabling organizations to make more informed decisions and implement effective strategies for its prevention or mitigation.

Improving Information Quality: The “Wise Crowds” Proposition⁴

Executives know . . . valuable information is scattered across the organization. They just don’t know how to retrieve it (Thompson, 2012, 1).

Managing complex, imperfectly understood systems (like defense acquisition programs, entails information that encompasses a broad perspective. We believe a good understanding of System Dynamics coupled with a solid working knowledge of data science⁵ is helpful for understanding that sort of information.

But that does not constitute a panacea. Information distilled into databases has at least two difficulties. First, those data sets are structured to answer (perhaps implicitly) specific questions. It may well prove difficult to use that data to answer new questions.

⁴ Our paper proposal promised a “deeper dive” into prediction markets (subject, of course, to editorial constraints). Building upon our previous work in this area (summarized here), we consider issues relevant to using prediction markets as tools for practicing program managers. Hence, our extensive references to Thompson (2012).

⁵ As discussed for example, in Pickar and Franck (2021).



Second, distilled databases are generally assembled at the cost of some helpful information.⁶

Distilled data can take information out of context and distort meaning (Nguyen, 2024). In many cases, there is no substitute for local knowledge. We assert that tools such as prediction markets have significant potential to aggregate information in ways that exploit local knowledge to enhance program management.

In this section, we continue our previous inquiries regarding prediction markets as a potential method to predict emerging problems in defense acquisition programs. If adverse developments can be expected and lead to actionable information⁷, management would be better equipped to mitigate those effects (making program schedules more resilient).

Substantial experience supports the hypothesis that estimates from a group can be more accurate than, say, expert judgments. On the other hand, groups can be spectacularly wrong—e.g., financial bubbles, long-shot winners, and black swans.

A framing assumption for groups being collectively wise (potentially) is that every member has private information. Each person's information includes insights and errors (of various kinds).⁸ In a "proper" group setting, the (private) errors across the group tend to cancel out in the collective opinion, while the private sets of information add to the quality of that opinion (Surowiecki, 2004, pp. 10, 41). For example, Hayek (1945/1971, pp. 17, 19–23) and Smith (1776/1937, pp. 13–16) discuss the ability of a crowd of market participants to reach a beneficial economic equilibrium.

Various lines of inquiry have identified **characteristics of "wise crowds."**

- Cognitive diversity is formed in good part by the heterogeneity of private information. Insufficient "cognitive diversity" can lead to "groupthink" and associated pressures to conform (Surowiecki, 2004, pp. 23, 38).
- Independence of members promotes a diversity of errors in the sets of private information, which are more likely to be canceled out.
- Decentralization (in an organizational sense) can foreclose the tendency of hierarchies to filter out information and judgments at lower levels.
- Aggregation produces a collective assessment related to the entire group, which can lead to an evaluation, forecast, or decision. Aggregating a group's collective "wisdom" implies a method other than hierarchical screening, such as prediction markets.

Prediction Markets

"The advantage of prediction markets is that they can benefit from the wisdom of crowds. By collecting and weighing the predictions of a large number of traders, they can provide a market-wide forecast that is generally more reliable and balanced than any single expert opinion" (Peters, 2022).

Even with a wise crowd, designing a well-functioning prediction market is easier said than done—even with the substantial body of research and experience available.

Self-Fulfilling or Self-Negating Group Predictions: For example, a group prediction of an untoward acquisition program event can lead to management actions to prevent that

⁶ E. B. White (1938) provides an interesting (albeit overstated) view of the pitfalls of distilled data.

⁷ Joseph and Sconion (2020) offer an interesting perspective regarding this issue.

⁸ One can view each set of private information as having two components: useful knowledge and errors, without individuals being aware of how their private information is divided between those components.



event. That is, the group's assessment could be self-negating. This accordingly complicates determining the winning bets.

Positive and Perverse Incentives: Prediction markets look like and can operate like betting markets. As such, there can be incentives to engineer a favorable outcome, which has happened in sports betting markets. This problem can be addressed by limiting the size of the wagers. On the other hand, motivated participation is essential, and this can be addressed by increasing the stakes. However, motivating traders through increased stakes might be substantial incentives to be correct, with the associated potential for perverse incentives (for the enterprise the prediction market is intended to enhance).

Definition of Outcomes: Typically, prediction markets focus on well-defined binary outcomes (like win or lose) that occur at a definite time. But what happens if the outcomes are more complicated?⁹ Suppose a wise group identifies an emerging problem in an acquisition program (such as a schedule slip). Suppose that alerted program management also undertakes a remedy that averts the crisis.¹⁰ How do the prediction market rules determine the winner?

One way around this problem is to have more complicated results. For example, group members could choose an outcome in perhaps two parts. "Asking 'If this, then what?' questions usually involve a prediction market with two complementary questions: 'How much will x be if y occurs?' and 'How much will x be if y does not occur?'" (Thompson, 2011, pp. 20–21).

Another obvious issue is that acquisition programs (especially MDAPs) are lengthy and have uncertain termination or milestone dates. Defense acquisition prediction markets operating arena will likely need special care in framing the questions upon which to place bets.

Potential Pitfalls in Structuring a Prediction Market

Organizational Culture: As Thompson (2012, p. 10) put it, "The key to success of the company's prediction process is their corporate culture." Grafting a prediction market into a hierarchy of risk-averse participants is likely to encounter substantial difficulties (Thompson, 2012, p. 180).

Posing Useful Questions: What questions apply to program management, and how should they be identified? This is one major issue related to organizational culture. Should the questions be posed by program leadership (who may be blissfully ignorant of emerging problems) or "bubble up" from the workforce? If the latter, how are the best questions identified, and how is a consensus about "good" questions formed? Previous experience indicates "good" questions improve the performance of prediction markets (Almenberg et al., 2009). This seems to be a significant issue related to organizational culture and its receptiveness to bottom-up modes of operation.

Manipulating Prediction Market Outcomes: Large, strategically-placed bets can significantly affect the market outcome—somewhat like a short-sales campaign to influence stock market prices. The counterargument is that such actions motivate other prediction market participants to negate those effects (Thompson, 2012, pp. 22–23). As recent

⁹ Almenberg, et al. (2009) note this to be a major issue for prediction markets involving questions of scientific research. It's reasonable to suppose that this is also an issue for technical endeavors such as major defense programs.

¹⁰ Not so far-fetched. Miller (2012, pp. 48–49) offers a method which can yield actionable indication of an emerging problem in acquisition programs. It's therefore reasonable to suppose that prediction markets could also provide similar warnings.



experience (Ramkumar, 2024) indicates, manipulating markets (in general) with broader objectives in mind can take on some fascinating forms.

Manipulating Events: This is arguably the most severe potential pitfall. If prediction market results are accepted as credible, and if the market attaches a high probability to an “If x, then y” bet, then an agent (market participant or not) who cared deeply about y could be (perversely) incentivized to take unusual steps to assure x happened.¹¹

Legal Complications: These include the following (Thompson, 2012, p. 223–227):

- running afoul of a rather complicated structure of gambling prohibitions at various levels of government;
- potential susceptibility to outcome manipulation through illegal means, and;
- potential to facilitate insider trading (in other markets).

Information Issues and Market Functioning: If little reliable information is available to the market participants, there is not much useful information to aggregate. Accordingly, those participating are more likely to offer guesses than considered assessments (Thompson, 2012, p. 209).

Comments on Prediction Markets

There seems to be a sweet spot for prediction markets in which (a) the participants collectively (but not individually) possess sufficient information and (b) a question not readily solved with specialized (expert) skills.

However, transplanting the prediction market model is easier said than done. The DoD is a top-down organization with members who are generally risk-averse. Potential applications in a DoD context have not been widely explored. The issues and problems raised here are hypotheses warranting further inquiry, including practical experience and lessons learned.

Concluding Comments

As with our multi-year schedule research inquiries, this paper is about improving the state of the art for estimating and executing defense acquisition program schedules and making them more resilient to unforeseen events. This year’s focus has been on the role of system dynamics and prediction markets in managing complex projects. The case studies provide examples of the criticality of understanding the system forces at work and that, while essential, cost and technical responses can fail to address the entire problem. There is potential for prediction markets to improve schedule information quality. We believe prediction markets, mechanisms that aggregate the opinions and information of many participants to produce forecasts or decisions, may provide valuable insight into the mechanics of the system that is a weapon program.

In conclusion, this paper furthers our research agenda on schedules and how to make them more resilient to unforeseen events (and what to do when resiliency isn’t enough). Systems approaches, case studies, and consideration of prediction markets to improve information quality offer insights into managing complex projects. Understanding the art and science of planning and executing weapon system acquisition schedules is fundamental to delivering systems on time.

¹¹ For example, A prediction market in 2004 gave George W. Bush a 91% chance of reelection if Osama bin Laden were caught, and 67% if not (Thompson, 2012, p. 53). The Bush Administration was, in effect, incentivized to assign an increased (and possibly ill-advised) priority to capturing him. Almenberg et al. (2009) also note the adverse possibilities of strategic behavior.



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Timeboxed Earned Schedule Approach (TESA): An Innovative Framework to Program Schedule Management for Programs within OTAs

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Abstract

Use of Other Transaction Authority (OTA) vehicles helps accelerate research and development (R&D) of prototype technologies for government entities. However, OTA is not subject to Federal Acquisition Regulation (FAR) performance reporting requirements. This increases the potential for cost and schedule performance risk. To reduce this risk, the Office of Naval Research (ONR) Code 34 Force Health Protection portfolio is leveraging an innovative timeboxed earned schedule approach (TESA) to program schedule management that provides performance situational awareness without impeding the benefits of OTA for streamlining research and development.

TESA appropriates concepts from Agile project management and earned value analysis to provide a schedule performance monitoring protocol across multiple programs, projects, and performers. The approach retains EV's cumulative performance analysis benefits for evaluating schedule accomplishment across multiple efforts and accommodates different audience summarization needs at a variety of abstraction levels.

Introduction

The Navy's Future Naval Capability (FNC) program seeks to accelerate the transition of Office of Naval Research (ONR)-developed solutions to the fleet. To overcome collaboration and transition barriers, government research and development (R&D) programs may leverage OTA vehicles to support the development of prototype technologies. Not being subject to the FAR, OTA accelerates R&D by permitting use of commercial-like, negotiated agreements that can be awarded in 90 days or less; allowing highly flexible use of intellectual property; and promoting unique public/private partnerships to achieve program objectives.

However, the extent to which OTA is not subject to the FAR also includes performance reporting requirements (e.g., schedule, cost, and technical progress) wherein "there could be little, if any, performance reporting required" (Office of the Under Secretary of Defense for Acquisition and Sustainment [OUSD A&S], 2023, p. 27). This aspect of OTA offers potential risk in the form of "diminished oversight and exemption from laws and regulations designed to protect government and taxpayer interests" (Congressional Research Service, 2019, p. 8).



OTA's characteristic tension between the benefit of accelerated development and the potential for risk from diminished oversight requirements prompted interest in a simple Earned Value (EV)-like program schedule management approach that would provide schedule progress insight with minimal imposition on performers, beginning with initial implementation within two ONR Code 34 (Warfighter Performance) R&D programs. This paper describes the problem (e.g., desired outcomes, constraints), the approach undertaken to address the problem's facets, and the result of the TESA that was quickly devised and implemented within a few weeks to address program schedule control interests.

The Problem

Responses to professional practice problems must not only satisfy the desired outcomes; they must also contend with constraints that limit the range of response options. With respect to desired outcomes, a capability was sought to systematically answer these typical schedule management questions:

- What is the current schedule performance ...
 - summarized across the overall perpetual portfolio of programs and projects?
 - summarized across the projects constituting a respective program?
 - summarized by each performer's project(s)?
 - evaluated for each task specified in a respective Statement of Work (SOW)?
 - summarized by alternative decomposition hierarchies (e.g., technology architecture roadmap, integrated master plan)
 - What are the implications of the longitudinal performance trends at any of these respective levels of summarization (e.g., prognostication, schedule recovery realism)?
- Which activities are contributing to significant variances, the insight to which can facilitate remediation conversations (e.g., corrective actions, warranted replanning)?
- What is the characterization of actual cost expended relative to planned cost? What has been spent? What remains to be spent?

Although a conventional EIA-748 EV management approach (National Defense Industrial Association, 2018) seems suited to answer the preceding questions (especially those requiring alternative summarization hierarchies), the following constraints limited the schedule control approach options due to the nature of the R&D program contracts and budget:

Negligible obligatory reporting requirements – The statements of work (SOWs) only require performers to provide quarterly progress reports in the form of narrative presentations or reports. Enlisting performer support for complex program/project management (PPM) controls and reporting not specified in the SOW might prove difficult.

Availability of limited schedule information – The available schedule information might best be characterized as, “Here are the high-level tasks to be completed to receive payment for a respective milestone.” The schedule information in the SOWs is typically limited to the identity and description of Level 1 tasks and, in some instances, Level 2 tasks. The SOWs also include tables specifying payment milestones with corresponding dollar amounts and anticipated delivery dates. Although the payment milestone information includes designation of requisite tasks,



thereby signaling at least a deadline finish date for each task, no task start date information is available.

Costs are allocated to SOW-specified payment milestones but not SOW-identified tasks

– This condition affects the resolution of cost distribution with respect to time on which a conventional EV management approach relies. For example, suppose a payment milestone with a designated value of \$1.5 million is scheduled for delivery at “project start plus three months.” Since there is no reasonable means for arbitrarily distributing that cost to that milestone’s requisite tasks specified in the SOW, the resultant cumulative *Planned Value* plot is too coarse to provide sufficient resolution for schedule control. In this example, the cumulative *Planned Value* would be zero for the first 3 months of that project, negating evaluation of whether the project is “on schedule” during that time interval.

Diversity in performers’ schedule management practices and maturity – One example of schedule management practice diversity is the variation observed in performer-level schedule progress reporting cadences. Performers’ status reporting cycles for their operational control varies by organization (e.g., weekly, bi-weekly, mid-month, month-end, 27th day of the month).

Regarding practice maturity, although some performers appear to exhibit schedule management rigor suitable to the context of their respective projects (based on conversations with some of the principals responsible for PPM controls), other performers rely on subjective characterization of progress (e.g., “Progress towards realization of milestone X is approximately 45% complete”).

No established schedule information protocols – The SOWs contain no prescription of obligatory schedule information protocols (e.g., data elements, format and electronic sharing of schedule management artifacts). The combination of the aforementioned diversity in performers’ schedule management practice maturity in conjunction with the prospect of reasonable performer concerns about disclosure of proprietary R&D methods as may be reflected in their schedule management artifacts constrains employment of a portfolio/program schedule management approach that would need to rely on sharing of Performer schedule management artifacts.

Need immediacy – Although operational protocols for cost management were already in place, the need to implement a capability to systematically answer the previously discussed schedule management questions was immediate; the programs and projects were already in progress.

In summary, a schedule management approach capable of providing answers to schedule management questions needed to honor the aforementioned constraints. Furthermore, simplicity would be necessary to move quickly and elicit support for an approach for which performers had no SOW-specified obligation.

The Approach

One of the dilemmas in formulating a suitable schedule management approach is that neither the schedule management literature nor the practice standards in project management professional societies’ bodies of knowledge (e.g., PMI, IPMA, AACE International) provide prescriptive guidance wholly sufficient to address the programmatic needs and constraints. For example, although one might presume that uniform prescriptive guidance exists for practices like an Integrated Master Schedule (IMS), “one box does not fit all” situations. As the Department of Defense (DoD; 2023) noted, “The IMP [Integrated Master Plan] and IMS should be tailored and scaled according to the size, content, maturity,



and risk of the project” (p. 9). Ultimately, practitioner discretion shapes the tailoring decisions to fit the practice context.

In lieu of limited literature guidance, the needs and constraints of the R&D programs necessitated a reflective practice response (Schön, 1983) characteristic of the “rethinking project management” (RPM) school of thought (Winter et al., 2006). The RPM movement advocates that the approach for addressing a particular PPM practice situation emerges from rigorous adaptation of the current body of knowledge to the unique context of that situation (Remington & Pollack, 2011).

This section describes the approach that resulted in the formulation of TESA. The first subsection presents a conceptual framework borne of reflective practice that informed TESA along with the supporting rationale. The remaining subsection discusses the employment of TESA (i.e., practical application).

Conceptual Framework

Earned Schedule

The need to summarize schedule performance at a variety of abstraction levels, including support for alternative summarization hierarchies (e.g., technology architecture roadmap), warranted consideration of a cumulative EV-like approach. To realize that outcome, TESA uses cumulative EV mechanics wherein the evaluation is focused on the abscissa temporal relationship between cumulative *Planned Value* (PV) and *Earned Value* (EV).

In an example illustrated by Figure 1, the cumulative EV noted for the Status Date should have been achieved at the earlier date identified by the equivalent cumulative PV. Since the X-axis is delineated in temporal units of measure (i.e., days, weeks, months), the offset between the current cumulative EV and the equivalent cumulative PV indicates the number of days the project is ahead or, in the case of the example depicted in Figure 1, behind schedule.

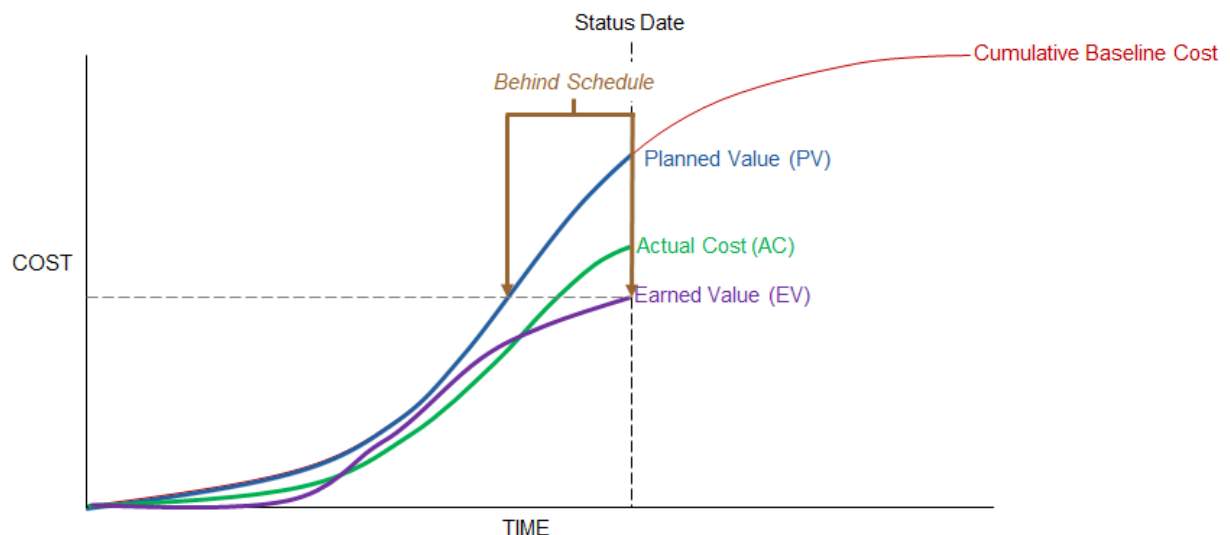


Figure 1. Illustration of the Abscissa Temporal Relationship Between Cumulative PV and EV

The relationship between cumulative PV and EV is well known. This relationship provided the basis for actualizing measurements for an *EV Forecast Finish Date* (Oliver,

1999) and a *Schedule Recovery Date* (Oliver, 2002). Lipke (2003, 2012) proposed formalization of this aspect EV analysis advocating the concept of Earned Schedule (ES), the fundamental tenet of which is illustrated by Figure 2.

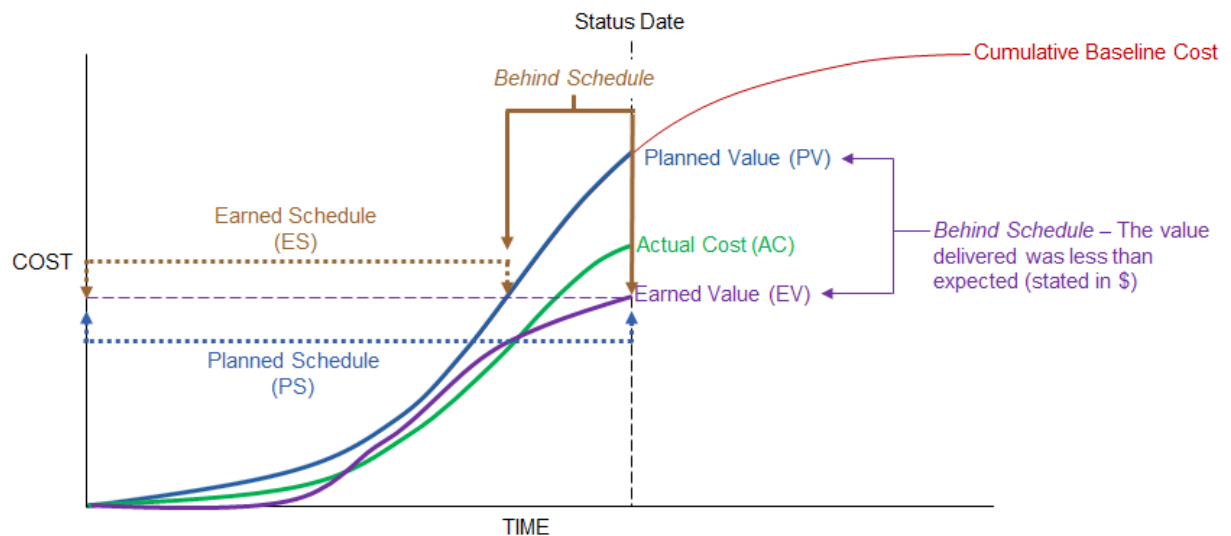


Figure 2. Illustration of Earned Schedule (ES) and Planned Schedule (PS) in Contrast With Conventional EV Schedule Variance

Lipke's work intended to address EV's historic dilemma of expressing schedule performance stated in currency units of measure (i.e., cost) that focused on the ordinate relationship between cumulative PV and EV. For example, suppose that for a respective Status Date, the cumulative PV indicates the project should have delivered \$8,000 of EV. If by that date, only \$6,000 of cumulative EV has been delivered, conventional EV analysis would characterize the project as being "\$2,000" behind schedule. Although the Y-axis offset between cumulative PV and EV does indicate the extent to which a project is ahead, behind, or on schedule, the valuation of schedule variance in terms of "dollars and cents" communicates little about the magnitude of that variance in temporal units of measure (e.g., days, weeks, months). In contrast, ES provides a meaningful evaluation of EV-based schedule performance expressed in temporal units of measure.

Where TESA parts company with Lipke's (2003, 2012) ES approach is the basis for establishing cost. Lipke's cost-basis for ES is situated in cost defined in currency units of measure, but ultimately expressed in temporal units of measure (e.g., days). TESA's contention with two of the previously discussed constraints—availability of limited schedule information and allocation of costs to only zero duration SOW payment milestones—precluded use of currency units of measure as a cost basis.

To address these constraints, TESA proceeded with a reasonable assumption that although the SOWs provide no information about the duration or start and finish dates for each specified high-level task, the performers likely have that information, which would have been necessary to finalize the SOWs. The extent to which this assumption is reliable reduces the likelihood of an implicit constraint about performer concerns of incurring additional overhead work to support new schedule controls not specified in the current SOWs.

Since task duration can be established for SOW-specified tasks, as described in Table 1, TESA used *duration* as an EV cost basis instead of cost stated in monetary units of measure.

Table 1. Characterization of Detail Task PV, EV, and Actual Cost (AC) Based on Task Duration as a Cost Basis

Metric	Characterization
PV (i.e., PS)	PV, when based on Duration as a cost basis, indicates the number of days of task outcome (i.e., planned accomplishment) the task was obligated to deliver by a designated Status Date. For example, suppose that <i>Task A</i> has a baseline duration of 10 days and was scheduled to have started on Monday morning of the current week. As of the Friday “end of day” Status Date in this current week, <i>Task A</i> should have delivered 5 of 10 days of intended task outcome(s). If—for the illustration purpose— <i>Task A</i> was situated in the construction industry and represented the work to complete rough-in electric power distribution to floors 1 and 2 of a building, assuming the goal at the end of week 1 was completion of rough-in for floor 1, the PV (i.e., expected outcome) by the Friday status date is a 5 days of <i>Planned Schedule</i> (i.e., completion of floor 1).
EV (i.e., ES)	EV, when based on Duration as a cost basis, The number of days of delivered task outcome (i.e., actual accomplishment). Continuing with the preceding example, suppose the Actual Start of Task A did not occur until Tuesday morning due to late delivery of materials. If by the Friday status date, an additional remaining duration of 1 day is needed to complete floor 1, the EV (i.e., delivered outcome or <i>Earned Schedule</i>) is 4 days. As the <i>Earned Schedule</i> value of 4 days is less than the <i>Planned Schedule</i> value of 5 days, <i>Task A</i> is 1 day behind schedule
AC	Although TESA’s focus is evaluation of schedule performance, characterization of AC from an ES perspective is warranted. When <i>duration</i> is used as an EV cost basis, AC reflects the passage (i.e., expenditure) of time defined by the interval between a task’s Actual Start and “time now”. Whether used effectively or not, the expenditure of time is ongoing and cannot be halted. Continuing with the previous example, although the task is behind schedule, the 4 days of ES has an AC of 4 days; the task is on budget from a duration-based cost perspective. Upon eventual task completion, AC equals Actual Duration.

TESA’s utilization of duration as an EV cost basis is not without support. In recounting use of alternative EV cost bases (e.g., effort hours, binary) for several thousand projects within a global IT system integrator’s portfolio, Peterson and Oliver (2001, Application section, para. 2) observed:

Granted, the earned value methods exercised on this project would not satisfy either the Full/DOD or ANSI EV implementation levels. They neither adhere to DOD prescriptions for reporting and auditing, nor would they satisfy all 32 ANSI earned value criteria. However, with at least the Level 3/EV-Lite approach, the BCWS, BCWP, and ACWP developed at each reporting were no different at the project level than they would have been with the full rigor of either Full/DOD or ANSI-compliant approaches. Furthermore, this was accomplished with minimal overhead. In fact, the actual evaluation of EV performance with EVAnalyzer [Oliver, 1999] is done with one click of a button. If the overall intent for developing EV information is project control, does the rigor of Full/DOD or ANSI matter, particularly when the resulting control information, available for management decision-making, is the same?

Khamooshi and Golafshani (2014), who further explored the implications of ES (Lipke, 2003, 2012), advocated use of duration as an EV cost basis for evaluation of schedule performance:

overemphasis on EVM and using cost as a proxy for schedule performance could provide misleading information to the project team in assessing the schedule.



Therefore, to provide more accurate performance measures there's a need to decouple the schedule and cost dimensions. With that in mind, we developed the following *duration-based* [emphasis added] performance measures along with their analogues EVM (cost-based) counterpart measures to more accurately present schedule and cost status. (p. 1023)

Agile Timeboxing

In the conception of TESA, observations of Agile practice warranted consideration to address initial concerns about task duration granularity for SOW tasks with durations potentially spanning more than two reporting periods. Barring use of alternative progress evaluation metrics (e.g., a task entailing repetitive activity of similar durations like “install a new entry doorknob for each of 220 hotel rooms” wherein each installation instance likely requires the same duration, and therefore the number of completed rooms can serve as a measure of schedule progress), schedule management professionals ideally prefer that the final disposition of a detail task be known by no later than the subsequent reporting period. This reduces the likelihood of repeated subjective assurances from task owners across multiple reporting periods that task progress is on schedule.

Thus far, the typical TESA reporting interval has been monthly. Therefore, the ideal maximum duration for any detail task (i.e., a task at the lowest level of detail that is not further subdivided into additional subtasks) should not exceed 2 months.

Since some of the tasks specified in the SOWs were observed to likely have durations spanning more than two reporting periods, the initial conception of TESA proposed the use of timeboxing, appropriated from Agile's sprint concept, wherein project work is apportioned into a consecutive series of fixed duration timeboxes. For example, Figure 3 illustrates decomposition of a fictional SOW payment milestone (i.e., MS 1) into three 10-day duration consecutive timeboxes wherein the start date of the first timebox reflects when work in support of MS 1 will commence and the finish date for the final timebox concluding on the planned MS 1 completion date.

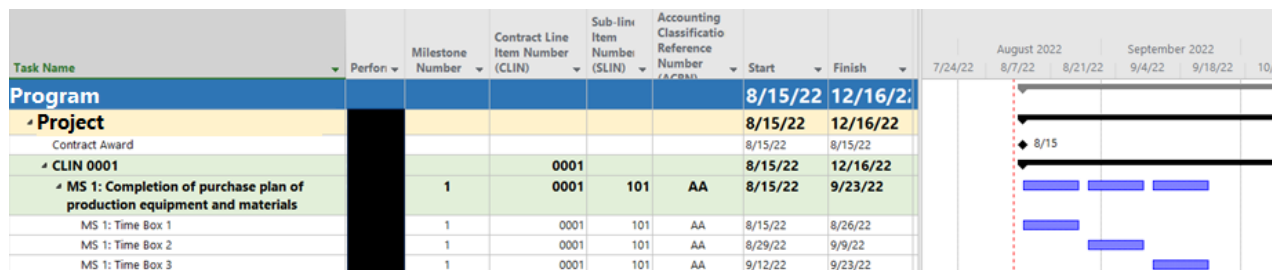


Figure 3. Illustration of Payment Milestone Timeboxes

The proposed approach for TESA arbitrarily proposed that one to five objectives be defined for each timebox. These objectives serve as criteria for establishing what Agile practitioners call “done-done” (i.e., exit criteria signaling whole completion of the timebox).

Although use of uniform consecutive timeboxes with designated objectives remains a useful option for TESA (hence retention of that term in the approach name), in practical application, conversations with performers revealed their preference for using SOW-specified requisite tasks for the respective payment milestones as timeboxes, despite some of those tasks spanning more than two reporting periods. The rationale for this modification is situated in performers' routine familiarity with summarizing their progress to the high-level SOW tasks for narrative status briefings. Thus far, despite tasks with durations spanning

more than two reporting periods, TESA seems sufficient for answering the previously discussed schedule management questions.

Schedule Artifact Characterization

As illustrated by Figure 4, although the TESA schedule artifact serves the purpose of an IMS, clarification of its nature is warranted due to the various mental models regarding the IMS construct that are often informed by visions of an overarching master schedule that includes *all* tasks from every constituent project schedule. Although this vision shaping expectations of IMS constitution has been observed in some large monolithic programs within the defense and aerospace industries wherein the IMS owner can enforce uniform schedule management protocols, the literature is relatively silent about the extent to which such approaches constitute best practice for all situations. Furthermore, advocacy that the IMS be representative of *all* activity does not require that every detailed task be in a singular schedule artifact. Barker (2014) noted:

The PMO IMS does not need to be huge, but it should “pull” information that enhances the government PM’s SA [situational awareness] at any given time. A contractor might produce a 15,000-line schedule in order to cover its contract scope and associated tasks, but the associated government PMO IMS might only be 200 to 300 lines. A PMO IMS might expand in some sections to provide detailed insight into high risks but remain more general for low-risk areas. It will also expand and contract in size over time as the program evolves. External events or inputs that might influence the program are always included, along with key risk-handling efforts and decision points. (p. 22)

Task Name	Performer Status Date	Planned Schedule (PS)	Earned Schedule (ES)	PPC%	PC%	SP(%)	TSPI(es)	SV(es)	ES Forecast Finish	Baseline Cost	Cumulative Invoiced	Remaining Available (to invoice)
Portfolio	NA	6238 days	7085.11 days	57.16	64.92	1.14	0.82	-847.11 days	5/13/25	\$47,489,876	\$32,499,776	\$14,990,100
Program	NA	6238 days	7085.11 days	57.16	64.92	1.14	0.82	-847.11 days	5/13/25	\$47,489,876	\$32,499,776	\$14,990,100
Project A	4/23/23	1906 days	1906 days	100	100	1	0	0 days	NA	\$18,984,876	\$18,984,876	\$0
Project B	1/24/24	4332 days	5179.11 days	48.09	57.49	1.2	0.82	-847.11 days	6/4/25	\$28,505,000	\$13,514,900	\$14,990,100
Contract Award	1/24/24	0 days	0 days	100	100	1	0	0 days	NA	\$0	\$0	\$0
Phase 1:	1/24/24	4321 days	5167.01 days	56.81	67.93	1.2	0.74	-846.01 days	6/14/24	\$22,485,000	\$13,514,900	\$8,970,100
1.1	1/24/24	3457 days	4106.59 days	54.76	65.05	1.19	0.77	-649.59 days	7/8/24	\$17,970,000	\$11,483,150	\$6,486,850
1.1.1	1/24/24	289 days	374.5 days	54.84	71.06	1.3	0.64	-85.5 days	4/2/24	\$1,806,000	\$1,210,020	\$595,980
1.1.1.1 - Design Initiation	1/24/24	22 days	22 days	100	100	1	0	0 days	NA	\$90,300	\$90,300	\$0
1.1.1.2 - Design Parts Re	1/24/24	70 days	70 days	100	100	1	0	0 days	NA	\$577,920	\$577,920	\$0
1.1.1.3 - Design Fabricat	1/24/24	130 days	130 days	100	100	1	0	0 days	NA	\$541,800	\$541,800	\$0
1.1.1.4 - Test Report	1/24/24	67 days	152.5 days	21.97	50	2.28	0.64	-85.5 days	7/22/24	\$595,980	\$0	\$595,980
1.1.2	1/24/24	288 days	307.7 days	54.75	58.5	1.07	0.92	-19.7 days	10/22/24	\$602,000	\$403,340	\$198,660
1.1.2.1 - Design Initiation	1/24/24	22 days	22 days	100	100	1	0	0 days	NA	\$30,100	\$30,100	\$0
1.1.2.2 - Design Parts Re	1/24/24	69 days	69 days	100	100	1	0	0 days	NA	\$192,640	\$192,640	\$0
1.1.2.3 - Design Fabricat	1/24/24	65 days	65 days	100	100	1	0	0 days	NA	\$180,600	\$180,600	\$0
1.1.2.4 - Test Report	1/24/24	132 days	151.7 days	35.68	41	1.15	0.92	-19.7 days	11/8/24	\$198,660	\$0	\$198,660
1.1.3	1/24/24	288 days	288.49 days	54.75	54.85	1	1	-0.49 days	12/19/24	\$3,010,000	\$2,016,700	\$993,300
1.1.3.1 - Design Initiation	1/24/24	22 days	22 days	100	100	1	0	0 days	NA	\$150,500	\$150,500	\$0
1.1.3.2 - Design Parts Re	1/24/24	89 days	89 days	100	100	1	0	0 days	NA	\$963,200	\$963,200	\$0
1.1.3.3 - Design Fabricat	1/24/24	154 days	154 days	100	100	1	0	0 days	NA	\$903,000	\$903,000	\$0
1.1.3.4 - Test Report	1/24/24	23 days	23.49 days	8.81	9	1.02	1	-0.49 days	12/20/24	\$993,300	\$0	\$993,300
1.1.4	1/24/24	288 days	373.5 days	54.75	71.01	1.3	0.64	-85.5 days	4/2/24	\$602,000	\$403,340	\$198,660
1.1.4.1 - Design Initiation	1/24/24	22 days	22 days	100	100	1	0	0 days	NA	\$30,100	\$30,100	\$0
1.1.4.2 - Design Parts Re	1/24/24	69 days	69 days	100	100	1	0	0 days	NA	\$192,640	\$192,640	\$0
1.1.4.3 - Design Fabricat	1/24/24	130 days	130 days	100	100	1	0	0 days	NA	\$180,600	\$180,600	\$0
1.1.4.4 - Test Report	1/24/24	67 days	152.5 days	21.97	50	2.28	0.64	-85.5 days	7/22/24	\$198,660	\$0	\$198,660
1.1.5	1/24/24	288 days	379.6 days	54.75	72.17	1.32	0.62	-91.6 days	3/13/24	\$301,000	\$201,670	\$99,330
1.1.5.1 - Design Initiation	1/24/24	22 days	22 days	100	100	1	0	0 days	NA	\$15,050	\$15,050	\$0

Figure 4. Redacted Representation of the TESA Management Summary Schedule Artifact

The TESA schedule artifact is perhaps best characterized as a *management summary schedule* providing a level of detail (e.g., contractually-specified major tasks and

milestones) sufficient to enable intended users to understand all aspects of the embodied effort (Fard et al., 2017). It serves as a temporal boundary object enabling different stakeholders to visualize, make sense, monitor, evaluate, and share a common understanding of a complex endeavor (Chang et al., 2013).

Practical Application

As discussed in the previous subtopic, TESA's conceptual framework is situated in an ES time-phased evaluation of cost wherein "cost" is based on the activity durations for consecutive time-boxes or SOW-specified tasks, either of which are designated as requisite activities for respective SOW payment milestones. This subtopic describes how TESA is applied in actual practice with attention given to the enabling technology employed, the processes for schedule development and progress data capture, the performance metrics employed, and some examples of progress reporting.

Enabling Technology

Microsoft *Excel* was initially used during TESA's conceptualization. However, as evident from Figures 3 and 4, Microsoft Project was ultimately chosen for implementation based on the following considerations:

- provision of hierarchical summarization mechanisms, including Project's *grouping* feature for creating a variety of alternative virtual decomposition hierarchies (e.g., technology architecture roadmap),
- availability of temporal data types (e.g., duration, dates) and functions for manipulating those types,
- features for defining TESA's custom calculated fields,
- means for creating custom views leveraging traditional schedule management formats (e.g., Gantt, Task Usage) and facilities for developing custom reports, and
- programmatic access via Visual Basic for Applications to Microsoft Project's time-scaled data object. Although TESA does not presently use this feature of Microsoft Project, eventual use is likely to address tentatively envisioned future reporting needs.

Granted, Microsoft Excel could have been used for implementation. However, substantial work would have been necessary to do so. The choice to use Microsoft Project accelerated TESA's implementation.

Schedule Development Process

The process for incorporating a new SOW-defined body of work in the TESA management summary schedule artifact entails the following steps:

A brief overview of TESA is provided to any Performer lacking prior familiarity with the employment of TESA. The overview is intended to answer questions, clarify intentions, ensure comfort with the approach, and ultimately enlist their support.

The TESA administrator uses a Microsoft Project template based on the TESA management summary schedule to prepare an initial model of the payment milestones and high-level tasks (i.e., timeboxes) specified in the SOW. Although dependencies between tasks and milestones may be used, dependency logic is not required for TESA. Since the overall goal is establishing a baseline for "what's happening when," SOW activities (e.g., tasks, payment milestones) are typically entered as fixed duration events and positioned in time with a *Start-No-Earlier-Than* constraint date.



Note that the rationale for developing the initial schedule model for a new SOW separated from the TESA management summary schedule is to avoid disclosure of information about other programs and performers' projects that are already in the TESA management summary schedule.

The initial schedule model is sent to the Performer for their review and validation.

Upon the Performer's acceptance of the initial schedule model, the TESA administrator adds the information from that model to the TESA management summary schedule and establishes the performance measurement baseline for the newly incorporated information, after which the recurring progress data capture process begins.

Although not discussed as a discrete process, the TESA master summary schedule is always subject to configuration control. All changes to baseline information involve collaboration between the funding organization and the respective Performer(s).

Progress Data Capture

The process for progress data capture requires minimal effort by the performers. The rationale in so doing is to elicit their support for a new schedule management control not specified in their current SOW.

Although the present implementation of TESA utilizes a monthly status reporting cadence, the actual capture date within the month may vary by Performer (e.g., end of the month, mid-month, 27th day of each month). To reduce the Performer burden, TESA's practice is to gather information from each Performer *after* they complete their internal monthly schedule progress evaluation.

For each TESA monthly reporting period, Performers provide answers to three simple questions:

1. Are all objectives for an active task (i.e., timebox) complete? If so, that activity is marked as 100% complete (e.g., task ID 2 named *SOW Task A* appearing in Figure 5). If available, what was the Actual Finish date?

Did work on a new task (i.e., timebox) begin? If so, what was the Actual Start date (e.g., task ID 7 named *SOW Task Q* appearing in Figure 5)?

For any task (i.e., timebox) which previously started and is still in progress:

Progress completion through the Performer's *Status Date* is assumed (e.g., "whatever the Performer planned to accomplish by the *Status Date* is regarded as having occurred") by the TESA administrator and applied, resulting in an auto-calculated update of Actual Duration and by extension, Microsoft Project's %Complete value (i.e., duration completion percentage).

The Performer communicates either an updated forecast Finish date OR the Remaining Duration necessary to complete that activity (e.g., task ID 7 named *SOW Task Q* appearing in Figure 5 wherein the Performer is signaling that not only did the task start late by 1 day, but also that 2 additional days of Remaining Duration will likely be necessary to complete that activity).



ES Status	Task Name	Performer Status Date	Baseline Duration	Duration	Actual Duration	Remaining Duration	Planned Schedule (PS)	Earned Schedule (ES)	SV(es)	SPI(es)	PPC%	PC%	Jan
0	TESA Example	1/27/24	68 days	68 days	14.76 days	53.24 days	35 days	31.43 days	3.57 days	0.9	23.97	21.53	
1	Summary Task 1	1/27/24	68 days	68 days	14.02 days	53.98 days	20 days	19.55 days	0.45 days	0.98	21.51	21.02	
2	SOW Task A	1/27/24	10 days	10 days	10 days	0 days	10 days	10 days	0 days	1	100	100	
3	SOW Task B	1/27/24	25 days	27 days	5 days	22 days	5 days	4.75 days	0.25 days	0.95	20	19	
4	SOW Task C	1/27/24	40 days	42 days	5 days	37 days	5 days	4.8 days	0.2 days	0.96	12.5	12	
5	SOW Task D	1/27/24	18 days	18 days	0 days	18 days	0 days	0 days	0 days	0	0	0	
6	Summary Task 2	1/27/24	53 days	51 days	12.05 days	38.95 days	15 days	11.88 days	3.12 days	0.79	28.3	22.41	
7	SOW Task Q	1/27/24	22 days	24 days	13 days	11 days	15 days	11.88 days	3.12 days	0.79	68.18	54	
8	SOW Task R	1/27/24	17 days	17 days	0 days	17 days	0 days	0 days	0 days	0	0	0	
9	SOW Task S	1/27/24	14 days	14 days	0 days	14 days	0 days	0 days	0 days	0	0	0	

Figure 5. An Example of TESA Progress Data Capture

Regarding the rationale for the assumption associated with item 3.A, this is done because at the TESA level of abstraction, no finely granular information is available to reflect the quantitative mechanics that may be characteristic of a Performer's detailed project schedule like the resource allocation (e.g., full-time, part-time), availability (e.g., vacations, holidays, partial work weeks), incorporation of schedule risk contingency (e.g., deliberate introduction of free float to buffer task nodes exhibiting merge bias), intentional utilization of fixed duration tasks (e.g., an interval of time to model a response window for an external party), etc. However, this level of detail does not matter in the TESA context because the SOW-specified tasks—which for some SOWs encountered to date reflect individual projects performed under the purview of the Performer—already account for that finely granular detail; otherwise, finalization of the SOW would not have been possible.

TESA presumes that whatever the Performer intended to accomplish through the current monthly progress reporting occurred as planned. TESA's greater interest is whether that high-level SOW activity will still be completed by its Baseline Finish date OR will it be early or late, and if so, by how many days? As observed in Figure 5, this drives TESA's evaluation of ES performance.

Performance Metrics

Except for use of duration as a cost basis, most of TESA's performance metrics mirror their conventional EV counterpart. Table 2 describes TESA's core metrics.

Table 2. Description and Formulation of Primary TESA Performance Metrics

TESA Performance Metric	Description	Value Type	Detail Task Basis	Summary Task Basis
Performer Status Date	This date value is updated during each monthly TESA progress reporting cycle and propagated to all tasks (e.g., detail, summary) related to a respective SOW's body of work. The date entered coincides with a respective Performer's status update cycle. This feature of TESA accommodates Performers' status reporting date diversity.	Date	Manual Entry	Manual Entry

TESA Performance Metric	Description	Value Type	Detail Task Basis	Summary Task Basis
Planned Schedule (PS)	PS is the TESA equivalent to conventional EV's <i>Planned Value</i> . Derived from the <i>Baseline Duration</i> relative to the <i>Performer Status Date</i> , PS indicates the number of calendar days of accomplishment a task should have delivered.	Duration	<p>If <i>Performer Status Date</i> is a valid date Then</p> <p style="padding-left: 40px;">If <i>Baseline Duration</i> > 0 Then If <i>Baseline Finish</i> <= <i>Performer Status Date</i> Then <i>PS</i> = <i>Baseline Duration</i> Else If <i>Baseline Start</i> < <i>Performer Status Date</i> Then <i>PS</i> = <i>Performer Status Date</i> - <i>Baseline Start</i> Else <i>PS</i> = 0 End If Else <i>PS</i> = 0 End If Else <i>PS</i> = 0 End If</p>	Sum the PS values of related Detail Task children
Earned Schedule (ES)	ES is the TESA equivalent to conventional EV's Earned Value. ES is derived from the ratio of Actual Duration to the total Duration (i.e., Microsoft Project task <i>%Complete</i>) relative to the <i>Performer Status Date</i> . ES indicates the number of calendar days of accomplishment a task has delivered.	Duration	<p>If <i>Performer Status Date</i> is a valid date Then</p> <p style="padding-left: 40px;">If <i>Baseline Start</i> < <i>Performer Status Date</i> Then</p> <p style="padding-left: 80px;">If <i>%Complete</i> = 100% Then <i>ES</i> = <i>Baseline Duration</i> Else <i>ES</i> = <i>Baseline Duration</i> * <i>%Complete</i> End If Else <i>ES</i> = 0 End If Else <i>ES</i> = 0 End If</p>	Sum the ES values of related Detail Task children
SV(es)	Like conventional EV's calculation of schedule variance, SV(es) conveys ES variance, indicating the difference between PS and ES.	Duration	SV(es) = PS - ES	Use the Detail Task formula
SPI(es)	SPI(es) is comparable to conventional EV's calculation of a <i>Schedule Performance Index</i> (SPI) value, reflecting the rate at which project work is being delivered. Whereas an	Numeric	<p>If <i>%Complete</i> = 100 Then SPI = 1 Else If PS > 0 Then SPI = ES / PS Else SPI = 0</p>	Use the Detail Task formula



TESA Performance Metric	Description	Value Type	Detail Task Basis	Summary Task Basis
	<i>SPI(es)</i> value > 1 indicates a faster delivery rate, a value < 1 indicates a slower delivery rate. Tasks running on schedule as planned exhibit an <i>SPI(es)</i> value of 1.		End If End If	
Cumulative Baseline Duration	The <i>Cumulative Baseline Duration</i> is an ES counterpart to conventional EV's <i>Cumulative Baseline Cost</i> . It serves as variable for other TESA performance metrics.	Duration	Baseline Duration	Sum the baseline duration values of related Detail Task children
PPC%	PPC% indicates a baseline expected completion percentage. Like its conventional EV counterpart, PPC% conveys the level of accomplishment expressed as a percentage that <i>should</i> be complete by the <i>Performer Status Date</i> according to the baseline.	Numeric	If %Complete = 100 Then PPC% = 100 Else If Cumulative Baseline Duration > 0 Then PPC% = (PS / Cumulative Baseline Duration) * 100 Else PPC% = 0 End If End If	Use the Detail Task formula
PC%	Like its conventional EV counterpart, PC% indicates the percentage of what <i>has</i> been completed by the <i>Performer Status Date</i> .	Numeric	If %Complete = 100 Then PC% = 100 Else If Cumulative Baseline Duration > 0 Then PC% = (ES / Cumulative Baseline Duration) * 100 Else PC% = 0 End If End If	Use the Detail Task formula

Reporting

In addition to the core metrics presented in Table 2, TESA employs other calculated indicators to

provide alternative forecasts based on current performance trends (e.g., $TSPI_{(es)}$, ES Forecast Finish Variance, ES Forecast Finish date, correlation of milestone payment amounts with respect to time along with identifying what has been paid and what remains to be paid) and . . .

. . . generate condition-driven analysis narratives and graphic indicators that speed analysis and automate generation of executive summary reports.

Furthermore, since EV measurements like those employed by TESA can readily be summarized by any number of attribute-driven hierarchies, TESA takes advantage of Microsoft Project's grouping features to provide alternative analyses of schedule information.



This enables rendering cross-project views to answer questions like, “To what extent has progress been made on a capability R&D effort from a technology architecture roadmap perspective? Where are the gaps? What is the magnitude of the work that remains to be done to address those gaps?”

Figures 6 and 7 illustrate some of these “art of the possible” aspects of reporting. Other examples may also be seen in Figures 4 and 5.

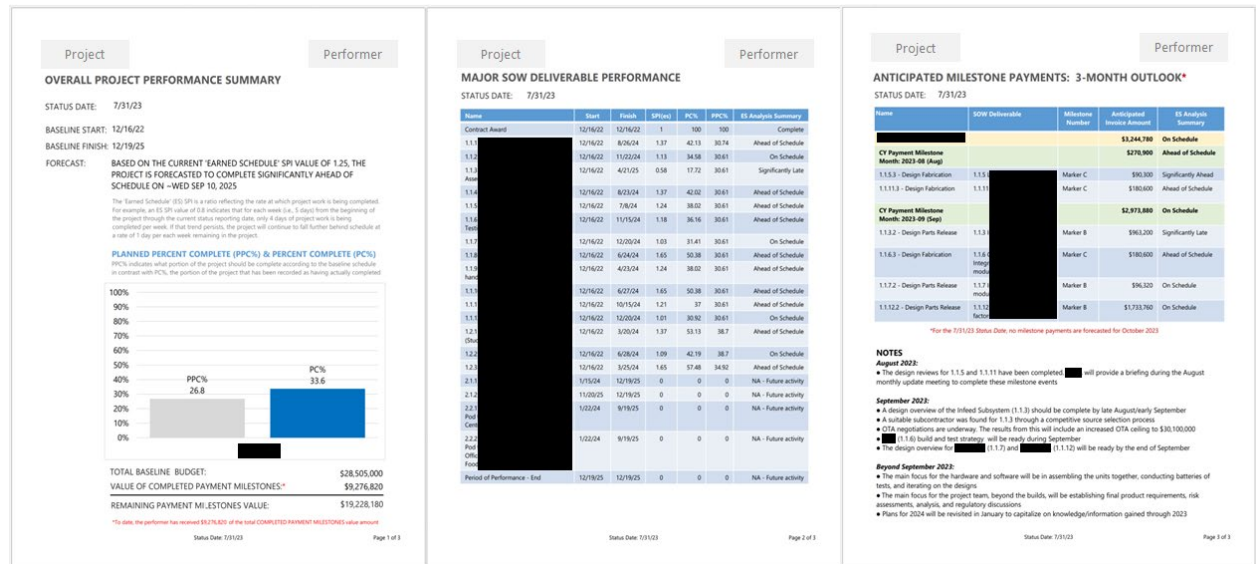
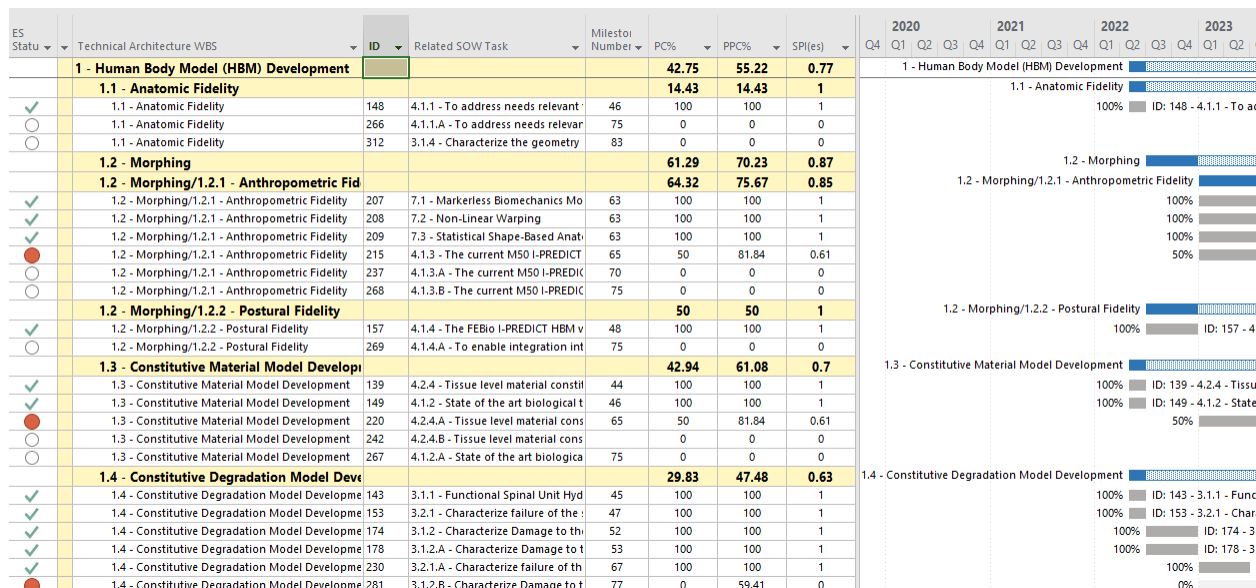


Figure 6. Redacted Example of an Autogenerated Management Summary Report for a Respective Performer



that culminated in proposition of TESA, this section describes the results beginning with the observed practical application benefits of TESA, as well as its limitations and their related mitigations. This section concludes with recommendations for further future research.

Benefits

Thus far in practical application, TESA seems sufficiently suitable for:

- constrained practice settings where schedule posture is an important situation awareness need and implementation time is limited,
- contexts exhibiting diversity in performers' project schedule management capability maturity and development methods (e.g., rigor sufficiency, artifact quality), which further complicates deployment of schedule control approaches of increasing complexity, and
- situations wherein SOW-specified project management obligations are negligible and enlistment of Performer support might prove challenging in direct proportion to the perceived additional overhead effort required to implement a schedule control process not specified in the SOWs.

Although the desired outcomes did not request accommodation of Agile contexts, as observed by Van De Velde (2017), ES approaches seem suited to address the agility practice dilemma of schedule performance accountability. When a sprint concludes, the technical debt incurred by the incomplete work from that sprint has both cost and schedule consequences that merit acknowledgment and address. As an ES-based approach, TESA could address that dilemma.

TESA's benefits include:

- a "light-touch" approach for providing schedule situational awareness with minimal effort, accommodation of variety in Performer status report dates; Performers are not required to operate together in lockstep for progress reporting,
- protection of Performers' proprietary work management methods by not requiring incorporation of all performer-managed schedule details into the TESA management summary schedule. The high-level activities and payment milestones specified in the SOWs are sufficient for implementation of TESA,
- not requiring dependency network logic to evaluate the consequential ripple effects of schedule accomplishment,
- independence from needing direct access to Performers' schedule artifacts, avoiding the complexity of a traditional IMS artifact, and
- retention of EV management's cumulative analysis benefits that simplify evaluation of schedule accomplishment across multiple programs and projects to support various audiences' summarization needs (e.g., portfolio, program, performer, project, capability roadmap).

Limitations

TESA is not devoid of limitations, three of which include:

- Duration granularity resolution risk* – As previously discussed in *The Approach* subtopic of *Agile Timeboxing*, schedule control risk increases for tasks whose duration spans more than two reporting periods. Agile timeboxing was initially envisioned as a risk



mitigation for this aspect of TESA. However, in actual practice, Performers preferred use of the SOW tasks instead of timeboxes with finer duration granularity.

Amelioration of this risk rests on the assumption that Performers possess detailed project schedules for their own operational control and are therefore capable of informing the higher-level SOW task summarizations.

No direct account for potential exhibition of merge bias risk inherent in dependency network design behavior – TESA does not rely on dependency network behavior for evaluation of schedule performance (i.e., the ripple effect), nor does it have access to the underlying details about the dependency network and nature of resource application within the Performer's local operational control schedule that might clarify potential opportunities for realizing merge bias risk.

However, even without incorporation of dependency information within the TESA management summary schedule or access to additional detailed information within Performers' operational control schedules, instances of steepening slope exhibited in the cumulative PS curve likely signal increased concurrent activity with a higher likelihood for incurring merge bias risk and therefore merit closer attention when "time now" traverses that interval.

Reliance on timely and accurate communication of performance information – The bane of any PPM control system is the quality and reliability of the information provided by respective project and task owners. TESA mitigation of this risk entails promotion of narratives that encourage Performers to provide reliable information. For example, one narrative routinely socialized through the TESA overview shared new Performers emphasizes that TESA is not a means for micromanagement; it helps the Sponsor visualize the totality of the portfolio and facilitates collaborative discussions to resolve emergent issues.

Recommendations for Further Research

The limited time with which to conceive and implement TESA in response to an immediate need necessitated a reflective practice approach (Schön, 1983). Consistent with reflective practice theory as employed by several professions (e.g., medical, legal, educational, architectural, project management), the authors framed the problem, engaged adaptive rigor in appropriating components from their profession's body knowledge, and devised a practice response situated in their professional experience and knowledge (e.g., Oliver, 1999, 2002; Peterson & Oliver, 2001).

The occasion of preparing this paper post-implementation of TESA provided an opportunity to discover additional literature further exploring duration-based EV-situated approaches. A systematic literature review with the intent of proposing a standard nomenclature for duration-based EV approaches seems warranted. Results from this research would better differentiate conventional EV performance measurement nomenclature from what Khamooshi and Golafshani (2014) have designated as *earned duration management* (EDM). As an example, TESA uses the term SPI(es) to differentiate its schedule performance index based on duration from conventional EV's SPI using a currency cost-basis. In contrast, Khamooshi and Golafshani's (2014) *Earned Duration Index* (EDI) provides terminological specificity for differentiating a duration-based schedule performance index from conventional EV's currency-based SPI indicator.



Conclusion

Regarding the question of whether complexity is a prerequisite for effectiveness, Hopej-Kamińska et al. (2015) observed, “structure should not always be simple but should be the simplest of all the possibilities” (p. 272). Despite its utilization of time-phased cost mechanics appropriated conventional EV, TESA seems to fit the characterization of being the simplest of all possibilities for realizing the desired outcomes while accommodating specific practice constraints. Consistent with the practical application tenets of reflective practice theory (Schön, 1983), monitoring of TESA's effectiveness as a practice response continues with modifications being made as needed.

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Leading Practices Iterative Cycles Enable Rapid Delivery of Complex, Innovative Products

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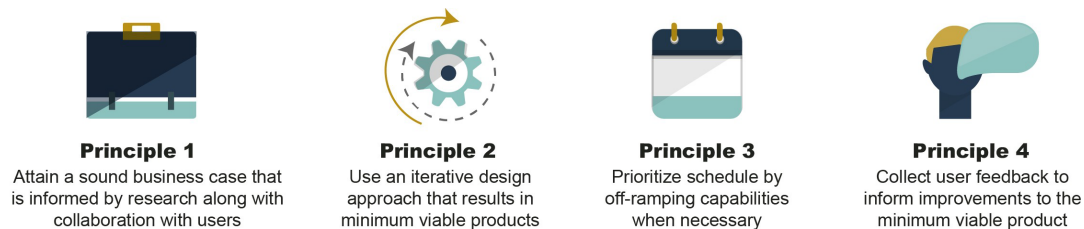
Abstract

The Department of Defense is increasingly acquiring complex products, such as combined networks of hardware and software, which require innovative processes to design, produce, and deliver. GAO has found that to consistently deliver new warfighting capabilities with speed, acquisition programs for cyber-physical systems, such as aircraft and uncrewed vehicles—must adopt new approaches to its acquisition structure. Solutions, though, are unlikely to originate exclusively within government. Rather, identifying the practices that leading companies rely on to deliver new cyber-physical products can provide crucial, cutting-edge information to acquisition leaders and, in turn, ultimately help DOD frame changes to its acquisition processes. This presentation will focus on GAO's recent work on innovative practices that can inform DOD's ongoing efforts to improve acquisition performance. The presentation will also draw on GAO's annual weapon systems assessments to discuss how DOD is beginning to implement some of these principles and practices.

Keywords: Innovation, iterative development, digital twins

Background

In March 2022, we found that leading companies consistently deliver innovative products to market with speed by relying on four key principles throughout product development. Implementing these four principles positions leading companies to satisfy their customers' needs and correspondingly grow their market share (see fig. 1). Appendix II further details these principles and their associated sub-principles.



Source: GAO analysis of company information; GAO (icons). | GAO-23-106222

Figure 1. Leading Companies Rely on Four Principles to Deliver Innovative Products to Market with Speed

These four principles, along with several of their sub-principles, provide important context for understanding the analyses included in this report. We describe below how we continue to leverage these leading principles in our work.

Attain a sound business case. Sub-principles address how leading companies conduct market research and obtain and use customer feedback to establish and then continually maintain a sound business case throughout development. This report discusses how the initial business case—one that underpins the very start of a product development—can evolve over the course of the product development effort. Our future work, however, will



discuss in more detail how leading companies establish key sub- principles underlying this business case, which include:

- investing time to research the marketable product;
- soliciting early feedback from customers;
- developing high-level cost and schedule parameters; and
- drawing from institutional memory and corporate knowledge to develop initial estimates, avoid earlier mistakes, and build off previous success.

Use an iterative design approach that results in minimum viable products (MVP).

Leading companies use modern design tools, such as digital engineering and additive manufacturing, throughout development for both hardware and software. Key concepts within this sub-principle related to this report include:

- The use of iterative design and testing allows leading companies to identify an MVP—a product with the minimum capabilities needed for customers to recognize value and that can be followed by successive updates.
- Digital engineering includes digital twins—virtual representations of physical products. Digital twins incorporate dynamic data of a physical object or a system— meaning the model changes and updates in real-time as new information becomes available. Unlike a digital twin, a 3D model is a static visualization of a physical aspect—meaning it cannot be updated without someone manually inputting new data, and is similar to paper design drawings in digital form. Digital threads are a common source of information that connect stakeholders with real-time data across the product life cycle.
- 3D printing is a type of additive manufacturing, a computer-controlled process that creates physical objects, such as aircraft components, by depositing materials, usually in layers.

Prioritize schedule by off-ramping capabilities when necessary. To achieve speed to market, leading companies use periodic reviews to monitor performance and work to maintain a realistic assessment of development activities. Leading companies will off- ramp capabilities—an industry term for removing them from the planned release—if needed should those capabilities pose a risk to delivering the product on schedule. The off-ramped capabilities can be deferred to a later release or terminated.

Collect user feedback to inform improvements to the minimum viable product. Leading companies establish a process to facilitate ongoing engagement with users and customers after delivery of the first iteration. They use this feedback to identify new features to include in subsequent iterations or new products.

Iterative Development Approaches for Cyber-Physical Systems

The rise of cyber-physical systems in product development has led to new iterative development approaches within industry. These approaches integrate modern software practices with hardware development processes to achieve speed in innovation and capability delivery to users.

Differences between Linear and Iterative Development

Historically, both hardware and software product development progressed through a linear process with sequential milestones. Companies solidified requirements prior to



development and delivered capability in a single completed program at the end of the development cycle. However, over the last several decades, software developers have utilized Agile practices, which provide iterations of capability that are continuously evaluated on functionality, quality, and customer satisfaction to increase innovation and speed in delivery. Now, as software increasingly dictates hardware functionality, companies are finding ways to incorporate the same iterative, Agile practices into products beyond software. Some of these methods include Modified Agile for Hardware Development Framework and hybrid models, such as a model that combines aspects of Agile and Stage-Gate®. Table 2 describes some of the differences between traditional, linear development and modern, iterative development.

Table 2: Comparison of Linear Development and Iterative Development

	Linear development	Iterative development
Requirements	Requirements are fully defined and fixed up front	Requirements evolve and are defined in concert with demonstrated achievement
Development	Development is focused on compliance with original requirements	Development is focused on users and mission effect
Performance	Performance is measured against an acquisition cost, schedule and performance baseline	Performance is measured through multiple value assessments—a determination of whether the outcomes are worth continued investment

Source: GAO analysis. | GAO-23-106222

Cyber-Physical Systems

Cyber-physical systems—sometimes called hybrid systems—are co-engineered networks of hardware and software that combine computation, communication, sensing, and actuation with physical systems. Within a cyber-physical system, software does not simply process data; it also interacts with the physical world. The software receives information about the environment through sensors, such as temperature, tire pressure, camera, or radar sensor data. The software then uses these data to instruct physical hardware, such as motors, pumps, or valves. The system’s functionality is controlled by software algorithms.

Major government acquisitions at DOD, DHS, and NASA increasingly reflect this close interaction between digital and physical environments. For example, satellites, uncrewed vehicles, aircraft, planetary rovers, and cooperating robots in a manufacturing line are instances of cyber-physical systems. Table 3 defines common elements of cyber-physical systems.

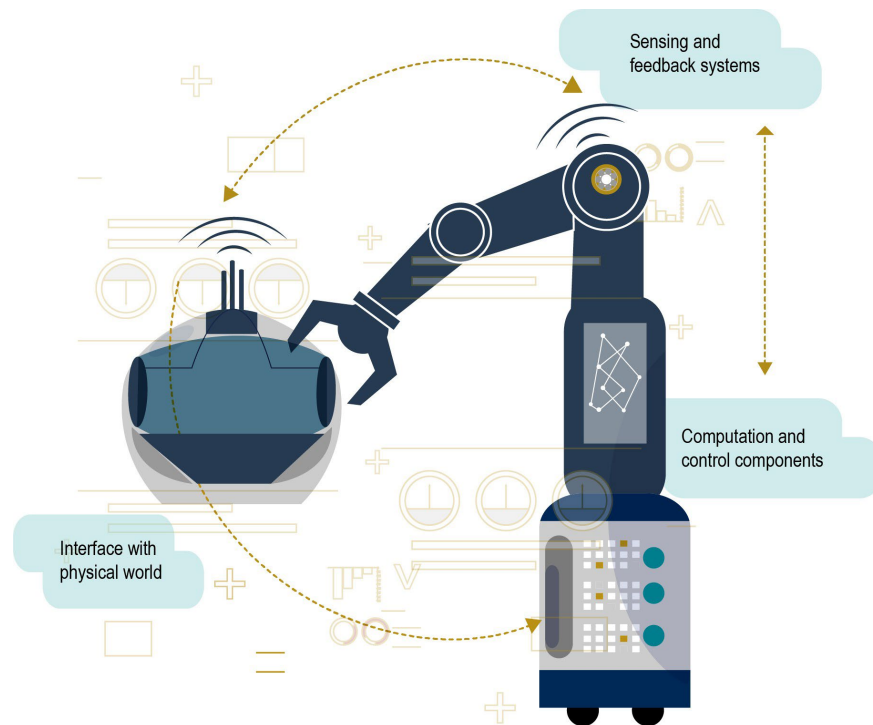


Table 3: Common Elements of Cyber-Physical Systems

Cyber-physical system	Description
Physical layer	Real object in the physical world
Digital layer	Algorithms for managing real objects
Interface	Interaction between physical and digital layers—such as control mechanisms and detectors; and interaction between physical and digital layers with a person
Domains	Different application areas for which stakeholders have subject-matter expertise
Cyber-physical system	Description
Modularity	Allows common elements to be combined and reused while retaining security and reliability
Cybersecurity	Helps to guard against malicious attacks.

Source: GAO summary of information from the National Institute of Standards and Technology and Institute of Electrical and Electronics Engineers. | GAO-23-106222

Figure 2 depicts the integration of digital and physical inputs in cyber-physical systems.



Source: GAO summary of information from the National Institute of Standards and Technology; GAO (illustration). | GAO-23-106222

Figure 2: Cyber-Physical Systems Integrate Continuous Physical and Digital Information

Leading companies develop cyber-physical systems as products for consumer use. As a result, we refer to cyber-physical products and product development throughout this report. Table 4 describes key concepts related to cyber-physical product development that are relevant to this report.

Table 4: Key Terms in Cyber-Physical Product Development

Key Term	Description
Backlog	The backlog is a list of features, user stories, and tasks to be addressed by the team, and is ordered from the highest ranked to the lowest ranked. If the team discovers new requirements or defects during development, these are added to the backlog. A backlog can occur at varying levels; for example, a product backlog is a high-level backlog that contains all the requirements for the entire program. An iteration backlog includes a list of user stories intended for that iteration. See description of user stories below.
Iteration	An iteration is a predefined, time-boxed, and recurring period of time in which product teams develop a working solution.
Stakeholder	A stakeholder is anyone who has an interest in the product. Specifically, stakeholders are parties that may be affected by a decision made by or about the product, or that could influence the implementation of the product team's decisions. A group or individual with a relationship to a product change, a product need, or the solution can be considered a stakeholder.
Sprint	A sprint is a short, time-boxed iteration that is intended to provide distinct, consistent, and incremental progress of prioritized features.
User	Users are the operators of the product. The user is an integral part of development and has specific responsibilities depending on the Agile methods used. The user is often synonymous with the customer, but at times the customer and the user might differ. This definition is organizationally and contextually dependent. For consistency, GAO refers to users throughout the report unless otherwise noted.
User story	A user story defines a high-level requirement by using everyday or business language. User stories are not vehicles to capture complex system requirements on their own. Rather, full system requirements consist of a body of user stories. User stories are used in all levels of Agile planning and execution.
Velocity	Velocity measures the amount of work a team can deliver in each iteration. Commonly, this is measured as user story points accomplished per iteration. For example, if a team completed 100 story points—a unit of measure for expressing the size of a user story—during an iteration, the velocity for the team would be 100. Velocity is a team-specific abstract metric and is generally not compared across teams as a measure of relative productivity.
Verification and validation testing	Verification and validation testing is a set of independent procedures that are used together for checking whether the program meets the requirements and specifications, that is, that it fulfills its intended purpose. To simplify, GAO refers to these procedures as validation in the report.

Source: GAO analysis. | GAO-23-106222

Leading Companies Progress through Iterative Cycles of Design, Validation, and Production

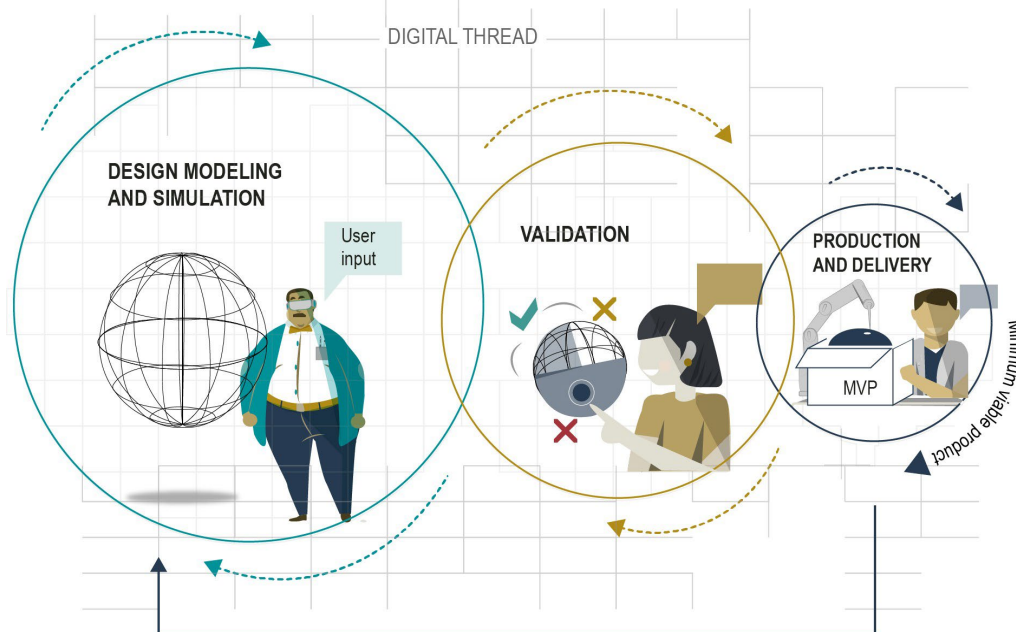
Leading companies employ an iterative structure when developing complex, cyber-physical products. The iterative process involves continuous cycles, which, similar to Agile software development, revolve around companies rapidly developing and deploying products. Key practices are common throughout the iterative cycles. For example:

- Leading companies seek and obtain continuous user feedback—feedback from the actual operators of the product—throughout the iterative cycles.



- Leading companies capture this feedback to determine if the design is meeting user needs and reflects an MVP—a product with the minimum capabilities needed for customers to recognize value.
- Leading companies continually feed this product design information into a real-time digital thread—a common source of information connecting stakeholders with real-time data across the product life cycle to inform product decisions.

Other development activities—such as modeling, validating, and refining specifications—overlap between cycles as product teams design and test sub-components and integrated systems. Figure 3 depicts key elements of this structure.



Source: GAO analysis of leading company information; GAO (illustration). | GAO-23-106222

Figure 3: Leading Companies Progress through Iterative Design, Validation, and Production Cycles to Develop a Minimum Viable Product

Knowledge Gained through Iterative Cycles

We found that leading companies increase knowledge about a system's design through each iterative cycle of design, validation, and manufacturing. Leading companies do not attempt to start development with a business case that includes a detailed specification of requirements. This approach differs from traditional linear development, which fixes operational requirements needed to deliver a capability to meet predetermined performance criteria. Instead, development begins with a high-level need statement or idea. Throughout development, this high-level need is progressively refined into distinct requirements.

Leading companies enable the initial business case to evolve over the course of product development. For example, Siemens ensures that the business case connects to research and development and technology management, so that research and development efforts focus on providing key technologies to be utilized in future new products. This means that research and development for a specific product does not end with the product—it continues so that future iterations of the product will have new, innovative, and mature technologies available.

The outcome of the business case development is the high-level framework of an MVP that the company will develop. This framework validates that the planned iteration of a product is responsive to a market need, underpinned by realistic expectations about technology development and achievable within defined cost and schedule parameters for that iteration. Knowledge acquired during design modeling and simulation and validation further refines the business case. Leading companies capture data from these iterative cycles in a digital thread. They then use information in this digital thread to inform decision-making, such as how to refine requirements or whether to make certain changes to the product's design. Table 5 outlines knowledge acquired during iterations in development.

Table 5: Product Development Cycles Characterized by User Feedback and Refined Knowledge Captured within a Digital Thread

	Product Development Cycles		
	Design modeling and simulation cycle	Validation cycle	Production and delivery cycle
User feedback	Users provide input to define design specifications for the minimum viable product, using multiple iterations as needed	Users agree design meets needs for minimum viable product, or design returns to modeling and simulation	Users provide feedback on desired product improvements to inform subsequent iterations
Knowledge captured in digital thread	Specifications that ensure the design meets most essential user needs	Integrated prototype that is tested in multiple environments to verify performance and can be manufactured as the minimum viable product	Optimized manufacturing tools and processes and insight into efficiencies for future iterations

Source: GAO analysis of company information. | GAO-23-106222

The number of iterative cycles that a product requires varies according to product type and team. For example, for products that are entirely new to develop, NVIDIA anticipates several phases of iteration across the design modeling and simulation, and validation cycles. The product team uses these multiple iterations to ensure all hardware, software, and infrastructure needs are validated through testing and user feedback. When NVIDIA develops improvements and updates to existing products, the product team starts with the existing design and makes updates that continuously optimize the product. Personal computers, for example, are largely in this category. The technology is mostly known, so NVIDIA can leverage this more advanced state and optimize existing designs.

Key Metrics for Delivering Minimum Viable Products

Leading companies structure product development around MVPs to ensure that they deliver essential product capabilities to users with speed. Under the iterative construct, schedule is a key driver, and companies make adjustments on performance, as needed. Accordingly, key metrics and measures track speed to market—generally the time measured from establishment of an initial business case to delivery of the MVP to users. For example, Danfoss measures time to market in its product development model, and seeks to reduce that time through iterative development. The metric begins at project start—which occurs after the initial business case is developed—and ends when the company delivers the product. Companies deliver new products on a schedule needed to meet customer needs and satisfy market demand. We previously reported that this speed to market calculation is relative to different product types and industries.



Leading companies often use metrics for cyber-physical products that reflect those within Agile software development, including velocity, sprints, and addressing user story points. For example:

- NEC uses velocity of development teams to identify the speed of each sprint, and then measures how many sprints are required to build and deliver the MVP. This allows the product team to better estimate the required schedule to build the product and communicate progress to the customer in a more transparent way.
- SAP is developing a metric that measures the time it takes to address customer feedback. The measure begins when the product team receives feedback and ends after the team places the feedback in the backlog and ranks, addresses, and delivers the product.
- For new physical products, Danfoss also measures progress of short, time-boxed sprints, which might be 2 to 3 weeks long, with a cadence that it can readjust depending upon customer need and type of program. This allows Danfoss to focus more on the project's progress and value added based on feedback, rather than simply checking whether it completed tasks and deliverables. This approach has shortened development cycles. For example, Danfoss representatives said that the company shortened its average time to market from more than 35 months in 2017 to less than 20 months in 2021.

Other key metrics used by companies revolve around establishing and verifying key performance specifications that define the MVP during design modeling and simulation and validation, which we discuss later in this report.

Leading Companies Increase Product Development Investments as MVP Design Matures

As the MVP design matures with each iteration, leading companies commit to increasing levels of resource investment for the product. They identify potential problems early through digital modeling and simulation and collaboration with stakeholders. As leading companies decrease risk, they proportionately increase funding.

Leading companies apply feedback about the design from cross-functional teams throughout iterative development—including design engineers, domain experts, cybersecurity teams, manufacturers and suppliers, marketing and sales teams, and customers and users.

For example, cybersecurity stakeholders include cybersecurity controls as specifications early in design and re-evaluate them as development progresses. According to the National Institute of Standards and Technology, cybersecurity is a necessary feature of the cyber-physical system's architecture to help ensure that capabilities are not compromised by malicious agents. Arista's Network Detection and Response (NDR) team builds cybersecurity into its products from the beginning of design through delivery and customer support. The team establishes security measures, such as firewall rules, to ensure there are no external actors affecting daily operations, and ensures its own devices are protected before writing the first line of code. To help ensure continued product security, Arista's NDR team also protects against vulnerabilities from outside sources, such as original equipment manufacturers or subscriptions to third-party code libraries. Arista's NDR team representatives said the codes in these libraries frequently have bugs and vulnerabilities that could be exploited, so Arista's NDR team builds in security features, and also puts a team in place to constantly look for risks from external sources.



Throughout all development cycles, stakeholders have access to real-time information through a digital thread. For example, Siemens' digital threads capture digital records of all states of the product throughout development, manufacturing, and service so that product teams and stakeholders can predict performance and optimize the product.

Users also rely on this information to identify areas where the product's design can provide the most value. The end result is that, rather than having a "relay" with handoffs of the product components to different stakeholders in succession, the digital thread enables parallel collaboration. We discuss the application of digital twins and digital threads later in this report within the context of specific development cycles.

The cross-functional structure also provides real-time knowledge that enables decision-making at the lowest appropriate level. For example, at Alphabet, Inc. (Google), the Product Manager acts as the "Chief Executive Officer" of the product and is responsible for defining the product, working with the technical team, and negotiating on product requirements that are achievable with each MVP.

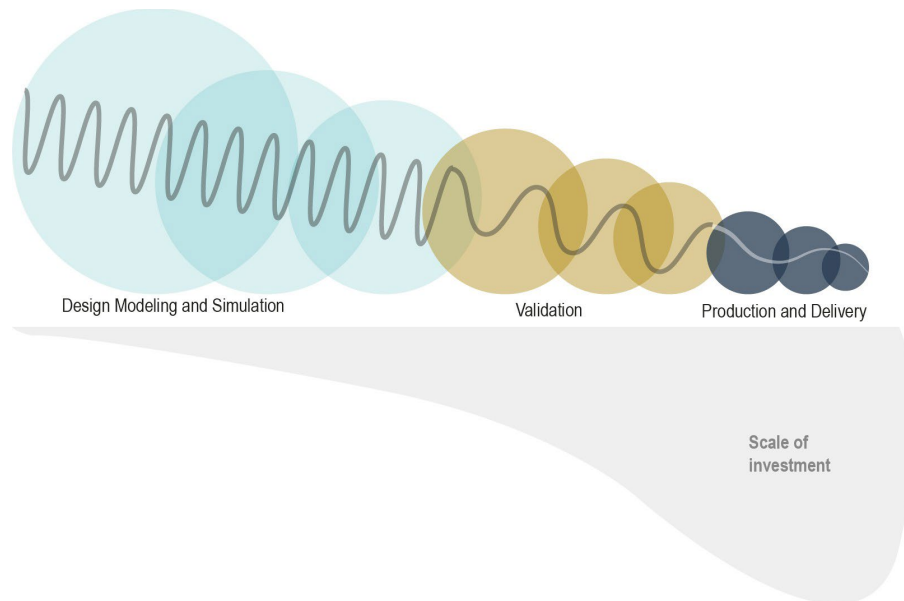
Investment Decision- Making

Leading companies regularly evaluate the product's value with users to determine whether it continues to meet the initial business case and warrants continued investment. Leading companies provide funding commensurate with the product's design and development progress, rather than give a product development team a substantial amount of funding upfront at development start. For example, Danfoss initially provides a small portion of the product funding. It then scales product funding as the development team develops the design, tests the prototype to refine requirements, and ensures the business case remains valid for the MVP.

In addition, leading companies acknowledge that detailed estimates will change as development progresses, and correspondingly scale funding to ensure the investment provides value. This approach differs considerably from traditional linear development, which generally relies on fully resourcing a project to meet predefined performance requirements at development start. For instance, Volvo Group used to set full budget commitments early at fixed milestone gates. This made ending product development, if needed, "painful" and slow, even if the product was no longer relevant. Now, with the adoption of iterative, Agile practices, Volvo Group scales funding to keep pace with development. As the design progresses and is validated with stakeholders through integrated testing, the product team meets with senior leadership to determine whether the company wants to continue to invest in the product or specific technology.

Through collaboration with stakeholders and early discovery of design risks and vulnerabilities, leading companies are able to increase investment as they minimize changes to the design (see fig. 4).





Source: GAO analysis of company information; GAO (illustration). | GAO-23-106222

Figure 4: Leading Companies Scale Investment to Increase as Frequency of Design Changes Decreases

Leading Companies Refine, Validate, and Produce a Minimum Viable Product by Employing Modern Tools and Engaging with Users

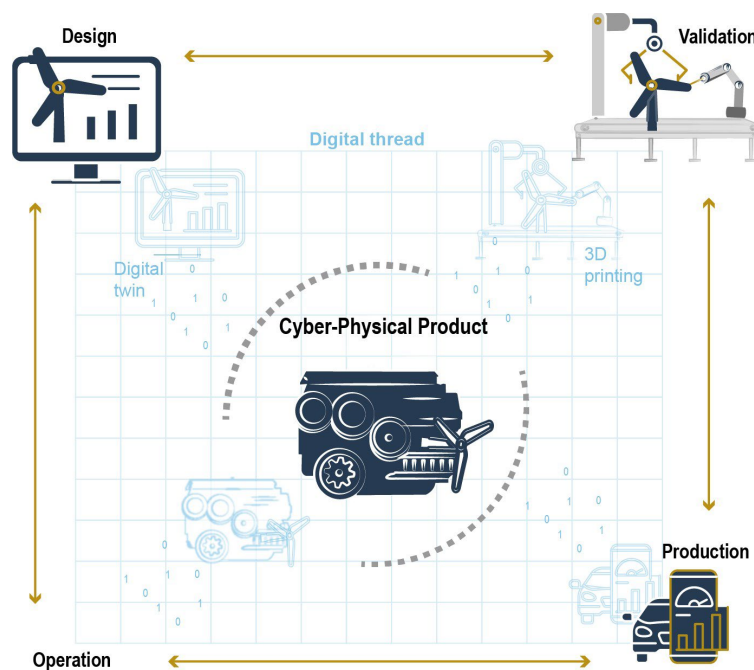
Leading Companies Model and Simulate Design Concepts with Users

Using digital models and user feedback, leading companies engage in a design modeling and simulation cycle to develop and refine the initial business case. We found that leading companies work with product users to co-develop requirements and indicators that can change. For example, using digital twins, Volvo Group can identify significant differences between the expected and actual performance of a truck's design and go back to the design team to iterate on the product design to meet the most important needs.

Through the design modeling and simulation cycle, leading companies repeatedly obtain feedback from selected users to inform design specifications. For example, during early design modeling and simulation, Arista's NDR team releases multiple, early iterations of the product to early adopters—the first users of that product—to solicit their input and feedback on product features. This user-centered design means that information gathered from users leads to building, testing, and redesigning through rapid iterations and innovation until the product specifications meet user needs.

Modeling and Simulation Input into Digital Threads

Leading companies leverage this collaboration with users to ensure the early design both provides performance and still has a valid business case. For example, when designing Pixel mobile phones, Google's product development team evaluates the right balance of features that optimizes performance at the target price. To meet the stated needs of North American customers, Volkswagen Group of America, Inc. (VW) made design changes to the interior of its ID.4 electric vehicle and to the exterior of its Atlas SUV. For ID.4 design changes, customer feedback from previous VW models, such as the Jetta, provided VW with the knowledge to change the interior of the ID.4 during design.



Source: GAO (analysis and illustration); bsd studio/stock.adobe.com (icons). | GAO-23-106222

Figure 5: Digital Thread Captures Information throughout Product Life Cycle

Companies develop digital engineering models during design modeling and simulation based on specific needs. In particular, leading companies use digital twins and 3D printed models to quickly determine the most optimal design of a product that meets users' specifications. Digital twins, as previously noted, are virtual representations of their physical products, and incorporate dynamic data of a physical object or a system. 3D printing is a type of additive manufacturing, a computer-controlled process that creates physical objects by depositing materials, usually in layers. Creating a new design is easier in a digital environment because it enables faster design iterations, using digital twins and 3D printing. During design modeling and simulation, product development teams refine specifications with user feedback. Doing so can even result in starting over with new design solutions. Table 6 describes how the digital modeling and simulation inputs to the digital thread help inform decisions about the product's design.

Table 6: Design Modeling and Simulation Inputs to a Product's Digital Thread

Model	Description
Digital twin	<ul style="list-style-type: none"> During design modeling and simulation, the product development team collects data to build the digital twin, either by connecting the digital twin and the physical world through sensors or by collecting domain data to build the twin digitally. The digital twin simulates the behavior of different designs and feeds those data into the digital thread. Stakeholders and users access this information to further define requirements and identify preferred design options.
3D printing	<ul style="list-style-type: none"> During design modeling and simulation, the product development team uses 3D printing to prototype early designs of a product, which provides initial validation of the digital model.

Source: GAO analysis of company information. | GAO-23-106222

At Danfoss, digital twinning allows for faster design iterations. For example, Danfoss representatives told us that a product development team can test 500 digital designs using a digital twin in the same time that it could test five designs using traditional design approaches. Through the rapid digital design and test cycle, the product team is able to model and simulate many more possibilities than with physical prototypes alone. HP uses digital simulation early in design as the first step in coding and developing initial use cases that HP engineers can show to users. Microsoft found that digital twinning consistently results in more efficient design. It allows product development teams to design each component of a smartphone to the appropriate thickness and weight.

Through the use of AI, leading companies can create real-time synchronized simulations that are physically accurate and obey the laws of physics. These simulations can aid the implementation of system-level digital twins. At NVIDIA, AI may augment a digital twin, standing in as a good representation of the physical model, such as representing employees in a factory or representing a driver in a digital twin of an autonomous vehicle.

Leading companies' use of specific domain knowledge—particular expertise or skills relevant to the product—and user input into digital twins provide confidence that capabilities can be developed to meet schedule and cost parameters identified in the project's business case. For example, at HP, the most critical aspect of the digital twin is that it reflects the right domain knowledge to understand how the system works. This domain knowledge includes internal factors such as heat as well as the physics of the external environment, which will affect a product's performance. These data, together with rapid digital design and testing, predict expected performance of the product.

Leading companies develop trust in digital twins by inputting high-quality data that capture information about the relevant domains. At Siemens, this requires input from users and understanding the manufacturing capabilities and other domains needed to create the product. Digital twins take fundamentally good information from physical engineering to build a foundation. Then, data from people, processes, and tools feed into those models.

A digital twin becomes more robust and reliable through continuous testing and correlation to the physical model in a real-world environment. NVIDIA trains its engineers not to trust the simulator immediately. Over time, engineers build trust in the model through correlation with a real-world version of the model—each instance of correlation proves that the model is correct in the specific area. Because NVIDIA has run simulations and correlated to the physical model and environment, it can document, demonstrate, and quantify reliability, establishing greater confidence in the model.

One challenge, however, is knowing when a model—and a design—is good enough. At Siemens, knowing the digital twin is good enough revolves around the data. Obtaining the correct product data during early design—such as by ensuring the data used to create the digital twin are accurate and similar to the real-world model—is what makes the digital twin an actual digital asset, and ultimately, what reduces dependence on physical prototyping.

In addition to the use of digital engineering, leading companies also use 3D printing, along with augmented and virtual realities to aid in product design. Augmented reality overlays digital content onto representations of the real world using smartphones, tablets, or glasses. Virtual reality completely obscures the real world, immersing users in digital environments using head-mounted displays. 3D printing allows product development teams at Danfoss, for example, to build early prototypes during design modeling and simulation cycles to obtain early user feedback on design and make early changes to the design based on that feedback. 3D printing is unique in that it enables this early, quick prototyping,



resulting in cost and schedule efficiencies. Product development teams also use augmented reality and virtual reality to virtually see a product in its space—for example, the interior of a virtual vehicle—before building a physical prototype, enabling the product team to visualize an integrated design.

Deferring Technologies and Prioritizing Capabilities

We found that leading companies only embark on product development once they assess and establish confidence that the underlying technologies in the product are sufficiently mature to meet user needs and support the product development schedule. Leading companies vigilantly monitor product technologies during design modeling and simulation and will not hesitate to defer any to future design iterations if they prove incompatible with schedule and cost parameters defined in the initial business case. For example, Google has engineering processes in place that balance the development of new product features while prioritizing meeting the target release dates for its Pixel phone launches. Volvo Group employs a common architecture design system that enables product teams to defer technologies from one product and insert that technology into a later product without disruption.

Further, the use of a backlog allows leading companies to organize, rank, and track capabilities for the product. This backlog includes both software and hardware functions. Ranked work is driven primarily by what the majority of users need. For example, Siemens employs risk-based analysis with users to transform input into prioritized development activities based on user needs within initial business case parameters. However, the backlog does not stand alone—it reflects a broader plan to achieve the overall goal of the product. At the start of development, Danfoss uses its backlog to help product development teams identify and rank the features and capabilities that are a part of that development cycle and map back to the overall product development plan.

Developing Design Specifications for Integration and Testing

We found that leading companies sufficiently develop design specifications to enable system integration and prototype testing. The outcome of design modeling and simulation cycles is a solution—in the form of an MVP—that companies can validate through testing. These design cycles give companies more confidence that they have made major changes by the time they are ready to validate the product. Danfoss, for example, starts design modeling and simulation with potential solutions. When the product development team is ready for validation, those solutions have become the product they intend to sell to their customers. By the time Google's Pixel device, for example, is ready for validation, design for that iteration is nearly complete.

Modular design supports prioritizing capabilities for optimal design. For example, Volvo Group's use of modular design allows it to develop different vehicle ranges from a single architecture. This approach enables customized solutions to a single vehicle to meet different user needs. The modular design means that Volvo Group can integrate different hardware components into a new design iteration and still easily produce vehicles at scale.

Leading Companies Validate Product Design with Users

Following design modeling and simulation, leading companies build fully-integrated prototypes—incorporating data from both physical models and digital twins—to test with users in the expected operating environment. As a part of this process, leading companies revisit the business case, assessing whether the MVP remains within cost and schedule parameters and still meets user needs. Leading companies use the results of these tests



and user feedback to update the product design, as needed, and prepare the MVP for production.

Testing Fully- Integrated Prototypes

Leading companies build system-level integrated prototypes—either physical, digital, or a combination—to test the MVP’s design established during design modeling and simulation. This prototyping incorporates all hardware and software components to test the product’s integrated functionality. As a result, testing of the fully-integrated system can uncover problems that were not apparent when subsystems were tested, both physically and digitally, earlier. Prototyping may also be used to test more than one design variation of a product to determine which best meets user needs.

While system-level integrated testing is a long-standing practice, leading companies now combine digital with physical prototypes to test the complete cyber-physical product with users in the operating environment. Digital twins inform the physical prototypes—which are built from digital designs—and also incorporate testing results from the physical prototypes to better simulate the product’s functionality. For example, HP creates 3D-printed parts from digital designs to test and ensure structural integrity. Similarly, Danfoss’ 3D printing lab prints physical parts from digital designs to observe how they fit together. Danfoss also provides the physical prototypes to its customers so customers can test the prototypes in their own products and ensure they will work together.

Data from the physical prototypes then feed back into the digital twin to continue testing and validating the product’s design. HP, for example, incorporates physical data into the digital twin to replicate how the product will behave in different operating environments.

Similarly, NVIDIA captures real-world data from sensors placed on test vehicles, then uses the data to reconstruct the operating environment in digital twins and run simulations for autonomous vehicles. As data are incorporated into the digital twin, they are also incorporated into the product’s digital thread and used to validate the design’s performance as an MVP (see table 7).

Table 7: Validation Inputs to a Product’s Digital Thread

Model	Description
Digital twin	<ul style="list-style-type: none"> During validation, the product team conducts systems-integrated tests—such as thermal or drop tests—on a physical prototype connected to the digital twin, or through a fully digital model. Test data inputs and design updates to the digital twin become part of the digital thread. Validation data are available to outside stakeholders—those with an interest in the product—to collaborate on design strategies and decisions and determine the minimum viable product.
3D printing	<ul style="list-style-type: none"> During validation, the product team uses 3D printing of certain parts or of integrated products to test their performance and collect physical data.

Source: GAO analysis of company information. | GAO-23-106222

By adding physical data inputs into digital twins, leading companies use modeling to simulate potential operating scenarios that have yet to be realized, leading to more robust testing. As a result, leading companies can run scenarios repeatedly with unlimited variations, building confidence that the products they designed will work once produced. For example, NVIDIA can apply data from car accident reports and insurance claims to a digital

twin for an autonomous vehicle, and use modeling to create rare and difficult scenarios for a vehicle's operation.

In some cases, leading companies use digital twins to gain insight into a system's design that cannot be obtained physically. For example, in developing Earth-2—an AI supercomputer intended to predict climate change—NVIDIA used a digital twin to simulate the inside of a nuclear reactor, which is physically inaccessible. Danfoss used a digital twin of an industrial motor drive to simulate its overload to the point of explosion. Compared with a physical test, which would have destroyed the prototype, Danfoss could identify the specific point of explosion, locate defects, and fix them in the digital twin.

Assessing Prototype Performance

In design validation, leading companies focus more heavily on how prototypes perform against goals for quality. For example, Arista's NDR team seeks to balance product completeness—the extent to which all planned features are included in the release— with product quality. Similarly, SAP tracks metrics related to defects found once users begin to interact with the product.

Leading companies use prototyping results to help assess whether the product will remain within the cost and schedule parameters established in the business case, and whether the product will still meet user needs. Leading companies may make adjustments to cost and schedule parameters in rare instances, such as delaying product delivery when the company needs more time to develop a key feature that is critical for a majority of customers.

Refining MVP Capabilities

After confirming the maturity of underlying technologies within the MVP, and with schedule as a key driver, leading companies evaluate the most critical functions and off-ramp product capabilities that are not essential and could delay the current release. As they work through validation, leading companies collaborate with customers and users to ensure the capabilities they are testing and the related product requirements are still the right priorities. For example, NEC ensures that all customer “must haves”—the capabilities that customers definitely need for the MVP—are satisfied first, before it adds less-critical capabilities. By maintaining flexibility on product specifications into design validation, leading companies can adapt the MVP to meet cost, schedule, and performance parameters.

Leading companies make off-ramping decisions for a given MVP largely based on customer and user needs, with the knowledge that they can add some of the capabilities in subsequent iterative product deliveries. Because the iterative process provides such opportunities, leading companies delay capabilities that are not ready until the next release or decide not to provide them if they are no longer needed. For example:

- To meet schedule, Microsoft may de-scope a product and deliver a subset of the full set of planned capabilities in the current iteration, then deliver the remaining capabilities in the next.
- HP identifies and off-ramps the capabilities that it does not need to meet the core functionality of the product.
- Siemens uses digital twins to support off-ramping decisions by examining the multiple designs in the digital thread and delivering the one that provides only the specifications that users need immediately.



With the various design options captured in the digital thread, leading companies can use them as a basis for the design of the next iteration and facilitate quick delivery of the next MVP.

Updating Design to Ready MVP for Production

Leading companies incorporate user feedback and results from the integrated prototype testing—including decisions about the minimum set of capabilities—into the product’s hardware and software design, modifying it as needed.

For cyber-physical products, hardware design is ready for production when the company and the customer agree that the MVP design has been sufficiently proven in different conditions and still meets user needs. The iterative process leading up to this point directly informs the decision, as leading companies have tested and adapted the design multiple times and incorporated feedback on the user experience. For example, after testing multiple versions with different designs for a keyboard in one of its laptops, Microsoft determined it had reached the final design for the iteration when the material adhered well to enclosures and looked “crisp.” For HP, the design must be scalable— that is, verified that it will work at scale in the field—which includes the ability to configure automatically and work without intervention.

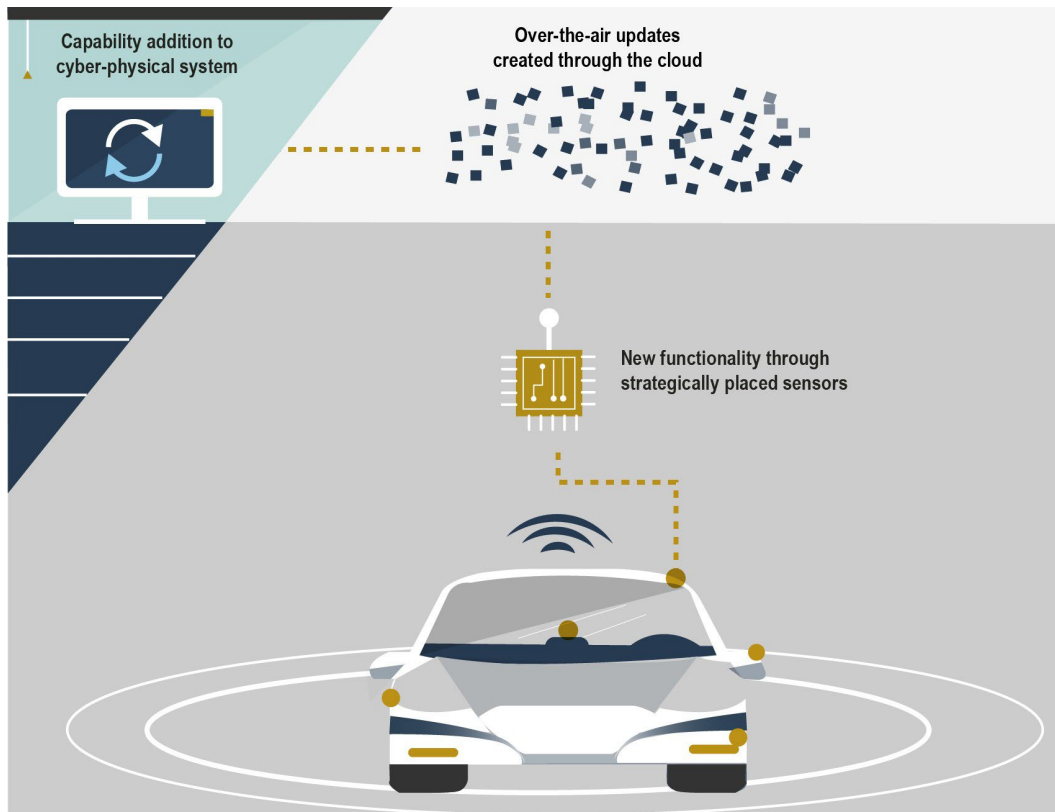
Leading companies are willing to accept an MVP that does not include 100 percent of the features they envisioned initially, provided the MVP still meets user needs. This approach helps to ensure the MVP can be delivered on time, and that the user will have critical capabilities in hand. It also sets leading companies up to improve upon products in the future. For example, NVIDIA determines when the design of the optical lens in a camera is “good enough” based on the extent to which simulated temperature changes degrade the image. HP considers whether the design has sufficient high-quality features to provide value. It aims to meet the vast majority—though not necessarily all—of the proposed requirements with the product, including basic requirements and the ability to improve in subsequent iterations.

Once leading companies are satisfied with the MVP design, they stop designing hardware for the given iteration and prepare parts for production, recognizing that they can add functionality through software updates later. For example:

- Microsoft completes the design of the MVP’s hardware—such as the display of a touchscreen tablet and the wire mesh on top of it—first, and then tunes software algorithms to enable the device to adjust to its surrounding environment or work with a stylus pen.
- Google and HP intentionally design their consumer electronics to enable software updates once they are in users’ hands. Google enables software updates across its products to ensure that products are able to receive improvements throughout their lifecycle.
- VW anticipates providing additional functions and features, such as improved functions for infotainment systems, to vehicles through software updates in the future.

Figure 6 provides a notional example of how leading companies provide these updates to MVPs once they are delivered. By the end of product validation, leading companies have tested multiple design iterations, addressed gaps found in testing with users, and validated the MVP design to ensure hardware is ready for production.





Source: HP and GAO (analysis); GAO (illustration). | GAO-23-106222

Figure 6: Leading Companies Add Functionality to the Delivered Minimum Viable Product through Over-the-Air Software Updates

Leading Companies Optimize Manufacturing of the Minimum Viable Product and Future Iterations

Once leading companies have validated the MVP design, they begin manufacturing products for delivery. The manufacturing planning process begins much earlier in product development, however. Leading companies start this planning while they are still designing the MVP itself. Through this early planning and the use of digital models, leading companies reduce the risk that manufacturing issues will delay product delivery. Leading companies gain further efficiencies and flexibilities through modularity in both design and manufacturing and collect customer and user feedback to continue improving products in subsequent iterations.

Planning for Manufacturing Using Digital Models

We found that leading companies begin manufacturing preparations early, while they are designing the cyber-physical product. As previously noted, leading companies' product design teams are comprised of those designing the product as well as stakeholders who will be producing it after testing and validation. Production stakeholders are involved throughout product design to ensure the manufacturing process can accommodate the design of the product. As a part of planning for manufacturing, product teams use digital twins to design efficiencies into the physical manufacturing complex and the production line that is housed there—which leading companies consider equally important to the design of the product itself.

Digital models optimize factory layout. Digital twins of factories allow for consideration both for workers and machinery before the factory is built. Equipment can be placed and tested digitally to simulate different production processes, changing a worker's position relative to a robot, for example, or the number of steps required to complete an operation. Leading companies have found that this drives greater cost and schedule efficiency. For example:

- NVIDIA is using its products to build a digital twin of a new electric vehicle factory years ahead of breaking ground.
- HP models its manufacturing processes using physics data to simulate an optimal mix of 3D printers and traditional manufacturing technologies. This provides data that HP can use to both confirm that a manufacturing process can successfully be completed and inform adjustments to a manufacturing process in response to irregularities that occur on the factory floor.
- Volvo Group uses digital twinning and virtual reality to test and optimize production flows.

Digital twins reduce risk in planning for production. Digital twins allow production teams to determine ranges of equipment stress and production capacity before production begins, including digitally testing robots to their maximum limits before using them. This knowledge reduces risk to the robots, because the manufacturing process can be adjusted to reflect those limits. Knowing this capacity also reduces the possibility of an expensive equipment replacement. For example, at VW, a robot that can lift up to a maximum amount of weight might exist on the manufacturing line, but a new part could be higher in weight. Process engineers consider these restrictions and possible alternatives during planning; they simulate the robots used in manufacturing to ensure safe and efficient production processes.

Leading companies utilize digital twins for manufacturing to reduce risks involved with advanced manufacturing processes required to produce complex designs. For example:

- Siemens builds electric components, but the company must first build a machine that makes the components. The product team has a digital twin of the machine on the factory floor that they can debug virtually for optimization of the real equipment to manufacture.
- Microsoft uses digital twins to simulate the injection molding production process of hardware components that have very tight variances to the appropriate thickness and weight.
- NVIDIA used a digital twin of the working environment to train robots to operate on the factory floor. It found that the robots complete such training more quickly in a digital twin than in real life.

Digital Monitoring of Production Progress

Once manufacturing begins, leading companies use digital twins to monitor production progress. A Kanban board—a tool developed for Agile project management to observe the flow of work and alleviate bottlenecks—enables teams to keep track of their work, which can be either physical or virtual. Activities are “parked” until the activities ahead of them are cleared, which helps ensure the production team executes key steps. Leading companies monitor the Kanban board and can make adjustments in real time, as needed. Danfoss uses Kanban for product maintenance and improvement, because it tracks process



flow. Identifying bottlenecks in that flow supports materials management for production. SAP uses Kanban with smaller teams for high-frequency delivery development projects. Such visibility into operational performance also provides transparency for management and senior leadership, who can track production progress based on real-time data.

The digital twin of the factory accesses the signals of the physical plant and enables production teams to detect anomalies or differences between the virtual and actual factory in real time. For example, if there is divergence between the two factories, the digital twin can identify it and signal the production team, which can then determine whether potential issues, such as a cyber-attack, may lead to breakdowns in operations. Such real-time data analytics contribute to production efficiencies through automation, as well. For example, Siemens' factory design includes automated deviation management, which saves the quality team from manually reviewing paper documents.

By simulating real-time factory operations using a digital twin, leading companies are able to troubleshoot manufacturing challenges and measure output to monitor schedule performance. The result is not only a physical product, but a digital record of the process as well. Volvo Group, for example, records a digital copy of every unique heavy-duty electric truck it produces and places it in a digital "garage," where it stores the digital design so it can provide the building blocks for future digital twins.

3D Printing for Manufacturing

Leading companies use advanced manufacturing processes, such as 3D printing, to solve specialty production challenges by printing parts directly from digital designs. 3D printing is particularly useful for producing low-volume parts that would otherwise be impossible to manufacture because of the precision required, such as Danfoss' manufacturing of equipment joysticks that conform to the grip of a specific operator.

Since a critical element of designing cyber-physical systems is being able to scale the design for production, product teams must identify when a 3D printed part is appropriate for a specific product.

For example, Volvo Group uses 3D printing for low-volume production of spare parts for already-fielded vehicles.

Leading companies also apply 3D printing for hybrid manufacturing, in which product development teams create a 3D component of a part, such as a pump, that is customized and highly efficient, and make millions of that single component to contribute to a larger system.

Table 8 describes manufacturing inputs to the digital thread used to inform current and future manufacturing processes.

Table 8: Manufacturing Inputs to a Product's Digital Thread

Model	Description
Digital twin	<ul style="list-style-type: none"> During production, in addition to the completed product, the company also has a data set that describes how the product was manufactured, contained in the digital thread. The digital thread documents all the steps in the manufacturing process, from the design of the machinery and toolset to the processes for assuring the product meets the company's quality standards.
3D printing	<ul style="list-style-type: none"> During production, 3D printers create specialized parts on a limited scale.

Source: GAO analysis of company information. | GAO-23-106222

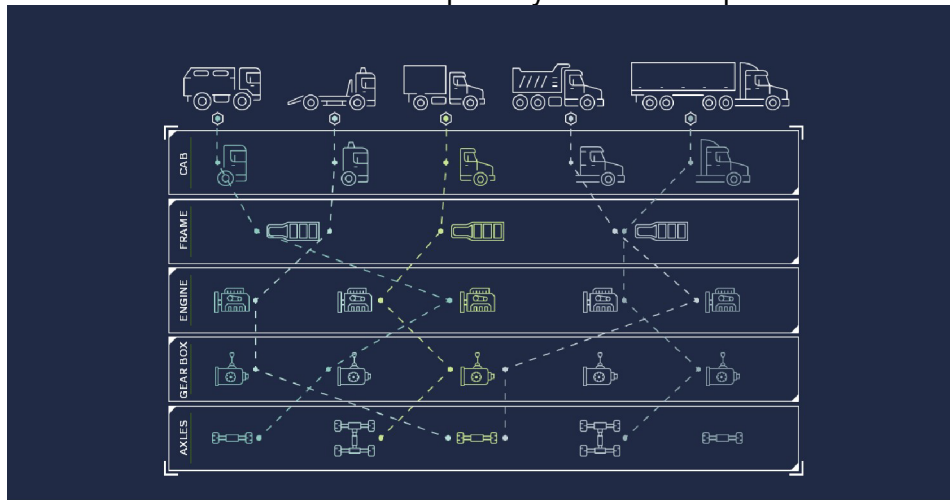


Modular Manufacturing for Efficiency

Leading companies are transforming their production processes to become more flexible through modular manufacturing—producing individual sections that can be assembled into different finished products. Specifically, modularity relies on basic designs that can be added, removed, or replaced to build different products, effectively speeding up the production process while also providing flexibility to customize products.

To support modular manufacturing, leading companies establish common standards that build on top of each other, which allows them to rapidly replicate production and reuse components already proven to work. For example:

- SAP develops standard software and then customizes the product to specific customer needs.
- Volvo Group uses modular interfaces similar to a building block set, and manufactures modules that the company can readily integrate to respond to similar customer needs with a set of scalable solutions. The application of interchangeable modules with modular interfaces helps the product team provide users with a unique product while at the same time reducing parts in production (see fig. 7). As a result, Volvo Group can mix and match modules in multiple ways to meet unique customer needs.



Source: Volvo Modular Interface Graphic (CAST). | GAO-23-106222

Figure 7: Volvo Group Develops Modular Interfaces to Manufacture Vehicles Efficiently

Collecting Feedback to Inform Next Products

After product delivery, leading companies collect user feedback to inform the next iteration of the product or the design of a new product. Leading companies obtain feedback from a variety of sources, including surveys, customer clinics, showcases, and social media. For example, Arista's NDR team asks users open-ended questions about their intended use of the product and its actual performance. At Cisco, product teams solicit feedback from users about the integration and performance of the MVP. For products sold through partners and the reseller community, Cisco collects user feedback indirectly through the seller about how well the application is working. Cisco uses the feedback collected through each of these means to inform improvements to subsequent iterations and products.

Soliciting user feedback about components within a larger system can require several steps. For example, since Danfoss makes the components inside an excavator

rather than the excavator itself, customers may not always see the value in their products, so the company showcases how Danfoss products can work in an end product, such as an excavator. This allows Danfoss to talk to two distinct customer groups—the end user as well as the end-product manufacturer.

Real-time data collected through hardware sensors or automated software also provide statistically significant information on system performance, such as how long it takes for the system to perform a certain task. This type of information provides actionable data in conjunction with qualitative responses on user satisfaction.

- Google products are designed and manufactured so that Google knows when certain buttons are pressed and the actions users take. This information can identify less optimal elements of the user interface, popular features that should become more prominent, or whether functions can be streamlined—for example, if it takes multiple “clicks” to accomplish a task.
- Arista’s NDR team also monitors user data to get insight into how well products are working. The NDR team may see that it is taking longer than expected for a user to move through several pages or steps, suggesting that the product could be more intuitive. The team can determine trends, such as whether users seem to be experiencing the same problems, and match that up with feedback to better understand problems.

Ultimately, leading companies do not view delivery as the finish line in product development. Rather, delivery provides a springboard for establishing a new business case for the next iteration of the product. Leading companies will structure this business case around improvements to the already-delivered MVP. Some of these improvements could be software-only in nature. Others could necessitate changes to both the hardware and software of the existing product. Leading companies will make these determinations on the basis of user feedback provided on the existing product, coupled with technical information and new knowledge captured in that product’s digital thread. This knowledge positions leading companies to identify a new MVP for the iteration and quickly progress it through the same design modeling and simulation, validation, and production and delivery cycles described above.

Appendix III details how leading principles of product development underpin iterative cycles to refine knowledge about the product, information that remains critical to both companies and agency programs alike. Accordingly, we expect these iterative cycles and the practices that propel them will provide acquisition leaders in government with an increased understanding of cutting-edge product development practices, which these leaders can, in turn, use to frame changes to their agencies’ acquisition processes.

We are sending copies of this report to the appropriate congressional committees and other interested parties, including the Secretary of Defense, the Secretary of Homeland Security, and the NASA Administrator. In addition, the report is available at no charge on the GAO website at <https://www.gao.gov>.



PANEL 12. ADAPTIVE ACQUISITION FRAMEWORK: LATEST LESSONS

Wednesday, May 8, 2024	
3:45 p.m. – 5:00 p.m.	<p>Chair: Brigadier General Frank J. Lozano, USA, Program Executive Office, Missiles and Space</p> <p><i>Accelerating the Adoption of Emerging Capabilities</i> Wilson Miles, National Defense Industrial Association, Emerging Technologies Institute</p> <p><i>Conceptualizing the Next-Generation DOD Innovation Ecosystem</i> Dale Moore, The Moore Group LLC</p> <p><i>Best Practices for Longer-Term Service Contracts</i> Mark Kaye, IDA</p>

Brigadier General Frank J. Lozano, USA—is the Program Executive Officer (PEO), Missiles and Space, Redstone Arsenal, AL. He is responsible for the development, production, fielding, sustainment, and international program aspects for assigned missile and space systems. BG Lozano assumed his current position in August 2022.

BG Lozano assessed into the Army Acquisition Corps in 2001 and graduated with an MBA from the University of Texas at Arlington. He served with Lockheed Martin Missiles and Fire Control in Grand Prairie, TX as part of the Training With Industry (TWI) program.

After completion of Command and General Staff College, BG Lozano was assigned as the Assistant Product Manager for Project Manager Soldier Weapons, PEO Soldier, followed by an assignment as an Ammunition and Demolition System Acquisition Manager for the Special Operations Command (SOCOM) and the Army Research Development and Engineering Command (RDECOM).

In 2008, BG Lozano was assigned as a Department of the Army System Coordinator (DASC) for Tactical Missile Systems and Ballistic Missile Defense Systems. BG Lozano was selected to be a Special Assistant for the Army's Vice Chief of Staff, GEN. As the Special Assistant, he provided insight, advice, and counsel on Army acquisition programs crossing many different functional capability areas.

BG Lozano commanded the Product Management Office for Soldier Protective Equipment, PEO Soldier from 2011 until 2014. Afterwards, he was assigned to the Joint Staff, J-8 Capabilities and Acquisition Division. Upon graduation from the US Army War College, BG Lozano was assigned as the Project Manager for the Lower Tier Project Office, PEO Missiles and Space from 2017 until 2020, followed by an assignment as the Integrated Fires and Rapid Capability Office PM. From April 2021 to May 2022 BG Lozano served as the ASA(ALT) Chief of Staff.

BG Lozano's operational and combat experience include deployments to Bosnia, Kuwait and Iraq. His awards and decorations include the Parachutist Badge, Ranger Tab, Legion of Merit, Bronze Star Medal, Joint Service Commendation Medal, the NATO Service Medal, the Army Staff Identification Badge, and the Joint Staff Identification Badge. He is certified in Program Management; Contracting; System Research; Planning and Engineering; and System Test career fields.

BG Lozano is married to the former Anne E. Yesconis of Dallas, TX and has three children: Olivia, Jackson, and Nicholas.



Accelerating the Adoption of Emerging Capabilities

Jacob Winn—is an Associate Research Fellow at the National Defense Industrial Association (NDIA) Emerging Technology Institute (ETI). Winn's research and analysis portfolio includes analyzing the funding of the defense science and technology portfolio, microelectronics modernization issues, and other acquisition and modernization technology policy issues. Previously, he worked on NDIA's Strategy & Policy team. He holds a bachelor's degree in International Affairs and Political Science from George Washington University's Elliott School of International Affairs. [jwinn@ndia.org / jacob-winn@comcast.net]

Wilson Miles—is an Associate Research Fellow at ETI. Miles's research and analysis portfolio includes analyzing the hypersonics and directed energy technology supply chains, ethics of artificial intelligence, the Joint Warfighting Concept, workforce issues, and other modernization technology policy issues. Miles previously held internships at multiple nonprofit organizations including CRDF Global, the Hudson Institute, and the Foundation for Defense of Democracies. He received his master's in International Affairs: U.S. Foreign Policy and National Security from American University's School of International Service and his bachelor's in International Relations from Linfield University. [wmiles@ndia.org]

Arun Seraphin—is the Executive Director of ETI. He was promoted from his previous position as Deputy Director in May 2023. Before joining ETI, Seraphin was a Professional Staff Member on the staff of the United States Senate Committee on Armed Services. His areas of responsibility included acquisition policy, Pentagon management issues, DoD science and technology programs, defense laboratories, Small Business Innovation Research program, manufacturing programs, and test and evaluation programs. He assisted senators in their oversight of DoD policies and programs, including in the authorization of budgets, civilian nominations, legislative initiatives, and hearings. [aseraphin@ndia.org]

Tom Driggers—currently serves as the Product Support Manager/Assistant Program Manager—Logistics, PM Marine Air-Ground Task Force Command and Control, Program Executive Office Land Systems. Driggers previously served in the Marine Corps for more than 18 years, working primarily in defense acquisition and logistics. He is a graduate of the Executive Leadership Development Program, and was a participant in the SIGMA Program, sponsored by the Assistant Secretary of the Navy for Research Development and Acquisition. He was also a participant in the Public-Private Partnership Talent Exchange Program where he served as a Research Fellow with ETI. [tommy.driggers@usmc.mil]

Abstract

The Department of Defense (DoD) is frequently criticized for its slow pace in adopting promising technologies, as well as its inability to field new capabilities rapidly, including those already available in the commercial sector. Despite numerous efforts, including leveraging commercial capabilities, the Department has not been able to implement a systematic means of adopting new technologies, instead relying on one-off cases and special organizations outside the traditional acquisition supply system. The National Defense Industrial Association's (NDIA) Emerging Technologies Institute (ETI) pursued a research effort to address these challenges. The research team used the resulting lessons-learned to explore how technologies, developed within DoD or commercially available, can be quickly and effectively provided to meet critical defense needs.

The report considers past case studies and interviews to develop a schema of six attributes of successful rapid development and adoption efforts. In short, these attributes are 1) high-level support, 2) reduced bureaucratic/regulatory hurdles, 3) available and steady funding, 4) mature technology, 5) manufacturable technology, 6) operational suitability. The report proposes a variety of recommendations including a new acquisition pathway in the Adaptive Acquisition Framework (AAF) as well as a variety of changes to DoD policies, budgeting rules and practices, and the requirements process.



Introduction¹

Acquisition reform is not new to the Department of Defense (DoD). Although reform efforts such as the “Better Buying Power” initiative and the development of the Adaptive Acquisition Framework have improved aspects of Pentagon acquisition processes, some perennial organizational, political, policy, and behavioral challenges that prevent the efficiency required to rapidly deploy new technological capabilities to the warfighter persist (Baldwin & Cook, 2015). Critiques of the acquisition process range from rigorous discussions of issues such as program structures, contracting mechanisms, the so-called “colors of money,”² requirements that limit program offices’ options, and an acquisition culture that does not incentivize well-planned risk taking.

Even while these barriers persist, to the frustration of policymakers and operators alike, it is striking that DoD has a history of “moving quickly” when it seems to matter most. When confronted with a true crisis or emergency warfighting need, the DoD can rapidly move through the design, development, testing, and fielding processes. Yet, despite numerous efforts, including leveraging existing commercial capabilities, the Department has not been able to implement a systematic means of adopting new technologies, instead relying on one-off efforts and special organizations outside the traditional acquisition system.

Several examples of DoD rapid acquisition success during emergencies are especially notable. For example, in the early preparation for the 2003 invasion of Iraq, DoD officials suggested that the development of a powerful “large-yield” gravity bomb would be of significant value in operations against the Taliban. In a matter of a few months, the GBU-43/B Massive Ordnance Air Blast (MOAB) bomb was developed by the Air Force Research Laboratory, and promptly delivered to the theater of operations. It is the most powerful conventional bomb ever built in the United States. Although building on the legacy of weapons that were first developed during the Vietnam war, the MOAB demonstrated that a new weapon could be researched, developed, manufactured, and deployed in record time under urgent need. Separately, the rapid development and fielding of the Mine-Resistant Ambush Protected (MRAP) vehicle in response to the crisis posed by improvised explosive devices (IEDs) also highlights that urgency can translate to rapid fielding.

Though inspiring, these examples are the exceptions that “prove the rule” and do little to dispel widely-held perceptions of the pace and responsiveness of traditional defense acquisition processes. The dominant theme in defense acquisition today has been programs running over budget, behind schedule, and delivering capabilities to national defense that often lag behind commercially-available products. As just one example, the USAF KC-46 Pegasus tanker was based on an existing commercial jetliner—the Boeing 767—yet still required more than eight years from selection to first delivery and has been plagued with operational deficiencies. Even at the smallest scale, the DoD is generally using microelectronic components in its weapon systems that are two generations behind the state-of-the-art available in commercial products. Many also feel that the Department’s incorporation of artificial intelligence/machine learning technology lags behind parts of the commercial sector even for similar uses and applications, despite the fact that much of the early work in AI was funded by the DoD.

¹ This report is an abridged version of an upcoming NDIA ETI report, to be published on our website: www.emergingtechnologiesinstitute.com

² The term “colors of money” in the DoD context refers to the different categories of financial appropriations made for distinct purposes: Research, Development, Test, and Evaluation (RDT&E), Procurement, Operations and Maintenance (O&M), and Military Personnel (MILPERS).



What actually happens within DoD organizations during emergencies that enable them to deliver results? Do organizations leverage acquisition systems during crises, or break them? Are there any attributes of successful rapid capability adoption efforts that can be incorporated into the standard development, acquisition, and deployment process?

Methodology

To characterize the DoD when it's able to develop and transition new technologies, ETI conducted a series of interviews with leading stakeholders across the public and private sector. These individuals included senior-level acquisition professionals, technical development experts, and those who succeeded in rapidly delivering new technologies through programmatic or leadership positions. In total, these interviews provided the foundation for this report. ETI used these findings to explore how available technologies can be quickly and effectively provided to meet critical defense needs and to identify examples of capabilities that are suitable for rapid development and adoption.

In addition to ETI-led interviews, this report reviews two examples of the DoD's rapid development or deployment of new technologies, which provide historical precedent for successful rapid technology adoption. These are the Massive Ordnance Air Blast (MOAB) program and the Mine-Resistant Ambush Protected (MRAP) Vehicle program.

The interviews and research also helped ETI synthesize broad attributes of these programs' success into six principles that can be used as a framework for current and future programs. Both the interviews and internal research help set the stage for ETI's proposal of a new acquisition pathway as well as a multitude of recommendations across the legislative, policy, financial management, and acquisition dimensions that can enable more rapid and effective technology development and deployment.

Case Studies

Overview

The ETI team looked at two examples of past rapid development and deployment efforts since the turn of the 21st century, including the Massive Ordnance Air Blast (MOAB) program and the Mine-Resistant Ambush Protected (MRAP) Vehicle program. Each case study demonstrates a time when the DoD wanted to rapidly develop and transition a new technology at three different scales: the service, theater, and global levels.

Case Study #1: GBU-43/B Massive Ordnance Air Blast (MOAB)

The GBU-43/B program built on existing Air Force Research Laboratory (AFRL) research on larger ordnances. Originally based on modifications to the older, Vietnam-era BLU-82, research efforts intended to build a larger ordnance that could navigate to its target using GPS. The program's inception came in the wake of the September 11 attacks and before Operation Iraqi Freedom, when senior leaders sought more powerful ordnance.

The capability was developed in-house at Eglin Air Force Base by the AFRL Munitions Directorate in response to a Joint Urgent Operational Need (JUON) notice, which provided substantial resources and alleviated bureaucratic hurdles in order to pursue the work. The project was able to use existing parts and infrastructure and effectively work with contractors to integrate new components, such as navigation fins and GPS systems. Ultimately, the quick development of the MOAB demonstrated is one example of the DoD—at the service level—finding ways to transition new technologies.

Urgency: The MOAB program was viewed as highly urgent in the lead-up to Operation Iraqi Freedom; the DoD was committed to producing a heavier ordnance on a



rapid timetable to fulfill a needed operational capability. Secretary of Defense Donald Rumsfeld stated the MOAB was created to put pressure on Iraqi dictator Saddam Hussein to surrender prior to, or soon after, the invasion. The issuance of a JUON indicated this urgency and bolstered efforts to provide both funding and bureaucratic resources towards the effort.³

DoD Leadership Support: Direct support and regular communication with the immediate office of the Secretary of Defense served as an instrumental piece to the development of the MOAB. In fact, the Secretary of Defense approved a DX rating for the MOAB program in 2007, enabling it to receive the highest priority for material delivery.⁴ Additionally, funding was quickly allocated to development efforts, leadership was encouraged to expedite operational tests, and waivers were issued to permit rapid testing.

Broad Technical Requirements: The MOAB program's requirements included an ordnance weight (approximately 18,500 pounds) and GPS navigation. Beyond these two criteria, the program team responsible for work retained wide latitude to use any existing components that could achieve this goal quickly. For example, the MOAB program office leveraged existing components and designs from the BLU-82 and was able to quickly sign a contract with Dynetics for GPS guidance and navigation fins.

Mature and Well-Understood Technology: The primary reason for MOAB's rapid technology development was due to the MOAB program office's decision to leverage existing technology. The MOAB program office intentionally limited the number of "science projects," wanting to minimize the amount of development for every single component. The only truly new parts were the navigation fins and bomb casing. The main difference between the MOAB and previous munition experiments was the attached navigation system. To do this, the AFRL team leveraged existing control actuation kits from the Joint Direct Attack Munition (JDAM), as they did not want to develop an actuator.

Identified Critical Material and Component Needs and Assigned Team Leads Early: Based on the urgency and available resources provided by the JUON, leadership was able to rapidly break down the project into parts and delegate more authority to team leads to move different parts of the project concurrently. These team leads were able to quickly identify key parts of the system (e.g., wiring) and engage contractors for these parts. This helped the system be ready for deployment at a moment's notice after testing was complete.

Leveraged Existing Components: The MOAB program office knew that only a small number of the bombs would be produced, and therefore was able to procure many existing components from other systems without needing to spend time on dedicated contracting. Additionally, because so many parts were used by predecessors, little manufacturing was required.

Rapid Operational Testing: Combined with the high-level political support available to the program, the first operational test took place less than a year after formal program inception. The ability to rapidly gain approvals and gain testing data immediately supported rapid fielding.

³ Joint Urgent Operational Needs are primarily identified by Combatant Commanders to designate the need to accelerate a capability being developed for ongoing joint operations. See Joint Chiefs of Staff (2021) or Defense Acquisition University (n.d.-a).

⁴ All prime contracts, subcontracts, or purchase orders in support of an authorized program are given a priority rating; a DX rating is given to programs that are the highest national priority. The Secretary of Defense has the authority to approve a program DX rated, whose orders must be fulfilled before non-DX rating programs. See Defense Contract Management Agency (n.d.).



The BLU-82 System and C-130 Delivery Provided a Baseline for Rapid Transition to Operational Use: Because a significant part of the system was drawn from the BLU-82, and because of the small number of weapons built, the U.S. Air Force was prepared to deliver the MOAB to the theater using its existing procedures for transporting, operating, and deploying such a munition.

Streamlined Authorities: Because MOAB was identified as a JUON, several authorities were rapidly streamlined (Joint Chiefs of Staff, 2021). For example, a typical capability's path through the Joint Capabilities Integration and Development System (JCIDS) requires reviews of program requirements for compliance with key performance parameters (KPPs), key system attributes (KSAs), and additional performance attributes (APAs). Capabilities identified as JUONs do not require these reviews. The MOAB program was also able to avoid other activities, such as analyses of alternatives (AOAs) which typically provide program offices important yet time-consuming opportunities to evaluate alternative capabilities, schedule plans, or contracting options.

Used Existing Research Budgets: Funding to develop and test was provided through the existing AFRL research budget, and existing Air Force procurement funding was allocated to purchase the initial units after successful testing.

Case Study #2: Mine-Resistant Ambush Protected Vehicle Program

The MRAP program was a DoD initiative that aimed to rapidly develop and deploy heavily armored vehicles to protect military personnel from the threat of roadside bombs, IEDs, and ambushes in Iraq. Because 75% of casualties were attributable to IEDs and other explosive devices in the mid-2000s, MRAP became the DoD's highest acquisition priority. With the goal of developing and delivering better vehicle platforms rapidly, the DoD's effort required significant participation and collaboration between OSD, the services, and various defense contractors. It took strong leadership and a coordinated effort to design and manufacture specialized vehicles with enhanced protection against explosions and ballistic threats at an accelerated pace.

Between February 2007 and October 2009, the program successfully developed and fielded more than 16,000 MRAP vehicles to both Iraq and Afghanistan (Feickert, 2008). The outcome of the MRAP effort was a dramatic reduction in casualties, providing enhanced protection for military personnel and improving their mobility and operational capabilities in hostile environments. The MRAP effort is one of the most well-known recent examples of the DoD fielding a new solution on a theater-wide scale.

Urgency and Focus: The MRAP program was driven by a sense of urgency to protect military personnel from the increasing threat of roadside bombs and ambushes. This urgency created a focused environment that prioritized rapid technology adoption and deployment. Additionally, focusing on an operational outcome mitigated the creation of detailed technical requirements that would have added complexity, thereby increasing time to delivery.

Leadership Support: The MRAP program received strong support from the highest levels of leadership, including the White House and Congress. The crisis-driven nature of the program, coupled with the recognition of its importance, led to dedicated support, enabling rapid decision-making and resource allocation.

Active leadership attention enabled urgency, public-private partnerships, expedited funding, streamlined acquisition processes, ensured leaders could choose experienced personnel for the project team, external support, which were key elements that contributed



to the program's effectiveness. These attributes are crucial for adopting new technologies rapidly and effectively, but require senior leader attention.

Clear Demand Signaling: The DoD was effective from the beginning in its pursuit of an armored infantry vehicle, which can be attributed to its understanding of the threat environment: warfighters needed a vehicle to better withstand IEDs. The DoD shaped the acquisition process to fit this operational challenge. Recognizing that no one company possessed the capacity to produce MRAPs in the required quantities, the DoD awarded Indefinite Delivery, Indefinite Quantity (IDIQ) contracts to nine different commercial companies and agreed to buy at least four vehicles from each. The criteria for awarding a contract were simple: if the company could produce a vehicle that met the minimum operational requirements, they were given a production contract. An important aspect of the MRAP acquisition process was the clear communication of contract parameters to vendors. The DoD thoughtfully shaped the market for the MRAP by continuously communicating its needs throughout its development process, while also preserving competition. Ultimately, five different truck manufacturers were awarded contracts (Bulkley & Davis, 2013).

Broad and Responsive Requirements: The ability of the DoD and industry to deliver the capabilities needed by warfighters was aided by requirements that defined a broad mission objective rather than specific technical performance criteria. That mission objective was to limit deaths resulting from IED attacks on operational forces. Two requirements which significantly drove program activities were: 1) the ability to withstand an underbody blast caused by the IEDs used in-theater, and 2) be able to operate on a slope, such as a hill, between a 45- to 60-degree angle without tipping over.

The simplicity of the overall set of requirements influenced how the acquisition process was shaped. For example, the initial requirements document was only a few pages long, which provided the program with more decision trade space. This is unlike most programs, whose requirements documents can reach up to hundreds of pages (Browne, 2017).

Those responsible for the MRAP's engineering were also in continuous communication with the requirements and operational communities as the MRAP systems evolved, allowing for direct feedback on system performance from operational users to design engineers. For example, initial vehicles were structurally rigid, but quickly received hardware modifications based on feedback from warfighters in theater submitted to an MRAP Executive Committee. The committee consisted of the acquisition, requirements, and in-theater warfighter communities to evaluate program's challenges and successes. Problems were identified by warfighters in-theater, who were in daily contact with the program office as well as MRAP manufacturers. The program office also participated in the medical autopsies of the killed-in-action to understand the physical effects of blasts. A team analyzed the weight and detonation patterns of every IED blast in theater. This information was shared with the manufacturing and engineering teams to ensure that system vulnerabilities were quickly identified and addressed. As soon as a new MRAP variant was developed, it was immediately put into production, oftentimes overnight.

Lead Service Identified Based on Mission Needs: Although the Army is historically the DoD's executive agent for tactical wheeled vehicles, or combat service support vehicles, the Joint Program Office (JPO) for the MRAP program was placed within Marine Corps Systems Command based on its history of taking calculated engineering risks and history of moving quickly when adapting vehicles for prior emergencies (Blakeman et al., 2008). The Marine Corps also had design and operational experience with the Husky route clearance vehicle used by Marine Combat Engineers. This non-traditional program



management decision was another example of prioritizing actual operational needs over standard bureaucratic practice.

Mature Technology: The program was able to leverage technical expertise from existing V-shaped hull vehicles such as the South African Casspir. The knowledge and experience gained from the Casspir, specifically regarding the armor and shock absorption designs, supported the construction of initial MRAP models. Additional existing technologies were used to iteratively improve MRAP vehicles based on operational feedback from warfighters. For example, the MRAP Buffalo version received a rear-door assist mechanism based on commercial-off-the-shelf hardware to improve crew survivability while reducing cost and not impacting production schedules.

Managing Potential Engineering Risks: The severity of the need for a new infantry support vehicle led to strategic decisions regarding engineering risk-taking, the speed of deployment, and the funding allocated for the MRAP program. There was expedited testing and granting of safety certifications to quickly bring *any* benefit to the Iraq and Afghanistan theater rather than *perfect* capabilities. The MRAP program office understood that this speed, and engineering decisions that were made to fit that process, could result in more risk to the warfighter. System improvements were deployed in increments because the need for new, more survivable vehicles improved the operational situation and outweighed potential engineering risks.

Early Identification of Supply Chains: Due to the urgent need to produce MRAPs, the DoD identified gaps in the supply chain early and quickly began to address them. There were several key sub-systems for which the DoD and Congress worked to identify foreign suppliers to alleviate domestic production shortfalls—such as for steel and vehicle tires. Identifying supply chains early is atypical for a program office in the research and development phase. The DoD was successful in addressing its supply chain issues for the MRAP program through clear and constant communication with industry. During the development process, the DoD kept in regular contact with the manufacturers to ensure they received timely information to support preparations for full-rate production.

MRAP Program Received a DX-Rating: To accelerate the manufacturing process, the Secretary of Defense approved a DX rating for the MRAP program (Sullivan, 2009). By giving the MRAP program a DX rating, the DoD assured priority access to available material for MRAP manufacturers, enabling industry to respond more rapidly and meet production requirements.

Experienced Acquisition Workforce: The success of the MRAP program was facilitated by a highly experienced acquisition workforce. These professionals possessed deep knowledge of the acquisition process, understood the urgency of the situation, and navigated through the various authorities and procedures efficiently. In addition to the rotation of professionals from Marine Corps System Command, the Army Tank-automotive and Armaments Command (TACOM) supported the program office.

Streamlining Traditional Acquisition Steps: The Secretary of Defense generally has legal authority to waive various contract requirements related to design, production, delivery, and performance, and did so for the MRAP program (U.S. GSA, 2024). For example, the MRAP was allowed to begin procurement before a systems engineering management plan was in place. In some cases, standard program documentation processes were also reduced. Not all processes were waived, such the Technical Readiness Assessment (TRA; Blakeman et al., 2008).



Transparency with Congress: The MRAP program received significant funding and support from Congress, who recognized the critical need for enhanced support vehicle protection in theater. The speed and level of funding provided was in response to the perceived operational need. The transparent relationship between the MRAP program and Congress helped minimize delays and ensure continued support of the streamlined acquisition process. When provided with a clear request and explanation, Congress was consistently willing to ensure the project had full support.

Appropriate Contract Types Selected to Meet Program Goals: Recognizing that one producer did not possess the capacity to produce MRAPs in the required quantities, the DoD awarded Indefinite Delivery, Indefinite Quantity (IDIQ) contracts to nine different commercial companies, and agreed to buy at least four vehicles from each. The IDIQ contracts allowed the rapid delivery of a small number of prototype units for evaluation at an agreed-upon price to the government.

Based on the evaluations, the follow-on contract vehicles used for the MRAP program were Unfixed Contract Actions (UCAs) so contractors could immediately begin delivering supplies and performing services with full expectation of reimbursement before the terms and conditions of the contract were finalized (DAU, n.d.-a). In the case of MRAP, UCAs enabled multiple companies to begin work on many aspects of the program in order to rapidly field the systems.

“Colorless” Money: In addition to providing both expedited and continuous funding for the acquisition and fielding of MRAP vehicles, Congress also made the funding “colorless.” This allowed the program office to allocate funds to research and development, procurement, operations and maintenance, and upgrades as required, with appropriate congressional notifications.

Discussion

Across these and other case studies, six overarching attributes of successful rapid acquisition emerge that meaningfully contributed to their rapid and successful development and deployment. They provide a methodology for identifying suitable technological candidates for rapid acquisition.

Six Principles for Rapid Acquisition

High-Level Support for Moving Funding and Bureaucracy: When efforts receive high-level bipartisan support from Congress and from across Services and agencies within the DoD, they are much more likely to succeed. First, prioritized and widespread support from senior officials and their staff can often enable more rapid reallocation of resources to meet program needs. This allows program managers to make decisions to address schedule and performance issues and take advantage of technological opportunities that may normally be more constrained by cost. Second, high-level support is essential for addressing sometimes time-consuming processes and standard practices that develop in all bureaucracies, especially those that are risk-averse in nature. That could include expediting decisions to move personnel between teams or departments, expediting acquisition decisions or processes, and waiving appropriate statutory and regulatory requirements.

Few Major Policy or Regulatory Hurdles: Even with the acceleration of program’s funding and acquisition processes, rapid technology efforts can also be slowed if other policy or regulatory hurdles stifle program managers. These could include financial management practices, laws governing reprogramming decisions, requirements processes, or laws and regulations governing competition in the acquisition process. These could also include other issues inside or outside the typical defense sphere, such as those addressing



environmental, ethical, economic, or even treaty obligations. In cases where these barriers do exist, high-level and broad support will be required to overcome them expeditiously. Transitioning the capability to a full program of record is eased by using more outcome-based requirements during development rather than stringent and specific technical requirements.

Funding Can be Provided for Transition Effort: Programs require responsive access to funding to enable rapid development and deployment of new capabilities. Program offices and industry suppliers are prone to work stoppages and other uncertainties when they are not provided access to early and steady funding sources throughout the development process. Additionally, funding that can be used for a spectrum of potential program needs (research, prototyping, testing, production, maintenance, and upgrade) supports rapid development and adoption. The use of flexible contract vehicles to quickly fund program or industry activities, or vehicles that guarantee reimbursement for industry outlays, can shorten the time from design to fielding.

Technology is Mature Enough to Warrant Rapid Adoption: Rapid acquisition programs are most successful when the underlying technology is already sufficiently mature by the time the effort has begun. Using mature technologies allows program offices to significantly reduce the development activities and time needed before testing and fielding. Simultaneously, supply chains and supporting infrastructure can be engaged and expanded more easily as production requirements grow.

Technology is Manufacturable at Required Scale: Rapid capability efforts are more successful when programs have access to prioritized manufacturing and supply chain capabilities that are already capable of producing required systems and technologies, as well as suppliers willing to contract with the government. This is critical for developing and adjusting supply chains, including optimizing sub-tier suppliers arrangements, in support of both operational prototypes and rapidly scalable manufacturing for production.

Suitable for Operational Use: When technologies are easily transitioned into operational use, they are typically characterized by requiring limited new training of personnel, few disruptions to existing logistical processes, consistency with current concepts of operations, and existing supply chains. Where possible, common parts from the existing inventory can be used to reduce logistics tails and enable rapid delivery to operational customers.

Recommendations

A New Acquisition Pathway

Outside of an emergency or a requirements “pull,” even in a situation consistent with the six principles a mechanism would likely be required to enable an emergent capability to be “pushed” to operators.

1. As such, the Secretary of Defense should create a new acquisition pathway and associated efficient resourcing processes, which bypasses the typical requirements validation stage and Planning, Programming, Budgeting, and Execution (PPBE) process, and instead offers opportunities to “push” prototypes into the acquisition process without a stated requirement. This “Immediate Opportunity” Pathway would enable a ready commercial or DoD-developed prototype to enter limited production for short deployments to relevant operators for field assessment. Then, the prototype would follow the typical adaptive acquisition framework guidance and move into the existing rapid fielding path of the middle tier of acquisition (MTA) pathway. The creation of this new pathway and all necessary authorities would require Congressional authorization.



Immediate Opportunity Pathway

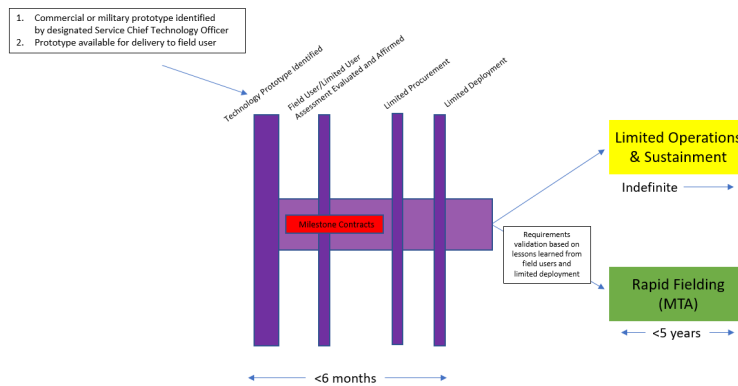


Figure 1. Immediate Opportunity Pathway

The end-users of capabilities—such as combatant commanders via the Joint Capabilities Integration and Development System (JCIDS) system—are chiefly concerned with developing requirements that address an operational or mission need. This can lead to prototypes that could improve mission performance, even incrementally, from entering the acquisition system. The use of the Immediate Opportunity Pathway would require the early identification of technologies to “push” a capability into the acquisition system.

2. This should be conducted by a designated individual, perhaps the Principal Technology Transition Advisor established by Section 806 of the FY24 NDAA within each Service (U.S. Congress, 2023). This designation could be provided to an existing or new office. CTOs should proactively identify advanced commercial or military prototypes, or systems and subsystems actively used in the commercial world, that could be immediately provided to operators for field assessment, regardless of whether or not a requirement has been formally established. These CTOs should be represented on the Functional Capabilities Boards (FCBs) or the Joint Requirements Oversight Council (JROC) to remain apprised of joint needs and to inform the requirements community about emerging capabilities.

To be eligible, the technology in question should possess a technology readiness level (TRL) at or above TRL 4 (AcqNotes, n.d.). It should also be assessed as readily manufacturable by the vendor. A number of authorities exist to access experimental prototypes including Cooperative Research and Development Agreements (CRADAs), Basic Ordering Agreements, and Procurements for Experimental Purposes (DAU, n.d.-c). These authorities can allow the DoD to buy the initial field prototypes from the vendor for validation. Vendors should then be provided with milestone contracts, a series of contracts based on the achievement of technical and performance milestones, to support the limited production and MTA phases as efficiently as possible if their capability is assessed and affirmed by field users. As a result of this process, vendors should be retained and funded along the MTA pathway as long as they continue to achieve agreed upon technical milestones.

Next, field users would have the opportunity to assess the prototype and affirm mission value. These activities should be funded via a line item within either Budget Activity 7 (Operational System Development) or Budget Activity 5 (System Development and Demonstration) within each Service’s Research, Development, Test, and Evaluation (RDT&E) account.

Upon affirmation of value to operators and ability to be integrated into mission activities, the CTO and Service leadership should be authorized to immediately enter into a limited procurement contract to support a condensed deployment of the capability. These activities, including reduced operations and sustainment, could be funded by several sources depending on the timing of the capability discovery. First, if the immediate opportunity is discovered during the annual build of the President's Budget Request, authorities should be provided to allow the DoD to request funding within the appropriate appropriation titles ("colors of money"). Second, if the opportunity is discovered after the budget has been sent, a mechanism should exist to tailor the budget request through dialogue between the DoD and the Congressional authorizing and appropriating committees to request money via the Service's Other Procurement appropriations category. Alternatives, existing mechanisms such as reprogramming authorities could be used to transfer money into the desired program. Finally, if the opportunity occurs outside those windows for modification, the capability should be prioritized for funding through rapid development and procurement initiatives, such as the Accelerate the Procurement and Fielding of Innovative Technologies (APFIT) program.

The service CTO should simultaneously work with the appropriate requirements authorities and combatant commanders to formalize and validate requirements and begin the rapid fielding path of the middle tier of acquisition pathway. This process would provide opportunities to iterate on the original technology—incorporating operator feedback—that was provided to the field and allow the capability producer to scale up production based on the already agreed upon milestone contract. Ideally, this market-shaping activity has already enabled the vendor to ready its supply chain and scale up production in a manner that allows MTA rapid fielding to take place.

This pathway should be evaluated as part of the DoD's modernization of the requirements development process mandated by Section 811 of the FY24 NDAA (U.S. Congress, 2023). This pathway broadly matches the intentions of that provision, and 811(b)(3) calls for re-aligning pathways to fit the mission of a more flexible, technology-forward requirements process.

Other Recommendations

1. Ensure that the existence of, and use cases for, a series of underused authorities is clearly described in DoD policy and instructions. Where appropriate, provide additional guidance or training to acquisition professionals and senior leaders' teams across OUSD(A&S) and the offices of the service acquisition executives.

The DoD possesses a substantial number of authorities that it can use to rapidly develop and/or deploy capabilities, both during times of crisis and whenever various stakeholders encounter a capability that would provide value to a component or the joint force. Some options especially relevant to rapid capability adoption include:

- 10 U.S.C. § 3458 (Legal Information Institute, n.d.-a): Authorizes the Secretary of Defense and service secretaries to rapidly acquire innovative commercial products using fixed-price contracts as a result of a competitive general solicitations known as commercial solutions openings (CSOs). Section 813 of the FY24 NDAA requires the DoD to use CSOs no less than four times per year on behalf of geographic combatant commands, though guidance should recommend the use of CSOs on a more regular basis.
- 10 U.S.C. § 3601 (Legal Information Institute, n.d.-b): Provides authorities for the urgent capability acquisition AAF pathway. These authorities allow for rapid development and contracting decisions once a JUON or JEON has been validated



after its introduction by combatant and component commanders. As of FY24, this has been extended to the secretaries of the military departments (see section 229 of the FY24 NDAA).

- 10 U.S.C. § 4004 (Legal Information Institute, n.d-c): Contracts awarded by competitive selection may include a provision allowing for the development and production of system prototypes, including options to procure additional prototyping units as needed.
- 10 U.S.C. § 4022 (Legal Information Institute, n.d-d): Provides authorities to competitively contract for prototyping projects, and to immediately convert successful projects into production contracts with the original contracted parties without the need for a competitive solicitation.
- 10 U.S.C. § 4023 (Legal Information Institute, n.d-e): Authorizes the Secretary of Defense and service secretaries to procure capabilities from any source for the purpose of experimenting with, or testing, these capabilities for use in national defense.
- 10 U.S.C. § 4025 (Legal Information Institute, n.d-f): Authorizes the Under Secretaries of Defense for Acquisition & Sustainment and Research & Engineering, as well as service acquisition executives, to execute prize competitions for advanced technology development. Competition winners may receive cash prizes or procurement contracts, inducing innovation.
- 15 U.S.C. § 638(r) (Legal Information Institute, n.d-g): As part of a Phase II SBIR/STTR funding agreement, this provision authorizes program offices and prime contractors to agree to sole-source Phase III work from the small business award recipient upon its successful completion of Phase II contract activities. This funding can enable small, innovative companies to more rapidly scale their prototypes into finished systems that otherwise may or may not have been commercialized.

Several new authorizations in the FY24 National Defense Authorization Act (NDAA) are also notable (U.S. Congress, 2023):

- Section 806: Requires the designation of a principal technology transition advisor (PTTA) within each military department. The PTTA will be a member of the senior executive service or general officer charged with identifying promising technologies funded by RDT&E, especially Science & Technology research and development programs, that could transition into military operations. The PTTA will also review technology developments in the private sector, research institutions, and university ecosystem.
- Section 811: Mandates that the DoD modernize its requirements development process through revisions to the JCIDS system. The effort must streamline documents and reviews, especially for programs that are not major defense acquisition programs (MDAPs). It must also re-orient requirements language to avoid “prescriptive language,” focusing instead on “mission outcomes and assessed threats.”
- Section 813: Requires that the DoD use commercial solutions openings (CSOs) at least four times per year on behalf of geographic combatant commands. CSOs function similarly to broad agency announcements (BAAs) but allow for the procurement of innovative commercial technologies to meet mission needs.



DoD guidance must ensure that these authorities are well-understood by the appropriate decision makers, their offices, and acquisition professionals across program offices. Where applicable, DoD guidance should provide avenues to push interesting innovations across the S&T enterprise to the appropriate program offices to determine applicability for prototyping or procurements using one of these authorities.

2. Ensure that the existence of, and use cases for, the wide variety of budgeting and appropriation mechanisms available to the DoD widely used and clearly communicated in the President’s Budget Request and other communications with Congress to support intentional efforts to rapidly field capabilities. Additionally, request new authority as-needed and modify internal DoD management practices in order to expedite allocation of funds to priority efforts.

Rapid technology capability adoption can be supported through a variety of sources of funding that are faster than traditional PPBE processes. Ideally, the funds are provided in such a way that they can support required activities in a timely manner. Not all of the sources need to be traditionally requested and appropriated funds, as this represents one of the slowest methods for providing funding for time-sensitive activities (PPBE Commission, 2024). Examples of sources of funding include specific appropriations for rapid procurement and fielding pots, working capital funds, supplemental appropriations, reprogramming actions, mid-year budget adjustments, Congressional adds, accelerating funding through UCAs, procurement prizes, and private capital investment. These mechanisms will more efficiently and responsively fund industry and government developers, manufacturing capacity, or the support of maintenance for upgraded fielded systems.

Additionally, Congress should raise the threshold for below-threshold reprogramming (BTR) for research, development, test, and evaluation programs to increase program manager’s flexibility to respond to changing circumstances. In line with the PPBE Commission’s recommendations, the BTR threshold for RDT&E should be raised to \$25 million (PPBE Commission, 2024, p. 246).

As the PPBE Commission described, program managers often struggle to “ingest new technology and innovation” without substantial disruption to existing funds. Raising the BTR threshold would, in addition to generally increasing programmatic flexibility, allow for certain rapid procurements of promising commercial technologies for immediate deployment through the new acquisition pathway, or the purchase and testing of new prototypes via RDT&E.

Congressional appropriations and subsequent DoD financial management guidance should allow low-rate initial production (LRIP) to be funded by RDT&E appropriation accounts. Currently, funding within procurement accounts support low-rate initial production efforts. This means that program offices must often request a reprogramming to begin receiving units for test and evaluation, or wait until a future year’s appropriation. Currently, the lack of flexibility creates some scenarios where leftover money is unnecessarily spent based on “use-it-or-lose-it” practices at the end of a fiscal year for potentially unnecessary R&D activities, even when the underlying technology has reached TRL 6 and would have benefitted from proceeding to LRIP ahead of schedule. Allowing programs to immediately use their existing resources to procure testable units would allow promising technologies to be tested and validated for warfighting use in a shorter period of time.



3. The Under Secretary of Defense for Research and Engineering should create and maintain a database for DoD stakeholders which documents successful S&T and SBIR programs and initiatives and relevant performers.

This database should be accessible to stakeholders across the DoD. The database would offer potential solutions for the immediate opportunity pathway described above. At the same time, the availability of well-documented success stories emerging from internal S&T activities can be an asset for decision makers willing to commit resources to reacting to emerging threats and developing capabilities based on previous investments. This database could be matched with operational and technical gaps, such as those identified in urgent needs statements and unfunded requirements lists.

4. Congress should also require the secretary of each service to solicit from the labs a number of items that are suited for rapid capability development effort. These materials should be released roughly on schedule with the submission of the President's Budget Request.

A greater view into the promising, early-stage work conducted by the service laboratories would provide the DoD with an annual exercise allowing it to take greater inventory of its projects, enabling it to recognize technology that could be transitioned into prototyping sooner. The report would also support service programmers' analysis of areas where more funding is required for transition of promising technology efforts, as well as to inform congressional appropriations processes. The information in the database recommended under recommendation 4 would likely be used to support this congressional mandate.

5. The Services should program, within their RDT&E accounts, funding to transition promising S&T concepts into the prototyping process. These funds are most appropriately placed under the control of the program executive officer responsible for acquisition and fielding of relevant systems. OUSD(R&E) and OUSD(A&S) should perform oversight to ensure that the Services are programming money for transition of their own successful S&T projects.

At present, defense-wide programs like the APFIT program rapidly transitions prototypes from small businesses into procurement and the Rapid Defense Experimentation Reserve (RDER) program both expeditiously tests and funds initial production. These programs are beginning to fulfill their role in bridging a particular "valley of death." However, similar sources of funding within the services outside of PEOs face bureaucratic challenges to transition technologies into programs of record.

6. The Office of the Assistant Secretary of Defense for Industrial Base Policy (OASD[IBP]) should conduct studies on the efficacy of market shaping modalities for national security purposes. Where appropriate as a result of these studies, the DoD should request funding for pilot programs to explore innovative contracting arrangements and market signals to the private sector.

The DoD has many of the tools traditionally classified as "market shaping" available to it. These include progress payments, prize competitions, and various types of contract provisions to reward technology developers who reach certain technical milestones. However, OASD(IBP) is well-positioned to look across the industrial base towards promising sectors or companies that would benefit from a more coordinated regime of market-shaping push- and pull-mechanisms to rapidly move a compelling warfighting capability from an early TRL to the field. Market signaling by the DoD entails clear intent and visible funding by a government customer to demonstrate the existence of a real and addressable technology



market. Such market signaling should appear in publicly available budget documentation, which would be better received than high-level documentation, strategic plans, or official statements.

7. The Under Secretaries of Defense for Research and Engineering (R&E) and Acquisition and Sustainment (A&S) should create a joint program to increase temporary transfers and details of personnel with the DoD between technical, acquisition, and operational organizations.

New exchange programs between program offices, S&T laboratories, warfighting components can ensure that acquisition professionals are aware of ongoing developments and needs that are not recognized by an official requirement. Experiential knowledge of the state of commercial industry can help contracting officers determine what incentive structures are correct to incentivize further system development, or to reach a deal for procuring an existing innovative commercial capability.

8. Increase the use of commercial solutions offerings (CSOs), including making use of the expanded authorities provided by the FY2024 NDAA. The USD(A&S) and the service acquisition executives should work to exceed the requirement to use CSOs four times per year on behalf of geographic combatant commands, and Congress should require an annual report on opportunities for CSOs.

CSOs represent a form of solicitation that is well suited to fund the rapid transition of commercial technologies to operational use. Although their use is growing within the DoD, including by the Small Business Innovation Research program, they are still used infrequently relative to their potential utility. CSOs could be used by the principal technology transition advisor, or another designated individual as part of the new acquisition pathway recommended in this report, to rapidly procure high-TRL commercial or defense technologies for warfighter use.

Conclusion

The DoD is frequently criticized for its slow pace in adopting promising technologies, as well as its inability to field new capabilities rapidly, including those already available in the commercial sector. At the same time, there are examples of rapidly-fielded technologies delivered in extremely short order to meet some critical need. Many authorities exist to enable rapid capability development and adoption, but these tend to go underused. In fact, many analysts have opined that the DoD has all of the authorities that it should need to move capabilities into operational use quickly.

This research does find underused avenues in the existing acquisition system. However, these authorities are not sufficient. This report finds six conditions that appear necessary in past cases when the DoD did succeed in rapid development efforts. These attributes—high-level support, limited policy and regulatory hurdles, available and steady funding, mature technology, manufacturable technology, and operational suitability—enable programs to move programs to fielding at a higher rate, both by creating an environment which permits the standard use of more innovative acquisition authorities and removes other barriers to success across the acquisition life cycle.

Outside of an emergency, there are exceedingly few situations where these six principles apply at the same time. However, various changes to the acquisition system would make it more likely to maximize as many principles as is feasible. The creation of an immediate opportunity pathway, for example, would align funding, manufacturability, and operational suitability to allow stakeholders in the DoD who see a promising technology to “push” it to a limited number of operational users by bypassing certain policy hurdles, such



as the need for an urgent requirement to be issued. In other cases, various systems could be implemented that would increase information-sharing and, as a result, create new high-level advocacy to support development efforts of promising capabilities. A deliberate and sustained effort to seek promising capabilities—mature or emergent—will ensure that the United States retains a technological advantage and maximizes the outputs of its highly productive innovation ecosystem.

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Conceptualizing the Next-Generation DOD Innovation Ecosystem

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Abstract

The Department of Defense (DoD) and its supporting Defense Industrial Base must affordably sustain our long-term competitiveness. Peer adversaries are seeking to change the status quo of the international order in their favor. To deter their aggression, the DoD must learn to create, adopt and adapt new technologies, innovations and capabilities at ever-increasing pace and scale. This requires the development of new mental models and leadership and organizational strategies that leverage the exponential pace of technological development. This research study is a meta-study of relevant research, theory and practice to better understand and articulate the Defense Industrial Base future challenges, enabling conceptual constructs, leadership styles, cultural and operational attributes, technologies, processes and policies that can help provide and sustain competitive advantage. This study converges a range of lessons learned, best practices, and emerging opportunities to develop conceptual views of new and novel operating models at various levels of the innovation ecosystem. These models reflect the theoretical applications of Complex Adaptive and Anticipatory Systems (CAAS) thinking, continuous learning and process improvement, innovation management, advanced technologies, and leadership and management strategies for accelerating cultural change and transformation. The results provide conceptual views, perspectives and mental models that support accelerating the research, development and deployment of advanced integrated warfighting capabilities to deter and defeat adversary aggression.

Key Words: Acquisition, Strategic Thinking, Systems Thinking, Lead Systems Integration, Innovation, Technology, Ecosystem, Learning, Artificial Intelligence, Data Analytics, Complex Adaptive Systems, Value Stream, Leadership, Collaboration, Teaming, Defense Industrial Base

Introduction

The Department of Defense (DoD) faces significant challenges to meet its Title 10 and National Defense Strategy responsibilities. The rise of near-peer and peer threats with displays of aggression and clear strategic intent has led to decreasing global stability, exacerbated by the global COVID-19 pandemic, and created destabilizing disruption and uncertainty. Additionally, these volatile conditions are accentuated by highly competitive global market forces and the exponential acceleration of emergent technologies.

To provide context, the 2024 Annual Threat Assessment of the U.S. National Security Community stated, "During the next year, the United States faces an increasingly fragile global order strained by accelerating strategic competition among major powers, more intense and unpredictable transnational challenges, and multiple regional conflicts with far reaching implications." It also said that, "This competition also exploits technological advancements such as artificial intelligence (AI), biotechnologies and related biosecurity, the development and production of microelectronics, and potential quantum developments to



gain stronger sway over worldwide narratives affecting the global geopolitical balance, including influence within it.” A particular concern is expressed regarding contested spaces and disruptive technologies in that, “the convergence of these emerging technologies is likely to create breakthroughs, which could lead to the rapid development of asymmetric threats, such as advanced UAVs, to U.S. interests and probably will help shape U.S. economic prosperity” (Office of the Director of National Intelligence, 2024; *The U.S. Defense Industrial Base: Background and Issues for Congress*, 2023).

To address this challenge, the 2022 National Defense Strategy states, “we will prioritize coordinated efforts with the full range of domestic and international partners in the defense ecosystem to fortify the defense industrial base, our logistical systems, and relevant global supply chains against subversion, compromise and theft” (*National Defense Strategy of the United States of America*, 2022), and the 2024 National Defense Industrial Strategy offers a strategic vision to coordinate and prioritize actions to build a modern defense industrial ecosystem that is aligned to the NDS” (*National Defense Industrial Strategy*, 2023).

Innovation ecosystems are considered to be dynamic and ever-changing co-evolutionary systems that compete and cooperate and that include a wide range of participants and contributing institutions with shifting patterns of resources, power and relationships that are continually influenced by internal and external forces. An innovation ecosystem takes an explicit systemic lens and is comprised of enabling policies and regulations, access to necessary capital and infrastructure, and a culture that promotes openness, digitalization, innovation and entrepreneurship through extensive and diverse networks and ubiquitous productive relationships taking a collective approach toward a common overarching vision and goals (Moore, 1996; Oh et al., 2016).

This research paper is a meta-study to converge, abstract and extend the most enabling and relevant research, theory and practice to better understand and articulate the Defense Industrial Base (DIB) future challenges, new and enabling conceptual constructs, leadership styles, cultural and operational attributes, technologies, processes and policies that can help provide and sustain competitive advantage. It synthesizes a wide range of insights and perspectives, lessons learned, best practices, and emerging opportunities to offer new mental models and conceptual frameworks for subsequent inquiry, reflection, dialogue and consideration at various levels of the DoD Innovation Ecosystem that can integrate these insights and foresights into a coherent whole.

Background

The complexity and scale of the DoD and its DIB makes adoption and adaptation of new and enabling technologies very difficult. The National Defense Industries Association Vital Signs 2023 Report states that the defense industry employs approximately 1.1 million workers and includes nearly 60,000 companies as of 2021 with spending and DIB contracts in all 50 states and the District of Columbia totaling \$390 billion (*NDIA Vital Signs 2023*, 2023). The dramatic consolidation of the DIB since 1980 from 55 to 5 major defense firms has decreased competition and negatively affected cost, schedule and performance of defense acquisition projects (*The U.S. Defense Industrial Base: Background and Issues for Congress*, 2023). The DoD Innovation Ecosystem as currently articulated consists of 281 individual organizations (Defense, 2024). This complexity represents unbounded potential for ecosystem-wide synergies, innovation and transformation to sustain its competitiveness. The DoD suggests that the United States needs “healthy, resilient, diverse and secure supply chains to ensure the development and sustainment of capabilities related to national security” (*The U.S. Defense Industrial Base: Background and Issues for Congress*, 2023).



With this complexity, a number of formidable efforts to help drive sustained competitiveness have been conducted. These have come in the form of strategies, plans and comprehensive assessments to help guide critical investments, actions and policies to improve. The following synopses provide the design and architecture foundations for this study to help conceptualize the Next Generation DoD Innovation Ecosystem.

The 2023 DoD Small Business Strategy underscores the importance of small businesses. It highlights the desire to harness the power of America's small, innovative, and agile companies to grow their contributions to the defense mission and to make it easier for small businesses to work with the DoD. It recognizes that small businesses provide our most creative entrepreneurs and most driven workers and that it is imperative that they be more engaged (*Small Business Strategy*, 2023).

The DoD Software Modernization Strategy is focused on accelerating the DoD Enterprise Cloud Environment, establishing a Department-wide Software Factory Ecosystem, transforming processes to enable resilience and speed, and institutionalizing the Development, Security, and Operations (DevSecOps) culture and process to automate, monitor and apply security at all phases of the software lifecycle (*Department of Defense Software Modernization Strategy*, 2021). The DoD DevSecOps Strategy Guide advocates for a Continuous Authorization to Operate (cATO) software governance process to underscore that “software is never done,” as described by the Defense Innovation Board. It also recognizes the need for software factories as part of large software supply chains to create pipelines of continuous software feedback loops and delivery. These software factories are driven by the “Relentless pursuit of Agile principles and culture” and a “mandate for baked-in security via integral and comprehensive security practices across the entire supply chain leveraging Zero Trust” principles” (*DoD Enterprise DevSecOps Strategy Guide*, 2021).

The DoD Digital Modernization Strategy highlights the Joint Information Environment (JIE), which is comprised of a set of discrete initiatives to support continual and comprehensive Department-wide Information Technology Modernization and advanced DoD information superiority. It is designed to support innovation for competitive advantage, evolve cybersecurity and resilience, and cultivate talent for a digital workforce by modernizing network, service, cloud and data center capabilities to enhance enterprise collaboration and provide enabling tools most affordably (*DoD Digital Modernization Strategy*, 2019).

The National Defense Science and Technology Strategy 2023 emphasizes the need for closer alignment across the science and technology continuum throughout the broader DoD Innovation Ecosystem. This strategy identifies 14 critical technology areas (Defense, 2023). Similarly, the National Science and Technology Council identified 19 critical and emerging technology categories and 104 sub-categories. These technologies are being combined and integrated to provide synergistic effects and capabilities. It delineates strategies to create and field capabilities at speed and scale by fostering a more vibrant ecosystem, strengthening collaboration with international allies and partners, non-traditional partnerships, applying innovation in industrial processes, continuously transitioning capabilities, communicating clearly, and protecting critical technologies (Council, 2022).

The DoD Office of Strategic Capital (OSC) was established to rectify the investment gaps that exist to help attract and scale private capital to technologies critical to the national security of the United States. Currently, the OSC is focused on component-level technologies with broad commercial application using financial tools such as loans and loan guarantees to complement private capital and create a multiplier effect. Strategic capital will



be focused on the application of public incentives and private funds to achieve national security priorities and is complementary to existing DoD Science and Technology, Research and Development, and Procurement Programs (DoD, 2024).

The DOD Adaptive Acquisition Framework represents the current baseline of guidance for DOD Acquisition Programs and provides new pathways for programs to follow to be more responsive to warfighter needs. Much attention has been placed on Rapid and Mid-Tier Acquisition as well as Software Development using the DEVSECOPS approach (University, 2024).

The Section 809 Panel Report of the Advisory Panel on Streamlining and Codifying Acquisition Regulations provides an extensive assessment that includes moving toward a more market-based approach. Portfolio management and process improvement are identified as key areas of focus to help reduce risk, apply more agile and adaptive methods, enable innovation, streamline, be more flexible, eliminate non-value-added documentation and approvals, and facilitate better communications with industry. The intent of the study was to “understand that DoD’s priority is defending the nation, and the DoD’s acquisition systems mission is to delivery lethality to warfighters by providing innovative products and services that allow warfighters to obtain and maintain superiority over near-peer competitors and non-state actors,” and to make recommendations that can “change from an industrial era bureaucracy to a more streamlined, agile system able to evolve in sync with the speed of technology innovation” (*Report of the Advisory Council on Streamlining and Codifying Acquisition Regulations*, 2019).

The Commission on Planning, Programming, Budgeting and Execution Reform highlighted 28 recommendations to help improve alignment of strategy and budget, foster innovation and adaptability, strengthen relationships between the DoD and Congress, modernize business systems and data analytics, and strengthen the capability of the resourcing workforce. The Commission’s work was influenced by two persistent trends: first, the emergence of the People’s Republic of China profoundly threatening the rules-based order, and second, the pace of global technological innovation and its continued acceleration. As a result, the Commission is calling for a transformational change in the Defense Resourcing System to support U.S. national security in an increasingly dangerous world (Hale & Lord, 2024).

The Atlantic Council Commission on Defense Innovation Adoption Final Report assessed the DoD innovation landscape and highlights the following challenges in adopting defense innovation (McNamara et al., 2023):

- 1) Outdated R&D Model
- 2) Long Timelines and Inflexible Execution
- 3) Fewer Companies Providing Defense Solutions
- 4) Valleys of Death
- 5) Hamstrung Workforce
- 6) Program-Centric Acquisition
- 7) Cumbersome Reporting from DoD to Congress
- 8) Limited Understanding of Emerging Technology

All of the insights from these strategies, studies and reports provide critical inputs to the design and architecture of the re-conceptualized Next Generation DoD Innovation Ecosystem as articulated in this study. A perspective worth noting is that the DoD has created a plethora of incubators, accelerators, pathways and various mechanisms to accelerate innovation. Concerns have been raised that these organizations are simply storefronts and orchestrators to help guide non-traditional firms where to go to make the



right connections within DoD organic organizations who are responsible for and routinely perform the requisite research, development, integration, test and evaluation of new technologies and innovations for program offices supporting programs of record (POR). These interfaces are critically important, but opportunities for consolidating, integrating and streamlining these intermediaries should be considered (Carberry, 2023).

The DoD Innovation Ecosystem is a microcosm of our larger national society but is a critical component to our National Security Innovation Base (NSIB). The RAND Corporation researched “The Sources of Societal Competitiveness: How Nations Actually Succeed in Long Term Rivalries,” which offers important insights to guide this research and the importance of taking a holistic ecosystem-level view. Key findings associated with national competitive success include national ambition and will, unified national identity, shared opportunity, an active state, effective institutions, a learning and adapting society, and competitive diversity and pluralism. As the study suggests, “learning is the essential foundation for adaptation, and adaptation is the practical application of learning” (p. 212), while “knowledge is the basic fuel for the engine of societal and competitive progress” (p. 217). Importantly, “Lasting competitive advantage in an uncertain global environment and a changing economic and technological context calls for emergent, bottom-up creativity, constant experimentation, and spirit of adaptation” (p. 3; Mazarr, 2022).

Considering the future, the NATO Science & Technology Trends: 2020-2040 report focuses on emerging and disruptive technologies as identified by over 6,000 active scientific and technical personnel with four overarching characteristics that are expected to guide future military development: intelligent, interconnected, distributed and digital. The report recognized the disruptive potential of data, AI, autonomy, space and hypersonics and expects the effects to come from their complex combinations and interactions. Organizationally, the five objectives of the NATO Science and Technology Organization are to be: innovative, integrated, inter-connected, insightful and to have impact (*Science & Technology Trends 2020-2040: Exploring the S&T Edge*, 2020).

The Air Force Global Futures Report: Joint Functions in 2040 provides an assessment of potential future operating scenarios and highlights the transformational potential of advanced technology and its impact and implications on the future joint force (Futures, 2023). Of particular interest for this study is the concept of the “metaverse” as highlighted in the Report. The metaverse concept merges both digital and physical domains into a fully immersive, virtual space transcending national borders and promoting continued interconnections and interactions at a global scale. The metaverse by its nature is an essential convergent technology for consideration in conceptualizing the future state of the DoD Innovation Ecosystem. It has been described as “a massively scaled and interoperable network of real-time rendered 3D virtual worlds and environments. These can be experienced synchronously and persistently by an effectively unlimited number of users with an individual sense of presence. The metaverse allows its users to have an immersive experience in a virtual environment, in which they can interact with each other, conduct business and forge social connections through their virtual avatars (Anderson & Trainie, 2022; “Toward a Successful Metaverse: The Case for Measuring Enabling Factors,” 2023). The metaverse, as conceptualized, is well positioned to drive the next stage of the industrial revolution by transforming all aspects of business across enterprise functions, including new employee experiences, new ways of working, and new-generation operations. It represents an anticipated \$5 trillion market by 2030 as it integrates transformative technologies across industry value chains, including digital twins, spatial computing, artificial intelligence, Web3 and blockchain. Cross-industry collaboration and synergy are required to fully build and realize the potential capabilities (Anderson & Trainie, 2022; *Exploring the Industrial*



Metaverse: A Roadmap to the Future, 2023; *Value Creation in the Metaverse: The Real Business of the Virtual World*, 2022).

To place our U.S. innovation competitiveness in a global context, the World Intellectual Property Organization (WIPO) has released their Global Innovation Index 2023, which assesses 132 countries across seven major categories: Institutions, Human Capital Research, Infrastructure, Market Sophistication, Business Sophistication, Knowledge and Technology Outputs, and Creative Outputs supported by 27 detailed subcategories. The U.S. ranking is #3 overall. As the Index suggests, U.S. improvements can be achieved in its Institutions, Human Capital and Research, Infrastructure, and Creative Output categories (*Global Innovation Index 2023: Innovation in the Face of Uncertainty*, 2023).

The Heritage Foundation produced its 2024 Index of Military Strength report to help place the present state of the U.S. military competitiveness in context. This report summarizes the Global Operating Environment, Threats to U.S. Vital Interests, and U.S. Military Power. They have assessed that the most concerning operating environment is the Middle East due to the political instability. The threats to U.S. Vital Interests come from China, Russia, Iran, North Korea and Non-State Actors, and are assessed as very concerning, and the Behavior of Threats, the Capability of Threats, and the Threats to U.S. Vital Interests are assessed as high. As these threats emerge, the U.S. Military Power overall is rated as Weak, with the Army Capacity, Navy Readiness, Marine Corps Capacity rated as Weak and the Navy Capacity and Air Force Readiness rated as Very Weak (Wood, 2024).

This context and the significant challenges we face are the impetus for this study, and the expressed need to rethink and reimagine how the DoD can best position itself, harness its full potential, and transform its operations for a new paradigm of operations that is driven to out-innovate, out-compete and out-perform potential adversaries in this highly contentious and threatening global context. The DoD has expressed the need to develop ever-more affordable solutions to deter these challenges, at a pace and scale reflective of these contextual dynamics, and under increasingly difficult budgetary pressures. This situation necessitates new and better ways of thinking and performing, to develop the disruptive innovations needed, and to utilize the available resources most efficiently and effectively. To do so requires creativity, imagination, and ingenuity at all levels to unleash the latent potential that exists across the DoD DIB, including academia, industry and government, and to integrate the best research, theory and practice and to synergize enabling technological capabilities in anticipation of future deterrence and potential conflict.

“The DoD continues to face challenges quickly developing innovative new weapons. These challenges even with their recent reforms to its acquisition process intended to help deliver systems to the warfighter in a timely manner.”

2023 GAO Highlights
(*Weapon Systems Annual Assessment*, 2023)

“DoD must undergo a generational transformation to build the enduring advantages that will deter the nation’s adversaries far into the future.”

“DIU 3.0” Scaling Defense Innovation for Strategic Impact,
CNAS, 2024

The Research Questions for this meta-study are:

1. What are the major factors and trends that will impact the future of DoD Acquisition?
2. What are the barriers and constraints to accelerating innovation into enabling capabilities across the DIB?



3. How can the DoD's Adaptive Acquisition Life Cycle evolve and transform to accelerate and exploit innovation, and best sense, anticipate and adapt for the future from a strategic perspective of the DoD innovation ecosystem?
4. How can the DoD be best organized, structured, and led to operate most affordably and meet the emergent and disruptive needs and requirements of the future?

Methodology

This study covers a broad span of disparate yet related and salient research topics to help conceptualize, develop and architect the DoD's Next Generation Innovation Ecosystem, as shown in Figure 1. Key terms and documents in each of these referenced areas were searched, reviewed, and assessed, while major themes and take-aways were identified. These were then assimilated and used for conceptualization and integration purposes into large-scale conceptual models to reflect the core concepts. The references used reflect a top-level holistic approach to scanning the broad range of the available literature to offer new insights and foresights focused on improving the DoD's Innovation Ecosystem. The convergence of these research sources and their findings, themes and concepts are brought into focus via highly abstracted and integrated mental models to help inform the design and architecture of a Next Generation DoD Innovation Ecosystem. Aggregated visual models are provided to simplify the complexity inherent in the existing DoD Innovation Ecosystem and to support and enable purposeful strategic thinking, understanding and dialogue to guide toward final design concepts and architectural solutions.

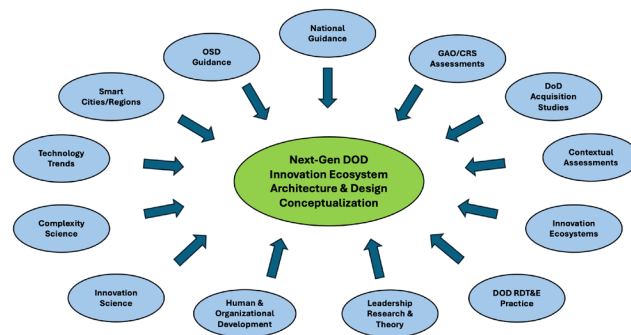


Figure 1. Meta=Study Domains for Conceptual Convergence

Research Questions

1. What are the major factors and trends that will impact the future of DoD Acquisition?

This research has identified major factors and trends that are impacting the future of DoD Innovation, including the ability of the DoD Acquisition system to adapt and adopt to changes and opportunities in the strategic environment. The following provides the major factors and trends identified in this research that require the development and deployment of a Next Generation DoD Innovation Ecosystem-level design and architecture.

A. Exponential Technology Accelerations/Emergent Disruptions: Technology is advancing at ever-faster rates, unleashing ever-more disruptive capabilities. The accelerated development of these critical and emerging technologies has been characterized as exponential, and even super-exponential, in terms of their rates of development. The strategic environment has been assessed and characterized as 'E-VUCA,' which represents the exponential acceleration of technology coupled with ever-increasing levels of volatility, uncertainty, complexity, and ambiguity. As a result, it is

recognized that the DoD must generate more innovation faster, and at greater scale than ever before (Jensen & Largent, 2018; Kurzweil, 2005; West, 2017).

B. Pace and Scale of Commercial Technology Research and Development:

There exists a vastly increasing opportunity landscape for the DoD as the result of advances in emergent technologies. New innovations are being fueled by a complex combination of entrepreneurship coupled with angel and venture investments, the rapidly scalable global commercial technology sector, and a new generation of advanced developmental tools and capabilities facilitating the accelerated development of both software and hardware. The ability for the DoD to adopt, and in many cases adapt, these new developments from commercial industry is a significant paradigm shift that must be specifically addressed and seamlessly incorporated into the flows of system development. Commercial technology developments have been supported through various venture investments as well as Federal Government-wide Small Business Innovative Research (SBIR) and innovation-related programs. The awareness, assessment, development and transition of these enabling technologies in a timely manner remains challenging and is an important design and architecture consideration for the DoD Innovation Ecosystem (Board, 2023, 2024).

C. The Imperative for Continuous Change and Transformation at Scale and at Pace:

To pace the threats and adapt to changing geopolitical conditions, it will be necessary for the Defense Innovation Ecosystem to embrace the need for agility and to create the conditions, climate and culture as well as the structural attributes that can evolve, morph and adapt at the pace and scale necessary – the speed of relevance. Core to enabling these conditions is the development and deployment of relevant change leadership skills that can engage and support continuous and adept reinvention and renewal in both organizational and system design, development and deployment. New leadership models and management capabilities are required to maintain competitiveness in a globally integrated and increasingly competitive landscape. Leaders must create and support the emergence of new cultural paradigms across the enterprise, and across broader ecosystems, to unleash human ingenuity and potential with the management and execution capabilities to bring new capabilities to the warfighter and every increasing rates (Garamone, 2024).

D. Need for End-to-End Acquisition Development Acceleration: It is recognized that the research, development, test and evaluation as well as manufacturing, production, assembly and delivery of new and enabling capabilities must accelerate well ahead of the rate of the threats, both current and anticipated. As DoD systems become increasingly complex, the demands for design, integration, testing and evaluation to produce the requisite data and analysis that ensure system effectiveness, safety, affordability and maintainability is an increasing challenge (Modigliani & Ward, 2019).

E. Continuous Innovation for Superior Capabilities at Scale: DoD capabilities must be appropriately scaled and deployed at the speed necessary to be relevant in a potential conflict. As systems become increasingly complex and integrated, the time and resources required to accelerate delivery in quantities across supply chains is particularly difficult. The DoD is becoming increasingly reliant on the robustness and resiliency of its supply chain, which has become extraordinarily complex, and potentially fragile and vulnerable to disruption.

F. Affordability: DoD acquisition system costs have continued to increase across the full life cycle. These costs can be attributed to increased government and contractor labor, material, and supply costs; inflation; and, most significantly, growing system complexity. Increasing system complexity drives data analysis, testing and integration



expenses and remains a factor in the cost growth of weapon system development, production, deployment, and support. DoD cost growth is a growing challenge given CBO projections that the federal budget deficits total \$20 trillion over the 2025–2034 period and federal debt held by the public reaches 116% of GDP (CBO, 2024; Porter et al., 2015).

G. Advanced Digital Tools and Enabling Capabilities: A major shift for the DoD and the commercial sector is the current digital transformation to create end-to-end digital threads, which include digital twins, model-based engineering, and advanced analytical capabilities. The fundamental principles of system development remain unchanged; however, the ways in which technologies can augment the inherently complex processes is significant. As artificial intelligence (AI), generative AI, Large Language Models, and eventually the disruptive capabilities of quantum computing enter the flow of systems development, further evolutionary and revolutionary changes will be necessary (*DoD Digital Modernization Strategy*, 2019).

H. Smart City and Smart Regional Concepts: Around the world, the application of the concepts of Smart Cities and Smart Regions are growing rapidly. This can provide important insights into the various considerations for DoD Innovation Ecosystem design and architecture. Being “smart” is an amalgam of different components that are working together, taking quick actions and making efficient decisions. It implies the use of computing and associated technologies such as Internet of Things (IoT) instrumentation and sensors, algorithms and cloud computing to enable new insights and intelligence to improve operations and decision making. But it also reflects a new cultural norm and social way of life that by its nature is constantly improving and growing capabilities as an “organic whole.” The major components of Smart Cities include Technology Factors, Institutional Factors and Human Factors. Technology includes both hardware and software with advanced computing, sensors and algorithms, virtual technologies, mobile technologies, and digital networks. Infrastructure includes governance and policy as well as regulations and directives that lead to smart communities and smart growth. The People component includes human factors such as knowledge and social capital, learning, creativity, diversity and education in this context (Nam & Pardo, n.d.; Yashar. n.d.).

I. Workforce Talent and Skills: With the rapidly accelerating emergence of new technologies and application toolsets, there are increased demands for personnel with the knowledge, skills and abilities to support weapon system acquisition across their life cycles. This is particularly true where subject matter experts in emerging technologies are required.

“One of the conclusions from studying the management of defense acquisition is that it requires specific technical knowledge and skills well beyond what many recent government managers, senior military officers, and assistant secretaries have acquired.” Defense Acquisition Reform 1960-2009 (Fox, n.d., p. 195)

The competition for talent continues to grow and challenge the ability of the DoD to support leading edge technology development activities at the pace and scale required. This demand signal comes from both national security and commercial industry and is only growing, necessitating aggressive strategies to attract, develop, retain and obtain the workforce needed to support next generation weapon system development and support.

“The first and absolutely necessary ingredient is knowledge. Technical innovation is itself, almost by definition, a new idea. But new ideas are rooted in knowledge that makes the new idea conceivable and practical...it is not possible to enable innovation unless one has a deep knowledge of the science and associated technology.”

Frank Kendall,



2. What are the barriers and constraints to accelerating innovation into enabling capabilities across the DIB?

A. Increasing System and Organizational Complexity: As DoD weapon systems become increasingly complex, the requirements to develop and deliver advanced capabilities become increasingly costly and time consuming. Commensurate with these developments, the DIB is a highly complex organizational ecosystem with a broad range of actors, each working toward local, corporate, national and/or global goals and objectives. As a result, there are growing requirements for social networking and connectivity to “connect the dots” and to facilitate collaboration and learning to get to a requisite level of understanding for meaningful action. This combination of system and organizational complexity adds significant challenges for both leadership and management as well as Innovation Ecosystem design and architecture (Cross & Parker, 2004; Xu et al., 2017).

B. Lack of Awareness, Learning, Understanding and Actionable Knowledge: A prerequisite for accelerating innovation and its development to create new and enabling capabilities is to be aware of the range of opportunities and then to develop an understanding if and how that innovation can solve a critical need or requirement. Once that understanding occurs and is shared across the key stakeholders, the new knowledge becomes actionable. Once knowledge is actionable, a clear vision with strategies and plans can be developed to support and execute the developmental process. This can include prototyping, modeling, test and evaluation and ultimately an accreditation or certification of the innovation for warfighter application in the intended context. The importance of making knowledge available at critical junctures in the DoD Acquisition Process is highlighted in the *GAO Weapon Systems Annual Assessment* (2023) to support critical programmatic decision points.

C. Lack of Requisite Skills and Enabling Capabilities: To support the development and application of an enabling innovation, the knowledge, skills, abilities, and capabilities must be in place. Without adequate and sufficient knowledge and skills across the broad range of applicable actors, within developmental disciplines, the transition of enabling innovation will be substantially impeded as buy-in is often required. Salient capabilities must be in place in terms of infrastructure, tools and facilities that support the acceleration of enabling innovations. All capabilities and resources for innovation development, maturation, risk reduction, testing and evaluation must be available and ready to support the critical path for accelerated development to delivery (McNamara et al., 2023).

D. Lack of Creativity and Ingenuity: Enabling innovation requires the creativity and ingenuity of subject matter experts thinking in new and novel ways to develop new and novel solutions. The development and integration of these capabilities combines deep subject matter expertise and the ability to consider new and novel concepts, ideas and capabilities into larger scale architectures and designs. This often requires the ability to relate or associate new information with what is already known and to think in non-linear, creative, improvisational ways that challenge the status quo or existing paradigms (Feinstein, 2023; Koutstaal & Binks, 2015).

E. Bureaucracy – Lack of Streamlined & Accelerated Processes: Complex organizations, enterprises and ecosystems can often have confusing, duplicative, or uncertain roles and responsibilities which can hinder value stream process flows. Without requisite clarity of process flows, and associated roles and responsibilities, the development and delivery of innovation can become onerous and time-consuming. Streamlining processes via process mapping with associated data analytics is a first step to



systematically accelerating innovation development and delivery. Once existing processes are well understood and practiced, process automation and reinvention can occur. Continuous process improvement can provide the foundations for re-imagining, re-engineering, ideation and ultimately the acceleration of innovation development to delivery (George et al., 2005; George Sr. et al., 2019).

F. Organizational Fragmentation: Organizations are typically hierarchical and decomposed into sub-organization elements to simplify their complexity. The interfaces between organizations can be poorly understood, while the motivations among various organizational elements may be misaligned. Organizations can be fragmented internally as well as between organizations, within and across the enterprise or ecosystem. The establishment of social relationships and networks is critically important. These are built on trust and mutual respect so that actors and entities can seamlessly work together, leverage each other's capabilities, and align to produce commonly held outcomes. Geographic distance and organizational isolation are constraints that can hamper meaningful interactions and learning, potentially creating stovepipes versus a seamless value stream of productive activity where all entities can connect and align for a common purpose (Burt, 1992; Cross & Parker, 2004).

G. Organizational Rigidity: Organizational change has proven to be a very difficult challenge. Organizations often have entrenched cultures, i.e., norms, values, beliefs and artifacts, as well as inertia that can inhibit both the adoption and adaptation of new and enabling operations. Organizational change can be hampered by a lack of awareness and understanding regarding the need and essence of the change, the perception of risk and unclear expectations, and insufficient intrinsic and extrinsic motivations and incentives. Organizations tend to have momentum within an existing paradigm, which may require additional energy, time and resources to address the new needs and opportunities. In order to effectively compete, organizations must continually change and transform to position themselves and fit into the ever evolving and changing competitive landscape (Hess, 2020; Xu et al., 2017).

H. Lack of Innovation Adoption and Adaptation: The opportunity landscape for new and novel innovations continues to expand. Mastering the ability to adopt and adapt innovation opportunities for transition to DoD weapon systems is a critical and increasingly important component of ensuring superior warfighting capabilities. Accelerating this process necessarily must be considered the end-to-end acquisition life cycle to streamline process flows and the creation of value (*Data, Analytics, and Artificial Intelligence Adoption Strategy: Accelerating Decision Advantage*, 2023; McNamera et al., 2023).

I. Lack of Available Resources – People and Money: Not only are relevant knowledge, skills and abilities as well as capabilities required to develop and deliver meaningful innovations, but there must also be the absorptive capacity across the ecosystem to do so along the critical path for innovation delivery. All the requisite resources are required to establish the broad range of capabilities and capacities necessary to effectively streamline innovation development and transition in a timely manner (Hale & Lord, 2024).

J. Climate of Trust: Trust acts as the lubricant that enables social networks to be effective in sharing information through meaningful dialogue to align expectations and resources. Large enterprises and ecosystems need to purposefully develop the social capital necessary to rapidly adapt and build broad-based consensus and understanding that turns into meaningful action. Trust among actors may be hampered by different motivations, incentives and reward systems, so maintaining openness, transparency and fairness



throughout enterprise and ecosystem-level operations becomes imperative (Cross & Parker, 2004).

3. How can the DoD's Adaptive Acquisition Life Cycle evolve and transform to accelerate and exploit innovation, and best sense, anticipate and adapt for the future from a strategic perspective of the DoD innovation ecosystem?

A. Expansive Contextual Awareness and Learning: Contextual awareness from the strategic to the operational and tactical levels is critical to informing DoD Innovation Ecosystem Operations. This is especially important regarding the need for awareness of rapidly emergent issues and opportunities that could be disruptive and fundamentally challenge existing paradigms. The exponential acceleration of advanced technologies is rapidly making existing systems obsolete and ineffective and is requiring continuous change, adoption and adaptation across a broad range of applications. It takes significant time for large-scale organizations or supply chains to develop, disseminate, deploy and institutionalize new ideas, concepts, technologies and shift paradigms, often far longer than the rate at which new changes are emerging. As a result, Dr. Joseph Stiglitz suggests that the importance of developing and implementation technology and learning to do things better is a central focus for society's continuous development and adaptation (Stiglitz & Greenwald, 2014). He notes that the government has a responsibility to build and learning society and that "one of the most important aspects of learning is learning how to organize to manage collectivities of individuals" (p. 49). Learning is rooted in curiosity, inquiry and reflection processes as well as social dialogue and exchange. A leading with questions paradigm helps supports a meritocratic and open environment for increased workforce engagement, curiosity and the generation of new and novel ideas and supports and accelerates learning (Marquardt & Tiede, 2023). Crowdsourcing has been shown, as a form of democratization, to be a highly effective approach to catalyzing new ideas and accelerating learning, building consensus and alignment, and fostering change and transformation at scale (Abbate et al., 2021; Alam et al., 2019; Chesbrough et al., 2014; Chesbrough & Appleyard, 2007; Stadler et al., 2021; Whitehurst, 2015).

B. Master Data, Information and Knowledge Management: The establishment and performance improvements of Smart Cities and Regions as well as global industries highlights the importance of leveraging data, information and knowledge. The ability to sense, make sense and give meaning in complex environments is becoming increasingly commonplace. This phenomenon relies on a foundation of sensors, algorithms, compute capabilities, the cloud, and the human-machine interface and has formed the basis for the Internet of Things (IoT) concept. This paradigm relies on the social capital of human networks to share critical insights, foresights and perspectives to anticipate and develop forward leaning strategies and plans as well as support critical decision making (*Data, Analytics, and Artificial Intelligence Adoption Strategy: Accelerating Decision Advantage*, 2023; Davenport, n.d.; Hurwitz et al., 2015; Ichijo & Nonaka, 2007; Jucevicius & Grumadaite, 2014; Nam & Pardo, n.d.; Nonaka et al., 2008; Subramaniam, 2022; Von Krogh et al., 2000; Yashar, n.d.).

C. Support Mil-Specs/Standards and Commercial Specification Engagement for Innovation Adoption and Adaptation: DoD engagement in specifications and standards communities, both internal to DoD but also those across the government and commercial sectors, is essential to improving technological awareness and accelerating innovation development, adaptation, adoption and transition. These documents represent codified knowledge at the edge of accepted understanding across the broader community. New technologies must be characterized, quantified and qualified to be considered for safety-related engineering applications. Engineers need to know that they can rely on well-



documented performance characteristics to meet stated and derived requirements and design criteria to inform analysis, develop prototypes and digital models, testing and evaluation to provide the basis for establishing confidence and reliability in procurement specifications, drawing callouts and work instructions, i.e., build-to packages for manufacturing, production, assembly and subcontracting. In some cases, emerging technologies can be adopted directly for DoD applications from commercial applications, specifications and standards, but often the unique warfighting requirements drive the requirement for adaptation of new technologies (Possehl, 2021; *Technical Standards, Invention, Innovation, and Economic Growth*, 2018).

D. Map & Streamline Processes and Organize around Process Flows – Create Trans-Enterprise Knowledge and Synergy: As complexity in both organizations and systems increase, greater confusion and obstacles to execution can emerge. Applying systems thinking and process improvement using visualization and data analytic techniques can clarify process flows and roles and responsibilities, as well as support continuous process improvement and automation initiatives. An increased understanding of process flows can help to inform organization design and reconfiguration efforts that further streamline value creation, development and delivery processes. Improved understanding and analysis of end-to-end process flows can create substantial productivity improvements designed to increase speed, agility, and quality while reducing costs. This is particularly important as organizations, enterprises and ecosystems expand the scope of their supply, development, and delivery chains. Supply chains can become bottlenecks or impediments for expeditious innovation delivery, necessitating the ability to monitor and control processes at the ecosystem level. Value stream processes and innovation-based organizations, enterprises and ecosystems need to be purposefully designed for both continuous experimentation to accelerate learning and exploitation of existing innovations to sustain competitiveness. This dynamic, iterative, and integrative capability is the essence of the Ambidextrous Organization concept. Ambidextrous organizations work to strike the balance between focusing on the short and medium term with the longer-term investments in growth so that they are well positioned to change, adopt and adapt as needed. The interface between these two domains has been identified as the Adaptive Space where these critical interactions occur to promote and accelerate innovation development and delivery. An organization has an effective innovation ecosystem strategy when it has both explorative and exploitive activities, proactively aligns innovation efforts and knowledge flows, anticipates future requirements, and partners to secure a key role in the ecosystem (Arena, 2018; Fransman, 2018; George et al., 2005; Nonaka et al., 2008; Subramaniam, 2022; Visscher et al., 2021).

E. Build Social Capital via Mutual Trust and Respect: Innovation Ecosystems are composed of individuals, organizations and enterprises that often are extremely complex and difficult to lead and manage. They require an environment that is open and collaborative such that they can create opportunities for making new connections between individuals, teams, and organizations so that they can work together most effectively. Organizational isolates do not receive the advantages of interchange with knowledge sources that more collaborative organizations obtain. Sharing both tacit knowledge gained through experience as well as explicit knowledge that has been codified is essential to maximize the value that new knowledge and learning can offer. The Nonaka-Tajuchi Socialization, Externalization, Combination and Internalization (SECI) model is based on leveraging critical opportunities to learn and improve. The SECI model scales from the individual level to the group and to higher organizational levels, transforming and sharing salient tacit knowledge so that it can become codified explicit knowledge that improves understanding and the overall corpus of knowledge the organization has to leverage. Continuously creating, updating and combining



new knowledge through social interactions with timely documentation and associated learning/training activities helps to provide the latest knowledge and insights that helps to build alignment and inspire a culture of continuous improvement. Outside of organizations are rich sources of knowledge that few organizations think about how to manage to create value beyond an immediate and specific piece of knowledge or information. Social Network Analysis (SNA) can be used as a powerful tool to assess these internal and external social networks, the levels of social capital that exist, and to find gaps or holes in network structures and pathways (Ichijo & Nonaka, 2007; Nonaka & Takeuchi, 2019; Nonaka et al., 2008; Von Krogh et al., 2000).

F. Create Opportunities at Scale to Connect, Learn and Share: Creating opportunities for social exchange and knowledge sharing across the broader innovation ecosystem will increase knowledge awareness, understanding and social capital, leading to a more knowledgeable and stronger leadership-at-all-levels mindset, attitude and orientation. Forums for exchange and dialogue that span multiple enterprise domains can create the “collisions” that spark new ideas and concepts. As Clay Christensen has suggested, “Breakthrough innovation rarely occurs within a technical discipline, or within a market, but almost always where you create a novel intersection.” Participation by actors in both focused and general events of interest provide important learning opportunities to expand knowledge networks, confidence in leading, and coalitions with a common understanding. Expanding knowledge networks can improve the scale and scope of collaboration and accelerate learning, innovation, change and requisite transformation at scale. Connecting individuals within and across organizations, especially at the enterprise and broader innovation ecosystem level, can create new opportunities and ways of doing business, new ideas and concepts for product development, and help to accelerate the development and delivery of innovation products and services by unleashing the latent potential within the ecosystem overall (Cross & Parker, 2004; George et al., 2005; Yeung & Ulrich, 2019).

G. Embrace Continuous Change and Transformation: Leading continuous change and transformation requires the creation of a climate and environment that offers the opportunity for open-minded exchange and dialogue, collaboration, synergy and learning at scale at the pace necessary to remain competitive. Organizations need help making sense of their context and complexity to accelerate their learning as well as their developmental cycles. A key role for leadership is the giving of sense and putting contextual situations and opportunities in perspective so that they have meaning. Developing the best questions in an open and trusting environment with safety-of-voice helps to trigger new thoughts and ideas, spawn meaningful dialogue and exchange, catalyze imagination and ingenuity, and foster change and transformation at a rate commensurate with the rate of learning, understanding and leadership confidence and support. Creating these conditions, when consistently applied over time, can evolve to become an accepted cultural norm with expectations that motivate and unleash new possibilities as well as create visions for the future that otherwise could not have been imagined (Boulton et al., 2015; Goldstein et al., 2010; Hess, 2020; Koutstaal & Binks, 2015; Marquardt & Tiede, 2023; Reeves & Read, 2009).

H. Innovative Culture and Ecology: A culture and ecology for innovation is now becoming a prerequisite for sustaining competitiveness. Culture is viewed as the norms, values, beliefs and artifacts that embody the nature of the organization. The ecology reflects the mindsets and attitudes intrinsic to organizational operations, as value is created and flows across the interfaces of organizational entities. Cultural change is a top leadership challenge and needs to occur at the frequency and pace of the contextual changes in the external as well as internal environment. Change occurs when there is a strong and rational



motivation, aligned incentives and rewards, clear expectations and communications, constancy of purpose and intent, and visibility of progress and alignment toward a common future vision. An innovation ecology depends on talent, firms involved, institutions, and capital, but more so on the identities, meaning, networking, capabilities, a culture of trust and pragmatic cooperation balancing on the edge of chaos where creativity and innovativeness are at the highest level (Davenport, n.d.; Fransman, 2018; Granstrand & Holgersson, 2019; Iansiti & Levien, 2004; Jucevicius & Grumadaite, 2014; Schein, 2016).

I. Technology-Enabled: Technology development continues to accelerate and disrupt institutions and shift paradigms of thought, operations, and the nature of deliverables as well as impact business models and strategies. Embracing new technologies to stay relevant in the highly competitive landscape is an imperative that mandates continuous adoption and adaptation of new technologies. New technologies are required to maintain relative agility and flexibility and require continuous learning, investment and assimilation into ecosystem-level operations. Technology refresh, while acknowledging the costs of technical debt, is a strategic focus area that requires continual attention and focus (Board, 2023; Council, 2022; Defense, 2023; Jones et al., 2021; Nam & Pardo, n.d.; *Science & Technology Trends 2020-2040: Exploring the S&T Edge*, 2020; Suleyman, 2023; Tapscott & Tapscott, 2016; Taylor, 2016).

J. Open Innovation and Open Strategy Development: The use of open innovation and strategy development collaborative forums, to include crowdsourcing within the innovation enterprise, can accelerate the innovation processes, improve ideation, and promote the development of innovative strategies that promote the emergence of new ideas and competitive strategies. Using an open innovation and strategy approach can change the innovation ecology from ego-systems to an open innovation ecosystem. An ego-system refers to a traditional, rivalrous context in which firms adopt closed innovation strategies with strict control over resources and strong intellectual property rights. An open innovation ecosystem provides a participative and trusting collaborative and integrative context by sharing knowledge resources across organizational boundaries. The transition from an ego-system to an open innovation ecosystem relies on an ecosystem-wide realization of the need to engage and participate, to build cross-organizational and enterprise social ties, alignment toward common goals, and the establishment of multi-way openness built on trust and reciprocity. The democratization of ideas fosters engagement and learning and supports critical change and transformation efforts needed at large scale. Platform technologies issuing important challenges and inquiries have demonstrated significant utility across innovation ecosystems. They help to build consensus and lead to the formation of critical coalitions around innovative ideas and concepts as well as strategic thinking. These open approaches promote a highly democratic and meritocratic climate where the best ideas are surfaced, considered, challenged, refined and ultimately offered for consideration by decision makers (Alam et al., 2019; Chesbrough et al., 2014; Chesbrough & Appleyard, 2007; Jensen & Largent, 2018; Stadler et al., 2021; Whitehurst, 2015).

4. How can the DoD be best organized, structured, and led to operate most affordably and meet the emergent and disruptive needs and requirements of the future?

A network-based approach to understanding, organizing, managing, and leading this complex ecosystem, well-aligned to the DoD Adaptive Acquisition Framework and synergized through appropriate engagement in the DoD 5000.02 Acquisition Process, can further unleash latent ecosystem potential. This is deemed possible through expansive new knowledge creation, sharing and accelerated innovation transition into DoD Acquisition Programs of Record. Applying network analysis techniques with big data analytics and



artificial intelligence can uncover important patterns and opportunities for improvement at large scale, making new and novel connections and building robust relationships for collaboration and synergy.

A. Emulate the Concepts and Theory that Support Complex Adaptive and Anticipatory Systems (CAAS) Thinking: CAAS are designed to reflect a strong sensitivity to contextual and environment changes with the intrinsic ability to rapidly adapt to sensory inputs while anticipating the implications of future trends, disruptions and scenarios. Leveraging Cyber-Cognitive capabilities, innovation ecosystems can combine and synergize advanced compute with human cognitive and open collaborative capabilities to create broad situational awareness, make sense and give information meaning in context, and filter and prioritize salient information to enable rapid decision making and organizational adaptation. This empowers a leadership-at-all-levels orientation and enables actions through trusting relationships that can respond at the required rate and scale to remain competitive (Boulton et al., 2015; De Jong, n.d.; Gharajedaghi, 2006; Goldstein et al., 2010; Obolensky, 2014; Tovstiga, 2013; Yarger, 2008).

“Leaders who try to impose order in a complex context will fail, but those who set the stage, step back a bit, allow patterns to emerge, and determine which ones are desirable will succeed.”

David Snowden and Mary Boone,

“A Leader’s Framework for Decision Making” (Snowden & Boone, 2007)

B. Map, Integrate & Automate the End-to-End Value Stream: It is critical to understand the roles and relationships of various organizations and enterprises in creating and delivering value. The value stream is the flow of value creation across the continuum of processes necessary to develop and deliver products and services. Identifying specific process steps and identifying those responsible for these steps is an important first step. This helps to clarify the roles and responsibilities, interdependencies, and the deliverables at each step, as well as the interfaces between process steps. As value stream inputs, processes, and outputs become better understood, process data can be gathered and analyzed. This can help to understand the barriers and impediments to the process flows so that they can be addressed. Gathering available data as well as instrumenting processes to gain a better understanding of the underlying performance can provide important insights for improvement. Typical process measures include metrics that address quality, speed and cost as well as performance to assess capabilities and capacities inherent in the value stream. Particular attention should be paid to the interfaces or hand-offs between processes to ensure that the needs of the upstream participants are being met and necessarily avoiding the “Valleys of Death.” Envisioning an improved future state can help provide thoughts and ideas for further improvement. Technology is playing an increasingly important role as organizations automate and streamline processes through the augmentation and automation of tasks and workflow reinvention (Abbate et al., 2021; Defense, 2023; George et al., 2005; George Sr. et al., 2019; Yeung & Ulrich, 2019).

C. Educate, Form and Align Enterprises to Engage in the End-to-End Value Stream: Once the value streams are clearly identified and understood, participants need to be aligned to determine where they can add value. Once aligned, the enterprise at large can be engaged and enabled to provide value-added inputs, processes can be executed, and innovative products and services can be efficiently and effectively delivered. Leveraging the power of each organization in an enterprise and the combination of enterprises across the value stream to optimize engagement enables learning, innovation and value-added contributions at scale. This strategy ensures that the best ideas and thinking are made



available at each step of the value stream across the diversity of the DIB (Haeckel, 2016; Moreira, 2017; Ross et al., 2006; Slama et al., 2016; *The U.S. Defense Industrial Base: Background and Issues for Congress*, 2023).

D. Build Synergistic Intra- and Inter-Enterprise Communities: Leaders can build alignment and synergy through developing, designing and deploying intentional interventions to drive connectivity, set clear expectations for ecosystem-level performance, and establish the metrics to measure progress toward goals and plans. Overcoming organizational inertia and cultural barriers as well as misaligned incentives can be major challenges to be considered. Building social relationships and capital through meaningful in-person and virtual interactions can promote the requisite conditions which maximize the performance of the innovation ecosystem and support the emergence of an inclusive overall innovation ecology (Burt, 1992; Cross & Parker, 2004; Jucevicius & Grumadaite, 2014; Moore et al., 2022; Pentland, 2014; Stiglitz & Greenwald, 2014).

E. Embrace Smart Ecosystem Concepts and Technologies: Smart Cities and Regions have now demonstrated the utility of large-scale digitization and virtualization using the Internet of Things (IoT) concept. IoT includes Advanced Compute and Cloud Computing and Big Data Analytics to enhance the understanding of highly complex and dynamic systems. Artificial Intelligence offers great potential to identify patterns in these hyper-complex systems. These applications are analogous to innovation ecosystems and are facilitated by multi/hybrid-cloud solutions offering the best available platform capabilities. The advent of Generative AI as well as Large Language Models, Quantum Computing and virtualization in the form of Augmented Reality, Mixed Reality and Virtual Reality can further support these concepts in the generation and analysis of data (Gershenfeld et al., 2017; Jucevicius & Grumadaite, 2014; Nam & Pardo, n.d.; Scoble & Israel, 2017; Yashar, n.d.).

F. Embrace Large Scale, Fully Integrated, High Fidelity Virtual Environments: Modeling and simulation representative of real-world entities and conditions offer important possibilities for rapid iterative system development and test that can accelerate learning and the overall design and development processes. Model-based Systems Engineering supporting Digital Threads with Open Architectures and comprised of Digital Twins provides a virtual testbed to streamline complex systems development and test. The DoD Joint Simulation Environment (JSE) provides an exemplary case for digitization and virtualization and is a premonition of future research, development, test and evaluation paradigms, methodologies, and strategies. Adding big data analytics and AI capabilities to these digital and virtual environments along with a desire for program data to be housed and stored in a trans-enterprise, secure multi/hybrid-cloud provides unique and enabling opportunities to develop 'sentient' capabilities across the entire DoD Innovation Ecosystem (Abbate et al., 2021; *DoD Digital Modernization Strategy*, 2019; Gershenfeld et al., 2017; Rogers, 2016; Siebel, 2019; Smith, 2018; Subramaniam, 2022; Wilson & Tyson, 2023).

G. Enhance Enterprise-level/Ecosystem-level Orchestration, Management and Leadership: To lead and orchestrate across the DoD Innovation Ecosystem, a comprehensive systems and strategic approach is required to continuously improve and develop operational capabilities. In hyper-complex organizational systems, fragmentation and disconnects can result that impede synergy and continuous improvement. Understanding how each organization or actor contributes to, and interfaces with, the larger scale value stream processes and programs is critical to accelerating innovation. Communication networks and interactive exchanges help to build awareness and understanding, while open collaborative platforms provide a venue for highly synergistic operations at the ecosystem level. Ecosystems have been described in terms of their scales, the activity at those scales, and the organizational knowledge required starting at the



individual level up to small groups that evolve into micro-enterprises that then collaborate to create federations that catalyze activities across the ecosystem. Commensurate with those scales is a focus on individual development to get to mastery of value creation processes that then evolve to multi-scale capabilities for interdependent innovation development toward shared visions of the future, co-investments, and ultimately, the requisite wisdom and expertise in all scales across the ecosystem. A major trend that has been identified is the continued augmentation and expansion of individual human potential through digitization, combinatorial effects, awareness and knowledge expansion providing the foundations for human value maximization (Abbate et al., 2021; Alam et al., 2019; Fransman, 2018; Goldstein et al., 2010; Granstrand & Holgersson, 2019; Iansiti & Levien, 2004; Jucevicius & Grumadaite, 2014; Moore, 1996; Moore et al., 2022; Obolensky, 2014; Oh et al., 2016; Subramaniam, 2022; Visscher et al., 2021; Wilson & Tyson, 2023).

H. Enhance Systems Thinking: Systems thinking is at the heart of learning organizations, and it supports an awareness and understanding of how all the individual elements work together to produce value. With this understanding, an inherent capability for continuous improvement is increasingly likely as ideas and new concepts emerge through dialogue across ecosystem elements. Improvements in one organization can more easily be transferred and replicated to others. The importance of systems thinking coupled with technical knowledge remains critical to identifying and mitigating program risks to cost, schedule and performance. The GAO has reported that more than half of the MDAPs that they have reviewed that have yet to deliver capabilities reported schedule slips over the past year and that these delays were often the result of technical and engineering challenges identified late in the program. Earlier attainment of knowledge has been found to improve program decision making and reduce cost and schedule growth. Systems thinking can provide the basis to better understand interdependencies and relationships within complex systems and organizations (Chaminade et al., 2018; Gharajedaghi, 2006; Johnson et al., 2023; *Weapon Systems Annual Assessment*, 2023).

I. Enhance Strategic & Anticipatory Thinking: As the strategic context becomes increasingly uncertain and potentially disruptive, there is an ever-increasing need to maintain astute contextual awareness, agility and responsiveness. The timelines required for the development, adoption, adaptation, and deployment of new and emerging capabilities continues to accelerate. As a result, the ability to step back, look at the bigger picture, and connect the past to the present with an eye toward the future becomes increasingly important. It becomes necessary to continuously challenge assumptions, paradigms and enable and empower organizations, enterprises and ecosystems to effectively respond in a timely and collective manner. Anticipating the broad range of potential future scenarios, to deliberate and decide on a desired vision for the future, and to establish a long-range vision and critical strategies and plans are essential to ensuring sustained competitiveness. Today, the implications of critical and emerging technologies and the convergence of multiple technologies into new capabilities pose an increasingly difficult challenge to sustaining operational relevance and maintaining deterrence (Boulton et al., 2015; De Jong, n.d.; *DoD Digital Modernization Strategy: DoD Information Resource Management Strategic Plan FY 19-23*, 2019; Huff & Jenkins, 2002; *Investment Strategy for the Office of Strategic Capital*, 2024; Tovstiga, 2013; DoD, 2024; *Weapon Systems Annual Assessment*, 2023; Yarger, 2008).

K. Create Agile and Adaptive Innovation Capabilities at the Speed of Relevance: To ensure sustained competitiveness, the DoD Innovation Ecosystem must adopt a mindset and attitude for continuous change and transformation. This is enabled by continuous improvement in processes, policies and practices that embrace the paradoxical



combination of competition and collaboration across the life cycle of weapon system development. Competition is critical to motivate and promote new and novel opportunities, while collaboration is necessary when combinations of actors can offer better solutions than an individual. Economists have used the term ‘creative destruction’ as the key to maintaining economic competitiveness. Creative destruction embraces the process of creating the new and novel for products and services relevant to markets, adopting the new and novel as a new offering or paradigm, and shedding the old faster than the competition. Evaluating potential business models that consider alternate acquisition strategies that support continuous change and transformation of capabilities, most affordably and effectively, can provide these same types of continuously creative and adaptive outcomes (Aghion et al., 2021; Arena, 2018; Feinstein, 2023; Foster & Kaplan, 2001; Haeckel, 2016; Holbecher, 2015; Moreira, 2017).

L. Enable Generativity and Creativity: Creating open-minded meritocratic environments that enable safety of voice and freedom of thought, with the time to think about critical needs and applications, can improve learning, ideation and creativity to support and spark innovation. New research discoveries and inventions can lead to the generation of new ideas and innovations that can provide both enabling and disruptive outcomes. Developing workforce mastery in existing and emerging technology fields and providing the time, place, space and support to think independently are essential components to accelerate the development and deployment of innovations for application (Feinstein, 2023; Goldstein et al., 2010; Koutstaal & Binks, 2015; McNamera et al., 2023; Nonaka & Takeuchi, 2019; Policy, 2015; Taylor, 2016; Von Krogh et al., 2000).

M. Align and Clarify Expectations, Incentives and Motivations: Across organizations and enterprises, there must be clear and unambiguous end-state goals, fashioned under realistic conditions that reflect the more holistic innovation ecosystem and value stream needs and expectations for excellence. Aligning expectations with incentives and leadership support creates the intrinsic and extrinsic motivations that can drive exemplary organizational performance. Leaders can articulate the importance and interdependence of each actor and element with their relationship to the value creation process across the organization, enterprise and ecosystem-levels to deliver on the desired end state vision, goals and outcomes. Leaders can effectively catalyze intrinsic motivation by identifying an enabling and empowering vision, providing the autonomy and opportunities to develop requisite mastery to pursue that vision and to support and promote their pursuit of the end state vision, goals and outcomes (Pink, 2011; Thomas, 2009; Visscher et al., 2021).

Discussion

“Things should be made as simple as possible, but not simpler.”

Albert Einstein

To meet the DoD future needs, a degree of re-imagination is necessary to capture salient insights and foresights and to assimilate and synthesize the requisite changes to take DoD Innovation Ecosystem-level performance to the next level. A holistic DoD Innovation Ecosystem re-conceptualization can help to coalesce key concepts and ideas and to support the design and architectural changes that are needed. This reconceptualization has three major components that are inter-related and must be integrated to achieve the full intrinsic potential – the structural, the cultural, and the technological. These are the three pillars that embody a conceptualized Next Generation DoD Innovation Ecosystem.



“We seek an agile strategic approach that guides decentralized action across DoD, inspires campaigns of learning, and leverages all our people, processes, and enabling technologies.”

Kathleen Hicks
Deputy Secretary of Defense

(Data, Analytics, and Artificial Intelligence Adoption Strategy: Accelerating Decision Advantage, 2023)

The Sentient & Wise DoD Acquisition Innovation Ecosystem – A Cyber-Cognitive Ecology for Continuous Sensing, Awareness, Understanding, Innovation, Transition, Improvement and Transformation

Conceptualizing and architecting the Next Generation of the DoD Acquisition Innovation Ecosystem requires the ability to scan, aggregate, assess, filter, synthesize and integrate disparate yet highly applicable fields of interest. Envisioning how the DoD Innovation Ecosystem, an extraordinarily complex concept, will and should evolve and emerge to ensure our national security is a paramount concern. Applying concepts, ideas and technologies that are continually identified and evolved provides a basis to take overall ecosystem-level performance to the next level. Today's complexity and tomorrow's chaos require both a level of abstraction to gain simplicity and a conceptual understanding, as well as an extrapolation to anticipate what the future may offer. Figure 2 provides a conceptualized view across the acquisition life cycle organized around the formation of enabling enterprises which engage as orchestrated collectives across organizational boundaries in the value creation process of the acquisition life cycle. These enterprises leverage emergent and enabling technologies to maximize value contributions across disparate organizational elements with the cultural elements and growth mindsets to maximize contributions where and whenever possible. Sentience and wisdom are two major pillars of a north star vision to achieve. Sentience, the ability to sense or feel, and to be acutely aware of the environment leveraging cyber-based systems along with human cognition to enable a human/machine consciousness to emerge from local and distant interactions. A sentient enterprise has been conceptualized to include an agile data platform, a behavioral data platform, a collaborative ideation platform, an analytical application platform, and an autonomous decisioning platform, while its agility depends on the optimization of people processes and technology all converging around data. It is also considered to be proactive, frictionless, autonomous, scalable, and evolving and emergent in nature. Wisdom, on the other hand, represents the highest level of cognition and results from expansive and deep learning and experiences which provide unique and valuable perspectives and context that guide collective actions and behaviors. Phronesis, the concept of practical and altruistic wisdom, rooted in the interactions between theory, practice, sound reasoning and judgment, is particularly applicable to DoD Acquisition, national security, and its implications (Massingham, n.d.; Nonaka & Takeuchi, 2019; Ratzesberger et al., n.d.).

Creating an innovation ecology, buoyed by highly interactive social fields, requires continuous sensing and monitoring of the environment. It promotes learning, entrepreneurship and innovation, new technology transition, and continuous improvement and transformation. The convergence of applicable technologies, methodologies, concepts, and capabilities highlights the broad range of opportunities that can be integrated into a future state design, architecture and operations. This offers a template for a next generation DoD Acquisition Innovation Model for value-added deliberations and consideration. Of significance are the highly dynamic and expansive network of continuously evolving and emerging set of integrated digital capabilities that, as an innovation ecosystem, can seamlessly connect and synergize enterprise-level activities to provide substantial competitive advantage. A proposed attribute of this conceptual model is the aggregation and



assimilation of essentially all DoD Acquisition-related program data anchored onto the value stream into a common, cloud-based architecture that can be analyzed, assessed, distributed, shared, reused and enabled at scale in real-time via platform technologies. This is designed to improve ecosystem-level and program-level responsiveness and timely outcomes, providing ready access to current knowledge and information while identifying important patterns and relationships that can provide critical insights and perspectives. Digitization and virtualization, using high fidelity system and organizational-level models linked across the continuum of the DoD Acquisition Lifecycle, provide the basis for programmatic synergies and new capabilities that are trans-programmatic. Housed in a multi-level, zero-trust secure enclave, these digital and virtual assets create what can be considered the DoD Mega-Verse (Fligstein & McAdam, 2012).

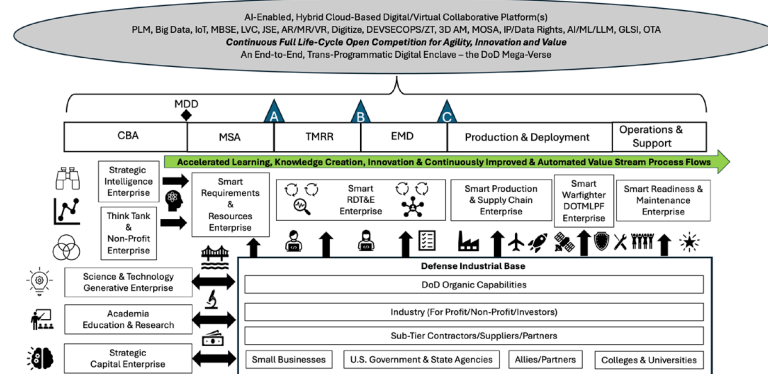


Figure 2. The Sentient & Wise DoD Acquisition Innovation Ecosystem – A Cyber-Cognitive Ecology for Continuous Sensing, Awareness, Understanding, Innovation, Transition, Improvement and Transformation

However, these efforts are just a starting place and insufficient to recognize and address the levels of agility, adaptiveness and anticipation required to compete in the future. The exponential acceleration of technology requires an extraordinarily rapid level of integration and synergy between humans and machines. Advancements have been demonstrated in Smart Cities and Regions around the world where sensors, data, algorithms and computing provide new and enabling insights and foresights to improve operations and efficiencies. These technologies enable new knowledge to be created, shared, assimilated, and institutionalized at ever-faster rates, fueling advances across the DoD acquisition life cycle at unprecedented levels, pace and scale. A key to achieving these outcomes is a new paradigm to effectively harness the power of advances in technology with streamlined and digitally enabled processes and an emphasis on mastery of human and organizational leadership, development, change and transformation.

Across the DoD Mega-Verse, reducing complexity and creating alignment and structure that allow maximum collaboration and innovation, coupled with streamlined and agile processes, and designed for continuous change and transformation is essential. By organizing the DoD Mega-Verse into distinct and highly networked collaborative enterprises operating within and across multiple portfolios, each enterprise plays a distinct and critical role in supporting the Adaptive Acquisition value stream. Enterprises are selected to maximize internal collaboration and synergy as well as provide unique and leading-edge inputs to enhance the DoD Innovation Ecosystem's ability to develop and deliver superior capabilities at scale. The innovation ecology, by design, supports a mission-driven entrepreneurial spirit with continuous and overarching emphasis on ecosystem-wide

improvement. This includes the coalescence, convergence, synthesis, and deployment of best practices and creates campaigns of learning that support innovation, knowledge, policies, processes and systems improvement.

Capabilities-Based Assessments require the collective intelligence of the Strategic Intelligence Enterprise (SIE) to evaluate global conditions and threats, the strategic thinking associated with Think Tanks and Non-Profits, the Science and Technology Enterprise creating and generating the new discoveries and inventions, and the longer-range Academic Research and Education Enterprise that helps to create and proliferate new knowledge and understandings.

During Material Solution Analysis, a Smart Requirements and Resources Enterprise (SR&RE) integrates insights and perspectives from across the DIB and operational warfighter community in support of JCIDS processes and develops and releases draft Capabilities Development Documents (CDD). The SR&RE senses, aggregates, consolidates, curates and assesses the Analysis of Alternatives (AoA) for PORs using mission engineering and kill chains as an ongoing and iterative analytical process, which drives generational waves of capability development, shifting paradigms at pace, linking relevant enterprises in a continuously evolving and emerging cognitive environment, building deep understanding and consensus for the ongoing PPBE process, and supporting the planning and allocation of available resources and requirements. The importance of taking a holistic view during the AoA process is highlighted by the DoD Assessment of Analysis of Alternative Studies in the Department of Defense as Compared to Best Practices to include ensuring that adequate AoA team resources are provided, including funding, time and personnel, and that the DOTMLPF analysis is conducted prior to the AoA. The rigor, discipline, and foundations that the SR&RE provides in their draft CDD must consider the view of the future, opportunities as well as threats, and the complex dynamics and agility associated with the E-VUCA strategic environment to balance TMRR POR technical, cost and schedule risk (Army, 2021; Joseph, 2021).

The TMRR and EMD Phases require a Smart RDT&E Enterprise that operates as an open innovation and developmental environment leveraging available modular open systems architecture (MOSA), platform and analytical technologies including high fidelity modeling and simulation, iterative virtual and physical prototyping, testing, and experimentation to accelerate learning, improve understandings, reduce risks and mature technologies, and refine concepts and technologies for follow-on development. During these phases, learning is maximized in a CAAS environment with engaged interactions across the DIB to support critical decisions that drive the trajectory of programs. This is where social networks built on competence, relationships and trust are critically important. To reduce operational complexity, processes should be clearly defined across the value stream with a clear articulation of expectations, roles and responsibilities as well as measures for continuous improvement. The ability to create streamlined processes with an open and collaborative innovation environment, where competition for value and innovation is essential.

The TMRR and EMD Phases represent the core activities where value is translated from science and technology to engineered and tested capabilities. This complex process is, by design, organized to replace old paradigms with a new, more competitive one in the current and future context within which it will be deployed. Acquisition strategies should consider how to maximize both the collaborative and competitive capabilities across the DIB to yield a continuum of affordable and effective improvements across the entire life cycle. Emphasis should be placed on embracing test and evaluation to support continuous learning and innovation. Test and Evaluation is enabled by robust live, virtual and



constructive testing environments, a model-based environment, and a digital workforce to support a more iterative design and testing approach representative of real-world conditions and operations. Consideration should be given to new, novel and proven business models including the use of Government as the Lead Systems Integrator and the use of flexible and rapid contracting such as Other Transaction Agreements to best leverage available and the most affordable capabilities across the full acquisition life cycle.

The Production and Deployment Phase in this model are supported by a Smart Production and Supply Chain Enterprise, which operates across the entirety of the DIB as well as with the Smart Warfighter DOTMLPF Enterprise to ensure that the Doctrine, Organization, Training, Materiel, Leadership and Education, and Facilities are in place to support acquisition system adoption in the warfighting environment. The Smart Production and Supply Chain Enterprise is designed to embrace next generation industry technologies, including artificial intelligence, digitization, the Industrial Internet of Things (IIoT) and Industry 5.0 technologies, including digital twin virtualization of production processes and facilities to continuously monitor and improve productivity and agility. Smart Factory concepts and capabilities connected and applied across the Smart Supply Chain can provide the next generation of integrated capabilities required to meet future DIB challenges. Automating and streamlining the end-to-end acquisition life cycle of processes across the DIB is essential to optimizing innovation and technology transition at the speed for relevance. The Smart Warfighter DOTMLPF Enterprise provides the operational foundation for adopting and adapting new capabilities as they are delivered, while providing feedback loops back to the DIB where and when needed to take full advantage. This is the final capability handoff to the user community to take advantage of the new and emerging capabilities. Significant change leadership will be required to seamlessly transition these new innovative systems and technologies into advanced operational capabilities. Enabling ingenuity and improvisation on the front lines can provide valuable feedback that can be used for future systems development and delivery.

The Operations and Support Phase is supported by the Smart Readiness and Maintenance Enterprise to minimize maintenance and sustainment costs while maximizing system readiness. Using Smart technologies including digital twins, sensors, algorithms, and compute capabilities can support real-time maintenance and predictive planning to minimize system downtime. Extensive data analytics are required to understand real-world performance and reliability that impact planned and unplanned maintenance actions. This data analysis is essential to provide feedback to system designers and acquisition planners to ensure that new knowledge is captured, codified, curated, assimilated and institutionalized as new Ecosystem-level understandings and considerations.

The operations within and across each enterprise of the Acquisition Lifecycle must be considered as an organic system that is continuously optimized through sensing and data analytics, process management, workforce development, social capital, leadership development and continuous and ongoing cultural evolution. Trans-Enterprise communication and collaboration, connecting actors across the continuum and fostering dialogue and exchange, are critical to improving and streamlining processes, building collective awareness and common understandings, aligning expectations, and optimizing the flow of data, information and knowledge as an integral part of a culture driven to consciously work together and improve warfighter outcomes.

Figure 3 provides a mental model for DoD Next Generation operations via ubiquitous and seamless interactions, built on social relationships and enabled by permeable organizational boundaries. These interactions across disparate activities start to build a clearer understanding of the end-to-end processes, the needs and requirements, the new



and novel opportunities, and technologies, and help to promote creative and innovative thought as a cultural norm. To succeed in the future, the DoD Innovation Ecosystem must be world-leading in new knowledge creation, ideation, generative innovation, conceptual thinking, and continuous learning and process improvement.

“The Department’s agile approach to adoption ensures a tight feedback loop between technology developers and users through a continuous cycle of iteration, innovation, and improvement of solutions that enable decision advantage.”

DoD Data, Analytics, and Artificial Intelligence Strategy

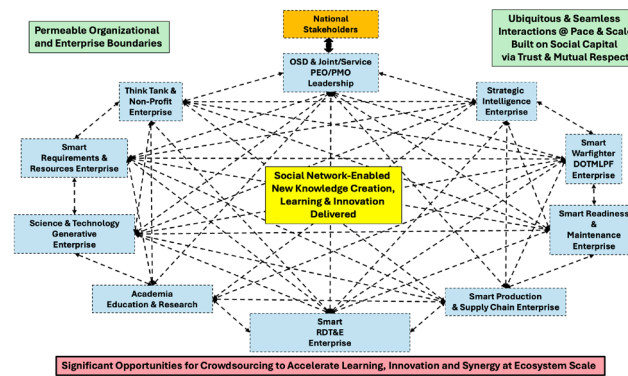


Figure 3. The Sentient & Wise DoD Acquisition Innovation Ecosystem via Emergent Social Networks: A Cyber-Cognitive Ecology for Continuous Sensing, Awareness, Learning, Innovation, Transition, Improvement and Transformation

Complex Adaptive and Anticipatory Ecosystem Model (CAAS)

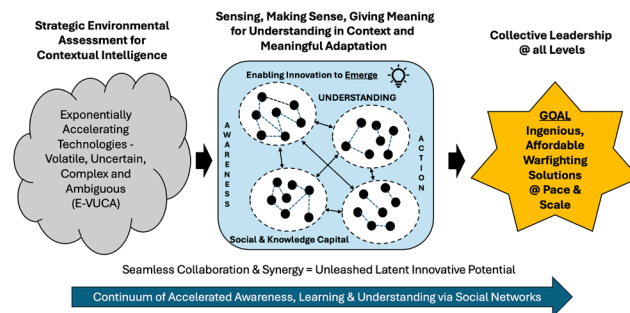


Figure 4. Complex Adaptive and Anticipatory Ecosystems Model

The CAAS Ecosystem Model, as shown in Figure 4, is designed to continuously sense the strategic and operational environment and provide the contextual awareness necessary for organizations to become aware, understand, and respond to emergent information at the pace and scale necessary to ensure competitiveness. Networks of actors, often grouped by organizational elements, are responsible to maintain awareness of their environment and interact across their social networks so that they can adapt to these sensory inputs. As dialogue and exchange occur, learning and understanding evolve, and a determination is made regarding how the system will respond and act. To achieve CAAS behavior, social networks create interactions across porous organizational boundaries in a seamless manner. Within the CAAS construct, leadership is acknowledged and recognized at all levels irrespective of position, but rather is dependent on value-added contributions. This creates the conditions that promote the type of open and meritocratic environment that

is necessary for meaningful collaboration, ideation and the emergence of timely responses. These engaging and inclusive environments are specifically designed and deployed to unleash latent human potential, synergy, and ingenuity and accelerate action-oriented learning and collaboration while building both social and knowledge capital. CAAS provide a strong anticipatory element to recognize the high rates of change in the strategic environment and the time required for planning to make necessary changes. Actors within the CAAS are focused on mastery of their cognitive skills and capabilities, including their ability to learn and think in agile and adaptive ways, and at the rates and levels of complexity needed to maintain competitiveness. CAAS actors are empowered to self-organize and to promote emergent behaviors in an open and trusting environment. CAAS are internetworked in a boundaryless manner to maximize access to external insights and foresights and promote ubiquitous knowledge creation and sharing. CAAS are also highly dynamic, fluid and ever-evolving agile organizations. They are constantly adapting by design, shifting their operations and paradigms, continuously experimenting with new and novel concepts and ideas while simultaneously exploiting competitive advantages. CAAS embrace and seek mastery for leading continuous adaptation, change and transformation to keep pace with their strategic context.

Catalyzing New Knowledge Creation, Learning & Innovative Capabilities

To maintain competitiveness, organizations must continually create, disseminate, and institutionalize new knowledge and innovative capabilities. As shown in Figure 5, these generative and distributive capabilities are rooted in organizational learning and innovating to address key challenges and opportunities while generating key questions, new ideas and concepts. Organizations can streamline these processes by integrating critical value streams spanning research, development, test and evaluation, and ongoing experimentation in the intended environment with feedback loops that foster learning. New learning informs the development of new theory and understanding, which can provide competitive advantage. New theory and understanding take a two-pronged path to benefit the organization as well as the systems which are being developed. The first path is the necessary codification of the new theory and understanding so that it can be most easily distributed, applied, and reused. The second path informs system development and application to provide new system-level capabilities that can be tested, verified and validated in an operational environment. Insights and foresights from both paths can feed back into the organizational generative operating system to further develop the next level of understanding and capabilities.

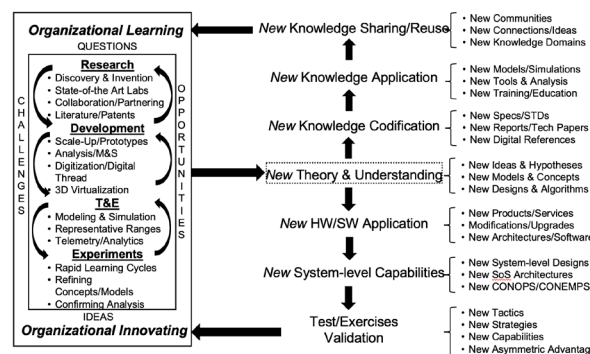


Figure 5. Catalyzing New Knowledge Creation & Innovative Capabilities

These proposed conceptualizations for the Next Generation DoD Innovation Ecosystem supports the DoD FY 2024 Annual Performance Plan Strategic Alignment



Framework by focusing on transforming the foundation of the future force, enabling a construct to make the right technological investments, by strengthening the resiliency and adaptability of the Defense Ecosystem, supports the development and growth of the future workforce and warfighter, and attempts to address a number of the institutional management priorities.

Conclusion

This study converges and synthesizes organizational development, leadership, technology and DoD Acquisition related research and theory sources to develop new and novel DoD Acquisition mental models, strategies and approaches to help offer a new Defense Industrial Base operating paradigm. DoD Acquisition programs and their portfolios must leverage the latest research, best practices and technologies to transform and increase innovation at lower cost, greater speed and increased complexity. The results of this study help inform the development of a future state strategies and operating models that can be used across the services to unleash and more fully leverage human ingenuity and potential; increase the diversity and complexity of value-added sources; enable learning and innovation as fundamental underpinnings to knowledge creation, management and utilization; leverage leading edge leadership theories and practice; and enable the accelerated adoption and adaptation of emerging technologies.

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Best Practices for Longer-Term Service Contracts

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Abstract

This project summarizes best practices identified by commercial companies, foreign governments, and State governments in using service contracts for periods longer than 5 years. The project also covers service contracts longer than 5 years used by the Federal Government. The findings indicate that relational management approaches are best suited for longer-term service contracts. This research better informs the Department of Defense on possibly increasing the number of service contracts longer than 5 years to obtain cost and performance benefits.

Background: Department of Defense (DoD) and Longer-Term Service Contracts

DoD and Service Contracts

This paper articulates best practices for using longer-term service contracts, as experienced and described by various practitioners. *Longer-term contract* is defined as an agreement in excess of 5 years.¹ Although this paper also summarizes instances or situations in which longer-term service contracts are desirable, its focus remains on best practices associated with implementing and managing longer-term service contracts. Starting with the premise that the decision has been made to enter into a longer-term service contract, we delve into how that decision can best be executed.

Every individual interviewed stated that longer-term service contracts were most applicable to highly technical or complex services with sustained demand. Such agreements often necessitate investments in human and physical capital by contractors, which require sufficient time to recoup such investments.

In fiscal year (FY) 2016, Department of Defense (DoD) contracting obligations were around \$300 billion for products and services. Services accounted for \$149.5 billion, or 50.2% of total DoD contracting obligations. It is expected this trend will continue.

The Federal Acquisition Regulation (FAR) states a service contract:

means a contract that directly engages the time and effort of a contractor whose primary purpose is to perform an identifiable task rather than to furnish an end item of supply. A service contract may be either a nonpersonal or personal contract. It can also cover services performed by either professional or nonprofessional personnel whether on an individual or organizational basis. (FAR 37.101, Definitions, 2023)

¹ As discussed in Chapter II, Congress provided the definition of a longer-term service contract in Section 854 of the FY 2018 National Defense Authorization Act (NDAA).



The definition offers an array of possible examples, such as maintenance of equipment, base maintenance, professional services, etc. (FAR 37.101).

Pursuant to policy initiated in the 1980s and continuing to this day, many functions once performed by military or U.S. government civilian personnel are now outsourced to contractors.²

“Service” Is an Expanding Concept

As technology progresses and business operations evolve, the scope of services is expanding. The end result will most likely be greater consumption of services vs. products (or supply)³ by the DoD (FAR 2.101). Typical examples are cloud-based software, analytical software, and data storage capabilities.⁴ Another example is the evolution of a more traditional function: procurement of hospital and medical supplies. Contractors integrate themselves into the inventory process of medical facilities and maintain stocks of materials at the customer site.

DoD’s Legal Authority to Enter into Longer-Term Service Contracts

This paper does not delve into the minutiae of the policies and laws as expressed in the FAR and Defense Federal Acquisition Regulation Supplement (DFARS).

There is a common misconception that government contracts are limited to a duration of 5 years on the combined basic and option periods. Both the FAR and DFARS allow contracts for service and supplies to endure for much longer periods. The FAR allows agencies to waive the 5-year limit in accordance with their own procedures:

Unless otherwise approved in accordance with agency procedures, the total of basic and option periods shall not exceed 5 years in the case of services, and the total of the basic and option quantities shall not exceed the requirement for 5 years in the case of supplies. (FAR 17.204(e), emphasis added)

DFARS authorizes the ability of agencies to contract for longer periods (DFARS 217.204, 2023).⁵

For DoD, the two general means to purchase the type of services contemplated in this paper are multiple year and multi-year.⁶ The close homonymy of these two phrases often leads to much confusion. The most succinct explanation of the differences is found in the FAR:

The key distinguishing difference between multiyear contract and multiple year contracts is that multi-year contracts defined in the statutes cited at 17.101, buy more than 1 year’s requirement (of a product or service) without

² An example is contractor logistics support for United States Air Force aircraft.

³ FAR 2.101 defines product the same as supplies: All property except land or interest in land. It includes (but is not limited to) public works, buildings, and facilities; ships, floating equipment, and vessels of every character type and description, together with parts and accessories; aircraft and aircraft parts, accessories, and equipment; machine tools; and the alteration or installation of any of the foregoing.

⁴ The Defense Information Systems Agency (DISA), for example, offers cloud service support. See *Cloud Service Support*, DISA, <https://storefront.disa.mil/kinetic/disa/service-catalog#/forms/cloud-service-support> for details.

⁵ DFARS 217.204 indicates periods of 10 years or longer are possible if the head of agency approves.

⁶ Indefinite delivery, indefinite quantity contracts are another means for the U.S. government to purchase supplies or services (FAR 16.504).



establishing and having to exercise an option for each program year after the first.⁷

A multi-year procurement of services commits DoD to buy more than one year's worth of requirements, but not more than five program years, in a single contract award (FAR 17.103).⁸ Thus, the DoD is committed to buying services required in more than one fiscal year.⁹ More specifically, a multi-year procurement of services obligates the DoD in advance of the availability of appropriated funds.¹⁰

We do not discuss multi-year procurements but instead focus on multiple year contracts.

DoD Practice and Longer-Term Service Contracts

We explored the typical length of service contracts in the FPDS data but were unable to affirmatively quantify the number of longer-term service contracts (Kaye et al., 2014). Our interviews provided two general rationales as to why the DoD is reluctant to intentionally engage in longer-term service contracts: one was budgetary, and the other was operational.

There are two budgetary reasons. First, multiple year contracts provide the flexibility to reallocate budget dollars as military needs change. Second, annual congressional appropriations are uncertain; even if the DoD executes a multi-year contract with notifications to Congress, subsequent Congresses may decrease overall DoD funding. This situation then puts the DoD in the position of decreasing funding for other programs, attempting to renegotiate contracts, or paying lump-sum cancellation charges to contractors with multi-year contracts.

With regard to day-to-day operations, although longer-term service contracts are permitted by the FAR/DFARS, our research indicates an institutional or cultural bias against such arrangements (in other words, it appears that there is a preference for 5 years as the maximum duration for service contracts).

Several primary reasons or explanations for the apparent institutional bias exist:

- Regular churn of contractors is positive, as it produces the best price.
- Churn keeps contractors on their toes.
- Industrial base—if the U.S. government does not share the wealth with a rotating set of firms or limit the number of longer-term service contracts, the number of future qualified bidders may shrink over time.
- Fear that contracts longer than 5 years may leave the DoD locked in with undesirable or underperforming contractors.
- A statement of work (SOW) can become stale over time on contracts of longer duration than 5 years.
- Past history of attempting longer-term service contracts has turned out less than optimal.

⁷ FAR 17.103 is the multi-year definition. FAR 22.1001 defines multiple year contracts as contracts having a term of more than 1 year regardless of fiscal year funding. The term includes multi-year contracts.

⁸ DFARS 217.171 provides for purchase of supplies relating to the service provided.

⁹ Congress is not bound to appropriate funds for future years. If this occurs, the DoD must cancel the contract and pay a cancellation charge (FAR 17.106-1(c)). Cancellation charges are standard clauses in multi-year contracts.

¹⁰ Multi-year contracting provides an exception to the Antideficiency Act (Pub. L. 97-258, 96 Stat. 923).



- Habitual behavior—it is easier to recycle shorter-term contracts than to try new approaches.
- Bureaucratic inertia—time and effort are required to seek exceptions to a standard 5-year contract.
- Lack of knowledge among contracting officers and program managers with regard to what is possible; thus it is easier to fall back on what has been done in the past.
- Turnover on the government side—military personnel often change jobs every 3 years, and civilian employees frequently change jobs as they move up the ranks.

Longer-Term Service Contracts

Although the general DoD mindset is averse to longer-term service contracts, our discussions with a variety of non-U.S. government entities clearly indicates they believe use of longer-term service contracts provides lasting value to the buyer. The term we heard repeatedly from these entities to describe their approach is *relational*; that is, they treat their service providers as strategic partners or critical suppliers. They view the purchase of key services as having the same importance as major capital investments in plant or equipment. The relationship between buyer and seller is much more than a purchase order.

A textbook definition of *relational contract* is one that involves a written agreement, interface protocols, and managerial interaction norms among the parties that seek continuous efficient and effective communication—all leading to the goal of minimizing friction in order to achieve commercial goals (Keith et al., 2016).

Congress and the FY 2018 National Defense Authorization Act

Pilots for Longer-Term Multi-Year Contracts

In Section 854 of the FY 2018 National Defense Authorization Act (FY 2018 NDAA), Congress seems to signal its opinion that the DoD may not be leveraging the benefits of longer-term service contracts.¹¹ In Subsection (a), it granted the DoD the authority to enter into five multi-year service contracts with duration of up to 15 years if options clauses were included and executed.¹² Section 854(b)(1) instructed the DoD to carry out a study on this matter and to include best practices from commercial companies, foreign governments, state governments, and civilian federal agencies.

When to Use and Not Use Longer-Term Service Contracts

There are many reasons for entities to use longer-term service contracts. This list is not exhaustive but illuminates major motivators brought forth by this research that are focused on best practices for longer-term contracts.

Need for Contractor Investments in Equipment, Facilities, and Technology

One of the prime drivers for longer-term service contracts is to provide contractors with the incentive to improve productivity through their own investment in facilities, equipment, and technology.¹³

¹¹ The formal title of Section 854 is *Pilot Program for Longer Term Multiyear Service Contracts*.

¹² Section 854(a) cited Section 2306c of title 10 U.S. Code. Section 2306c concerns multi-year contracts and acquisition of services; Section 2306b concerns the acquisition of property (supplies or products).

¹³ As an example, FAR 17.105-2 provides the rationale for using multi-year contracts (supplies and services).



Complex or Technically Challenging Services Requiring Specialized Knowledge and Abilities (Human Capital)

Economic theory and practitioner experience (especially emphasized by DoD personnel) indicated that services involving special skills, abilities, or talent were strong motivators to have longer-term service contracts.

Attracting More Qualified Bidders

A number of non-DoD practitioners highlighted that one driver for longer-term service contracts (coupled with other factors) is to attract more qualified bidders.

Obtaining Greater Value and Efficiencies

All of the foreign governments stated that cooperation between the parties added value to the work by solving problems more easily and efficiently.

Avoiding Workflow Disruption and Solicitation Costs

All the non-DoD interviewees considered the disruptions resulting from change of contractors as significantly negative.

Flexibility

Many of the interviewees stated longer-term contracts facilitate greater operational flexibility. This flexibility was particularly true with foreign governments and commercial firms.

Harmony in Working Relationships

A surprising finding is the desire for and recognition of value of harmony in buyer–vendor relations. Many of the interviewees believe that longer-term relationships lead to familiarity with each other’s abilities and awareness of work rhythms.

Industrial Base Considerations

The commercial firms and foreign governments all stressed the need to maintain an industrial base.

Managing Risk

A number of the interviewees—including the foreign governments—believe that if a national policy is to transfer risk to the contractor subject matter experts (SMEs), longer-term contracts will promote this practice.

Supported by Literature

The economic literature also supports the above-mentioned themes. Crocker and Masten (1988) note that the optimal contract length depends on a trade-off between negotiating costs and the costs of being bound to an inflexible agreement for additional time. Cohen and Agrawal (1999) view long-term contracts as offering price certainty, reduced transaction costs (by reducing the frequency of rebidding the project), more effective monitoring, and opportunities for investment, in return for reduced flexibility. The “short-term equals flexible” meme also appears in Vásquez (2007), where the need for flexibility leads to shorter contracts. This view is balanced by the long-term contracts, creating an incentive for specific investment. That investment may take the form of capital equipment or an investment in knowledge and skills.



Approach and Methodology

Practitioner Approach

The interviews we conducted with selected top-level practitioners in the public and private sectors were general in nature and focused on key facets of implementing and managing longer-term contracts, regardless of the mechanism.

Selection of Interviewees and Interview Approach

In alignment with Section 854(b), we interviewed individuals representing 37 entities from the following categories:

- Commercial companies
- Foreign allied government defense officials (foreign governments)
- U.S. States
- Non-DoD federal agencies
- DoD personnel, including senior procurement executives

The interviewees consisted of 11 commercial firms, four foreign governments, nine non-DoD governmental (federal, state, and local) organizations, and 13 DoD entities.

Interviews and Categorization of Comments and Statements

All interviews were conducted on a non-attribution basis in order to solicit candid statements.

Best Practices for Longer-Term Service Contracts

Background: How to Move Beyond Transactional Contracts to Relational Contracts

We identified six critical best practice areas through our interviews. What stood out among all our discussions with many non-U.S. government interviewees was an overarching emphasis on having long-term relational contracts with service contractors.

The underlying premise of successfully enacting the best practices enumerated below is a relationship approach based on the buyer and seller discussing and resolving differences in operations, services, and all aspects of the relationship. This relational approach stands in stark contrast to a traditional U.S. government “arm’s-length approach” business contract that involves contracting officers and lawyers acting as enforcers of contract terms and conditions.¹⁴

The six best practices discussed in the remainder of this chapter are as follows:

1. Create a strategic and management approach (environment) within the DoD that will enable longer-term service contracts.
2. Nurture and maintain a cadre of governmental personnel. The DoD requires SMEs to create and manage longer-term service contracts.
3. Develop and update business cases, which is key to the DoD’s ability to maximize value.
4. Communicate desired outcomes to industry. The DoD should describe and regularly communicate outcomes and not dictate statements of work.

¹⁴ It was noted by IDA personnel with DoD contracting experience that it was not uncommon to have a U.S. government contracts attorney, contracting officer, and acquisition manager participate in a contracts discussion with a contractor.

5. Emphasize critical contract elements. Share data and clearly articulate goals and metrics.
6. Manage the relationship and not the contract. Be responsive to new information and situations.

Create a Strategic and Management Approach: Set the Stage

The foundational insight that we heard from practitioners is that the organizational ecosystem must be geared toward having longer-term contracts, and leadership must be more than acquiescent.

View Services as Strategic

Our interviews with many commercial firms and foreign governments indicated that they view procured services as strategic to their missions. They perceive all services suitable for longer-term contracts to be just as important as capital equipment investments.

Industry Is a Friend, not an Enemy

We found a significant sentiment among DoD officials of suspicion or lack of trust in their dealings with contractors. The preference is for an arm's-length relationship—that at times can become combative or litigious. In a striking contrast, foreign governments stated they view relationships with service contractors as an important foundation for their defense structures. We heard a similar theme from the commercial sector, which views firms engaged as long-term service contractors as strategic providers.

Organizational Culture Focused on Enduring Long-Term Relationships

The overarching theme among many non-U.S. government interviewees was an organizational culture geared toward relational contracts for high-value services.

Senior Leadership Encourages Innovation and Experimentation

The interviewees emphasized that senior leadership must push and encourage contracting officers and program managers to use new contracting methods and processes or leverage existing ones.

Pragmatic

This insight is philosophical in that it combines realistic/open-minded interpretation of regulations and practical business acumen. This insight is summarized in the salient point put forth by one foreign government: What is the worst that can happen? Does someone die, or does cost go up by a minuscule amount because of market conditions?

Trust Governmental Personnel

We heard from state officials that empowerment of frontline managers is important. The consensus among all interviewees—including the DoD—is that senior leaders need to trust their personnel and not micromanage or second-guess them.

Fiscal and Budgetary

While the issue of congressional funding cannot be controlled by DoD officials, the uncertainty of annual appropriations arose multiple times in our interviews. DoD personnel regularly noted that the nature of annual appropriations complicates their contracting strategies.

Nurture and Maintain a Cadre of Governmental Personnel

Although the DoD outsources many services, the clear statement from the DoD and all other interviewees is that one of the most important best practices for using or managing longer-term service contracts is to have a robust and well-trained cadre of governmental



personnel. This recommendation pertains to operations and to contracting and financial functions.

Business Case: Bedrock of Success

The need for business planning and analysis was strongly advocated by most interviewees. Furthermore, the need for business case development reinforces the best practice to have a robust governmental cadre of personnel to direct such analyses prior to issuing a request for proposal.

Market-Facing Research

The commercial firms were particularly adamant on the need to understand comprehensively the market for the services to be procured under long-term contracts.

Benchmarking

In line with market research, the commercial firms said they would benchmark service providers in terms of quality, price, and reputation as part of the contractor selection process.

Not Static

Market research does not cease once a service contractor is selected. Regular evaluation of the market for innovations in service and price are routine.

Risk Analysis

The commercial firms were the primary proponents of risk analysis. Some of the considerations were:

- Price: How predictable? Could inputs increase?
- Team: Guarantees on team to be deployed—A or B team?
- Market changes: Will availability of talent or key inputs change over time?
- Confidence in contractor
- Cost to switch service contractors

Communicate Desired Outcomes to Industry

The approach is to tell industry the outcomes that are desired—and then hear what industry suggests in terms of approaches.

Emphasize Critical Contract Elements

All of the interviewees highlighted a number of contract elements they believed to be of importance.

Share Cost and Benchmarking Data

Almost all the interviewees and their contractors share cost and other benchmarking data.

Contract Form

Observations from many interviewees familiar with government contracts maintained that contracts suited for short time periods and transactional work should not be relabeled or retrofitted for longer-term services contracts.

Duration and Rewards

All of the participants emphasized that the market should dictate the optimal contract duration and that the contract duration should be appropriate for the type of work.



Learning Period for the Contractor

A majority of the foreign governments pointed out that on any new longer-term service contract, the first 2–3 years are a learning period for both sides.

Off-Ramps and Doors to Modifications

All of the foreign governments emphasized that they include off-ramps in their longer-term service contracts.

On-ramps

In line with the “rolling wave” contract renewals on the annual reviews, it might be appropriate to increase the renewal term if the contractor’s performance is exceptional.

Annual Cost Reviews

These reviews are not necessarily an attempt to audit or manage profit margins; rather, they represent an opportunity to exchange data and seek to ensure that the best market price is obtained for the buyer.

Measures/Metrics

The overwhelming message from all the interviewees is to use metrics that are easy to measure reliably and are fully controlled by the contractor.

Cost Escalation Clauses

The consensus regarding cost is that reviewing and sharing cost data are essential.

Contract Administration Plan

It is used to establish internal management protocols and help manage risk.

Government Gains Intellectual Property (IP) and Knowledge

Acquire knowledge and IP from the contractor. This goal is part of a strategy to keep the customer SMEs versed in latest techniques and technologies so the government can exercise appropriate oversight and due diligence.

Relationship Management: Manage the Relationship, not the Contract

The best practice that stood out in terms of innovation is relationship management. This method is a management and attitudinal method of managing contractors—in contrast to regulation-driven management.

Summary

This paper summarizes from a high-level perspective the best practices developed from using service agreements with durations in excess of 5 years. The best practices were identified through interviews with executives and senior leaders from a diverse array of entities—including commercial firms, foreign governments, U.S. states, and other federal agencies. Congress directed this research, and we understand the intent is to encourage the DoD to explore and pilot a greater number of longer-term service contracts. We believe doing so might bring significant benefits to the DoD.

The insights from most interviewees indicated that longer-term contracts are best suited for highly complex or technical services. These services necessitate highly skilled labor and expert management and typically involve capital investments in equipment and facilities, investment training, and education of workers.

We found that the DoD has the legal and regulatory authority to enter into longer-term service contracts. However, due to a variety of reasons—including business culture and beliefs, habitual practices, and possible complications presented by the idiosyncratic



U.S. fiscal and budget systems—it has largely declined to do so. Nonetheless, we identified instances in which the DoD does engage in long-term service contracts, but they seem to be relatively few and infrequent.

The clear message from a diverse array of practitioners is that to succeed at longer-term service contracts, the mindset and management approach must move from “transactional” to “relational”—that is, to treat service providers as strategic partners and manage the relationship in a collaborative manner that will endure for many years. The six high-level best practices we identified rest upon the foundation of this relational approach.

We believe the DoD can reap significant cost and performance benefits from successfully implementing these best practices. The experiences from our diverse group of interviewees—in particular the foreign governments—strongly suggest pilots and experimentation are well worth the effort.

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PANEL 13. ASSESSING THE DEFENSE INDUSTRIAL BASE

Wednesday, May 8, 2024	
3:45 p.m. – 5:00 p.m.	<p>Chair: Scott Sendmeyer, Acting Director of Policy, Analysis, and Transition (PA&T)</p> <p><i>The ‘Shrinking’ Defense Industrial Base: A Survey of Former DoD Prime Contractors</i></p> <p>Edward Hyatt and Llyod Everhart, George Mason University</p> <p><i>Mobilizing the Defense Industrial Base in the Event of Major Conflict</i></p> <p>Jerry McGinn, George Mason University</p> <p><i>Defense Acquisition Trends 2023: Meeting the Challenge of Production?</i></p> <p>Greg Sanders, Center for Strategic and International Studies</p>

Scott Sendmeyer—is Acting Director of Policy, Analysis, and Transition (PA&T), a retired Military officer with over 27 years of experience with the Department of the Army, with years of experience supervising, leading, and managing organizations in increasingly dynamic environments. Extensive experience in project management to include, developing guidance and strategies, planning, advising, and communicating complex concepts for senior executives at the military strategic and operational levels. A recognized expert in supervising diverse multi-functional project teams during contingency, deliberate and institutional planning. Proven leader in combat, humanitarian, security cooperation, and steady-state operations. Experienced manager at multiple levels of responsibility for training, administration, and organizational transformation. My primary focus has been creating, testing, deploying, and evaluating strategic guidance and risk analysis. This requires me to be knowledgeable, driven, and goal-oriented. A career that has challenged me has given me the opportunity to learn how to manage resources and accomplish complex goals.



The ‘Shrinking’ Defense Industrial Base: A Survey of Former DoD Prime Contractors

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Abstract

The recent decline in the number of prime contractors participating in the defense industrial base (DIB) is a well-documented and often lamented phenomenon, yet there has been a paucity of empirical research on the topic. This study was designed to investigate the types of contractors leaving the DIB and their reasons for exit, and to gain a truer estimate of the rate of exiting contractors in the “shrinking” DIB. Roughly 45,000 contractors that last held a prime contract with the Department of Defense (DoD) in Fiscal Years 2015–2022 were sent a brief survey investigating their presumed exit from the DIB. Of the 1,037 survey responses received, 679 were from contractors that acknowledged they had left the DIB and provided a detailed reason why they left. Three-quarters of the respondents were smaller businesses, reporting less than \$5 million a year in revenue and employing less than 50 employees. Roughly one-third of all confirmed exits cited an unfavorable characteristic of working with the DoD as the main reason for leaving the DIB, and moreover identified the specifically problematic characteristic(s). Results also indicated that existing estimates of contractor exits from the DIB are likely to be inflated by about 50%.

Keywords: Defense industrial base, Exiting prime contractors, Small business, Survey

Background

The defense industrial base (DIB), defined hereafter as the collection of contractors that provide the Department of Defense (DoD) with the products, services, and materials needed to operate, is a key feature of U.S. military superiority and innovation. The DIB currently includes roughly 50,000 prime contractors and a substantial number of subcontractors. The DIB is incredibly diverse. It is predominantly composed of small contractors but includes many medium-sized contractors, very large multinational corporations, academic institutions, non-profits, and global organizations. Contractors from all 50 states and dozens of international countries participate in the DIB. The DIB provides products and services across the economic spectrum “ranging from the production of complex platforms unique to the military (e.g., aircraft carriers) and the provision of highly specialized services (e.g., intelligence analysis), to the provision of general commercial products (e.g., laptop computers) and routine services (e.g., information technology support)” (Congressional Research Service, 2023, p. 1).



This juggernaut would appear robust and healthy on the surface, but several recent trends in the DIB have garnered much attention and concern. One such trend, a persistent decline in the number of contractors that comprise the DIB, has been observed by several studies (please see (Adjei & Hendricks II, 2022; Bresler & Bresler, 2020; Hyatt, 2023; National Defense Industrial Association, 2023; Office of the Under Secretary of Defense for Acquisition and Sustainment, 2022; Sanders et al., 2022; Schwartz & Johnson, 2023; United States General Accounting Office, 2021). Although some of this research has indicated that the rate of contractor decline in the DIB is reflective of shrinkage in the overall federal contractor base, its potentially deleterious impact on the DoD's ability to operate effectively is still a concern. Due to differences in definition and data interpretation, the normative value of the decline of prime contractors varies from source to source. Nevertheless, the general trend appears unmistakable. Figure 1 displays this decline using the data from the present study. It shows that from FY2015 to FY2022, there has been a total reduction of 19,292 contractors with an average year over year change of -4.66% (a net average loss of 2,756 contractors per year).

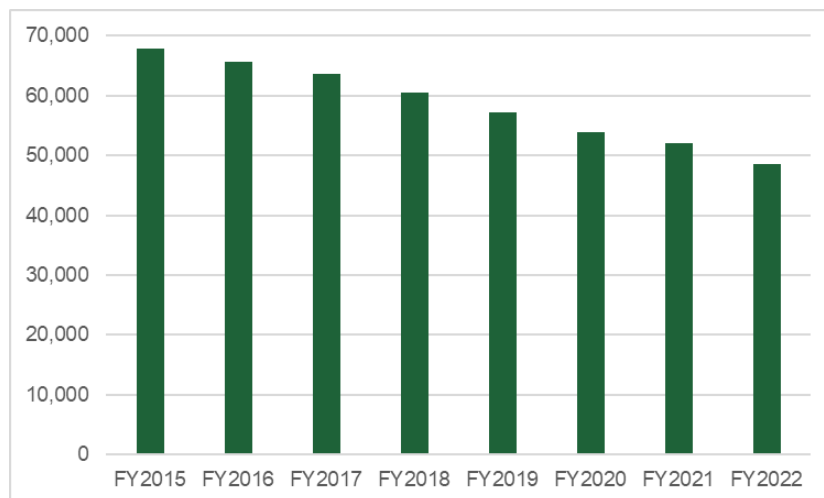


Figure 1. Number of Unique Recipient UEI

This issue has not escaped the attention of the Pentagon. DoD officials are aware of this potential issue and continue to see it as a major concern, as evidenced by comments from current and former Deputy Defense Secretaries:

The contraction of the traditional DIB (both commercial and organic) was a generation-long process and it will require another generation to modernize. (United States Department of Defense, 2023, p. 9)

What you've seen mostly in the more recent time is a drop in firms who are willing to enter the Defense Industrial Base, or firms who are already here leaving. . . . Why are people not staying, and how do we draw people in? Because that's the best way to sustain competition. (State of the Defense Industrial Base, 2023, 2:01:43–2:02:44)

A declining DIB is particularly concerning because economic theory and prior research strongly suggest that higher market concentration can result in higher prices, lower quality goods and services, and lower rates of innovation. Thus, a shrinking contractor presence in the supplier base is likely to have negative implications for the federal budget and taxpayers, as well as create hazards for the DoD at a time when U.S. military superiority and innovation is sorely needed.

When discussing the “shrinking” DIB, it is important to keep in mind that any change in the number of contractors in the DIB is the net result of subtractions (i.e., exits) and additions (i.e., entrants). Therefore, for the DIB to shrink/decline, the number of exits must exceed the number of entrants. However, while both components are important, they should be approached as theoretically unique issues since the factors that contribute to contractor exit are not necessarily the same ones needed to attract new contractors. In short, the issues of (lower) entrant rates and (higher) exit rates are likely to be at least somewhat distinct, even though they both contribute to a shrinking DIB.¹ This paper focuses on the issue of exiting contractors.

In summary, the decline of DoD prime contractors is widely reported and generally supported by the number of awards in federal government contract data. But several aspects of this broad issue are ripe for further exploration. First, *who* is actually leaving the DIB? In other words, is there a type of contractor that is disproportionately leaving the DIB, or is the problem widespread across the potential supplier base? Additionally, there has been limited research investigating exactly *why* certain contractors are leaving. This knowledge would be critical for the DoD to design effective interventions to address the most prevalent reasons for contractor exodus. Finally, while acknowledging there is a clear decline in contractor participation, *what* is the actual extent of contractor exit. This is important for understanding the magnitude of the problem of a shrinking DIB. This study was therefore developed to address these important gaps in our knowledge, and it was guided by the following three research questions:

Research Question 1. *Who* is leaving the DIB?

Research Question 2. *Why* are contractors leaving the DIB?

Research Question 3. *What* is the extent of contractor exit in the DIB?

Method

Data and Procedure

The co-authors relied upon data from two well-known sources for federal contracting data and contractor data: USASpending.gov and SAM.gov. The Award Data Archive from USASpending.gov contains batches of contract transaction data for nearly all federal government prime contract awards. The data from USASpending.gov was pulled from the February 8, 2023 batch. The raw data utilized for this study were all prime contracts for Department of Defense from FY2015 to FY2022.² This resulted in 32,106,737 DoD prime contract transactions with 284 variables for each transaction. SAM.gov provides data on all active contractors (termed entities in the SAM.gov database) as well as contractors that have become inactive in the previous six months. This study relied on a contractor information file downloaded on June 6, 2021. This relatively old file was utilized because current editions of the data from SAM.gov no longer contain entity contact information. In addition to these two primary sources, the co-authors conducted a survey to collect novel data to help answer the research questions posed above.

¹ The “shrinking” DIB is sometimes attributed to consolidation, primarily via mergers and acquisition in the defense market (see Office of the Under Secretary of Defense for Acquisition and Sustainment, 2022). However, the amount of yearly M&A activity cannot fully explain the total decline in the contractor base (see Schwartz & Johnson, 2023).

² This time frame was picked as a compromise between needing a few subsequent years to help determine which companies were likely to have “left” the DIB, but still recent enough as to limit the number of companies that no longer exist and would naturally be non-responsive to a survey.



To conduct a survey of contractors that have exited the DIB, the co-authors needed to (1) identify the relevant contractors that have presumably exited and (2) match each contractor with the appropriate contact information. To identify the relevant contractors to survey, the co-authors began by generating a list of all contractors for each fiscal year. There are multiple identifiers by which a contractor in the transaction data can be identified; this study used the Recipient UEI to identify contractors. The Recipient UEI was chosen over Recipient DUNS or Recipient Name because it was the only variable of the three to be populated for all transactions.

Once a list of all contractors in each fiscal year had been generated, the co-authors were then able to identify the contractors that have presumably exited the DIB. An exiting contractor was defined as a UEI with no record of contract action in all subsequent years. The last year a contractor had a contract action is considered the year they left, even though the exit may have occurred during the year of the final contract action. Table 1 presents the count of contractors presumed to have exited in each fiscal year. Exiting contractors have remained relatively stable over time with an average of 11,882 per year and a minimum of 11,083 (FY2021) and a maximum of 13,170 (FY2022).³ In total, there have been 83,175 contractors that have presumably exited the DIB from FY2015 to FY2022.

With the list of exiting contractors identified, the co-authors were then able to match at least one point of contact (POC) with each contractor based upon the entity data from SAM.gov. Unfortunately, the SAM.gov file did not contain a UEI field. Therefore, to match exiting contractors with points of contact, the co-authors reverted to using the DUNS number to match contractors with their points of contact. Of the 83,175 contractors presumed to have exited, 80,390 were matched with their corresponding DUNS number from USASpending.gov. This left 2,785 unmatched UEI. Of these 2,785 unmatched UEI, 2,672 were able to be matched to a DUNS number based upon the third contractor identifier from USASpending.gov data, Recipient Name. This left 113 UEI unmatched. The co-authors were able to hand match 83 of the remaining 113 through a search of entity profiles on SAM.gov using the UEI. This left 30 UEI unmatched. The remaining 30 UEI were not able to be matched to a DUNS number. Therefore, of the 83,175 contractors presumed to have exited, the co-authors had the necessary identifiers to attempt to match point of contact information for 83,145 (99.96%).

With nearly all UEI matched to their corresponding DUNS number, the co-authors were then able to use the DUNS number to associate information from SAM.gov with each contractor. The SAM.gov file originally contained 784,305 contractors. Three cleaning steps were necessary before matching points of contact with contractors presumed to have exited. First, a few thousand cases were observed where the same contractor was listed more than once. To prevent trouble with matching, only one instance of each “duplicate” was kept, resulting in a list of 779,350 contractors. Second, there were also contractors without contact information. Contractors without any contact information data were dropped from the set since there was no viable way of contacting them for the survey. Third, duplicate points of contact needed to be removed. There are three categories for possible points of contact in the SAM datafile: (1) Government Contracts; (2) Past Performance; and (3) Electronic Business. Each contractor can have none, one, or two people listed for each category, resulting in zero to six points of contact for each contractor. Wherever necessary, duplicates of the same email address for the same contractor were removed, leaving only one instance of each point of contact for each contractor.

³ The spike in FY2022 is not unexpected but likely inflated because there is only a single subsequent fiscal year to “confirm” that a contractor has in fact exited the DIB.



The initial set of presumed exited contractors and associated points of contact to survey was 49,633 contractors with 101,279 points of contact. An issue arose early in the survey process whereby the co-authors identified instances where the same point of contact was listed for multiple contractors. Since the co-authors did not want a point of contact to receive multiple survey invitations, and it could not be determined if the companies were truly distinct, the co-authors were unable to resolve the issue. Thus, these contractors and points of contact were removed from the distribution list and the final number of survey invitations were sent to 45,297 contractors via 89,799 points of contact. Table 1 shows the breakdown of presumed exiting contractors and corresponding points of contact per fiscal year.

Table 1. Sample Frame

Fiscal Year	Unique Contractors	Presumed Exits		Presumed Exits w/ POC	
		(Count)	(Percentage)	(Count)	(Percentage)
2015	67,768*	--	--	--	--
2016	65,669	12,057	18.4%	3,868	32.1%
2017	63,548	11,790	18.6%	4,266	36.2%
2018	60,502	11,885	19.6%	5,010	42.2%
2019	57,154	11,660	20.4%	5,962	51.1%
2020	53,866	11,530	21.4%	7,053	61.2%
2021	52,018	11,083	21.3%	8,341	75.3%
2022	48,476	13,170	27.2%	10,797	82.0%
Total	401,233	83,175	20.7%	45,297	54.5%

* Base year Unique Contractors are not included in calculations, shown for information purposes only.

Survey

The co-authors utilized the list of points of contact for presumed exited contractors to conduct a brief survey via Qualtrics.⁴ Invitations to complete the survey were sent to potential respondents using an email account specifically set up at George Mason University to handle surveys for the Baroni Center for Government Contracting. Due to daily limitations on the number of outgoing emails allowed per day, survey invitations were sent in batches of roughly 10,000 emails every business day (except Fridays) from May 30, 2023 through June 15, 2023. The survey remained officially open for new starts until 11:59pm on June 25, 2023, although respondents that had started a survey could return to complete it within 90 days of starting it.

The invitation text was customized to each recipient to include the contractor name, contractor DUNS, and presumed fiscal year of exit. This was done because personalized invitations achieve a higher rate of return and completeness (Heerwegh et al., 2005), and to ensure the respondents knew which contractor was being referenced in the survey. The invitations contained a unique link that could only be used once to complete the survey, although respondents did not have to complete it in one sitting or on a single device. Participants were assured that responses would remain confidential and only aggregated results would be reported.

In the survey, respondents were first required to confirm that the referenced contractor had in fact exited the DIB. Respondents who answered negatively to this question were thanked for their willingness to participate and exited early from the survey. This filtering question served multiple purposes. It allowed the co-authors to reasonably accommodate for the fact that not all presumed contractor exits would have in reality left the

⁴ Median time to complete the survey was 4 minutes, 12 seconds based on the 679 complete and usable responses.



DIB, it allowed the survey to reliably capture only the experiences of former DoD prime contractors, and the piped-in contractor information allowed the co-authors to later match respondents to contract-level information in the USASpending.gov data.

Respondents who confirmed their contractors had left the DIB saw two demographic questions about the contractor (net revenue and full-time employee count), followed by the all-important question about the primary reason for why the contractor no longer held a prime contract with the DoD. If a respondent selected “The entity stopped bidding for work with the DoD due to an unfavorable characteristic of working with the DoD” or “The entity has become only a subcontractor to DoD prime contractors,” a distinct follow-on question was asked to garner more details. Respondents were then allowed to add any final comments in an open answer format, and finally were given an opportunity to provide their consent and contact information for an optional post survey interview. The survey is provided in Appendix A.

Contractor Profiles

The co-authors relied on contract-level data from USASpending.gov to create contractor profiles for the entire population of the DIB (131,651 contractors). Since most contractors had multiple contract actions over time, the co-authors used only the contract action with the most recent action date in the raw data (e.g., 46,014 rows of contract administration data were associated with the 679 contractors with usable responses). In those cases where a contractor had multiple contract actions with the same action date, one was randomly selected based upon a unique row identifier. The result was a single row of contract action data for each contractor that allowed the co-authors to analyze characteristics associated with each contractor.

Results

The following section discusses the survey results, as well as the contractor profiles, in light of the three research questions: Who is leaving the DIB?; Why are companies leaving?; and What is the extent of contractor exit from the DIB?

Survey Response

The survey received 1,055 responses, but this included eleven pairs from respondents associated with the same contractor. In the case of seven pairs, the responses indicated different answers to the questions of whether or why a contractor had left the DIB; in these cases, both responses were removed since the accurate answer(s) could not be determined with certainty. The remaining four paired cases were consistent in their responses; in these cases, the most complete response, based upon Qualtrics percentage of completeness, was kept for analysis and the other one discarded. This left 1,037 total responses for potential analysis.

Of the 1,037 total responses, 176 responses were incomplete (less than 80% of survey complete) and utilized for passive non-response bias analysis (see Appendix B). The remaining 861 complete responses included 182 responses where the respondent indicated they had not left the DIB (95 responses) or they were not sure (87 responses). This left 679 responses representing contractors that were confirmed DIB exits along with a reason for departure and thus usable for analysis to address the research questions. The survey responses were skewed towards recent fiscal year exits, as was expected given the initial rates of confirmed points of contact and the practical likelihood that a more recently departed contractor would be more likely to respond.



Table 2. Survey Response Rate

Response	Number
Email invites sent	89,799
Total responses	1,037
Response rate	1.15%

Table 3. Survey Completion Rate

Response	Number
Total responses	1,037
Completed responses	861
Completion rate	83.03%

Table 4. Survey Response per Fiscal Year

	Responses		
	Number	Percent	Percent of FY Exiting Contractors
FY2016	93	9%	0.77%
FY2017	106	10%	0.90%
FY2018	106	10%	0.89%
FY2019	140	14%	1.20%
FY2020	157	15%	1.36%
FY2021	191	18%	1.72%
FY2022	244	24%	1.85%
Total	1037	100%	1.25%

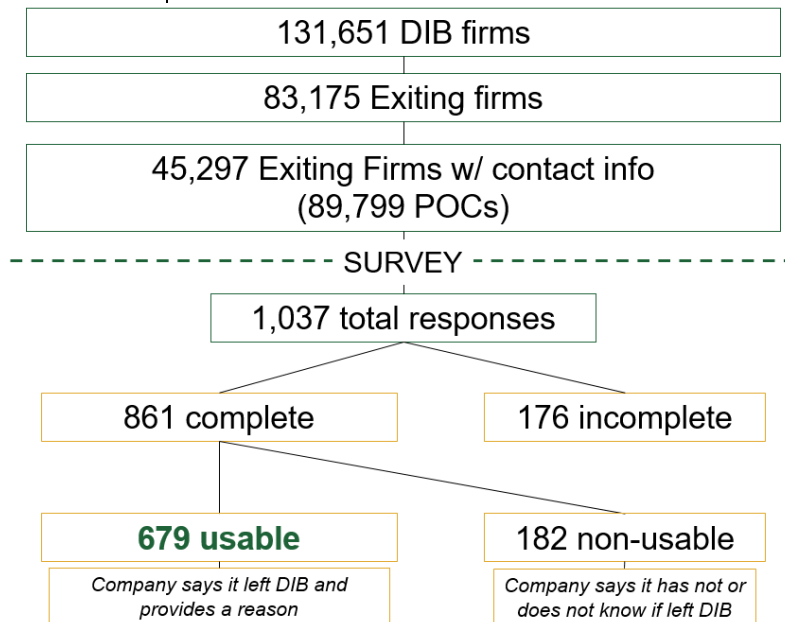


Figure 2. Survey Responses

Although the response rate was low (approximately 1%), this was not unexpected given the nature of surveying potentially no-longer-in-existence contractors using older contact information. However, the completion rate among the respondents was relatively high (approximately 83%). Most importantly, the sample size of usable responses achieves a 99% statistical confidence level with a +/- 5% margin of error, making the results potentially highly generalizable to the sub-population of contractors that have left the DIB. Additional non-response bias testing was conducted since this type of bias can threaten the external validity of survey results. Those statistical tests are detailed in Appendix B for interested readers.

RQ 1: Who is leaving the DIB?

The DIB is vast and includes contractors of all shapes and sizes. Table 5 displays a breakdown of contractor-level characteristics for the entire DIB (131,651 contractors), the exiting sub-population (83,175 contractors); and the usable responses (679 contractors). The co-authors chose five variables available in the USASpending.gov data that are probably of highest interest to generally describe contractor characteristics. The five variables are size, location, organization type, commodity, and industry.⁵ Overall, the exiting sub-population is similar to the entire DIB. The proportion of contractors for nearly all characteristics within each variable are only a few percentage points higher or lower than the corresponding proportion for the entire DIB. Furthermore, the characteristics constituting the greatest percentage of each variable follow the same ranking (with one exception due to high levels of unclassified data). Thus, the exodus of contractors from the DIB can be reasonably classified as broad based and impacting practically every type of contractor within the DIB.

Table 5. Contractor Characteristics*

Variable	Characteristic	Entire DIB	Presumed Exits	Usable Responses
Size	Small Business	95,834	61,930	110
	Other than Small Business	35,816	21,244	569
Location	Northeast	19,246	12,210	118
	Midwest	20,377	13,279	110
	South	49,966	30,765	242
	West	29,895	19,007	165
	Island Areas**	1,131	777	3
	International	11,009	7,117	41
Organization Type	Corporate (not tax exempt)	68,001	36,525	368
	Corporate (tax exempt)	4,383	2,200	28
	Foreign government	83	42	0
	International organization	1,513	766	6
	Partnership	12,580	7,097	59
	Sole proprietorship	10,615	6,915	33
	U.S. government entity	1,753	807	3
	Other	8,572	5,315	43
Commodity	Research and Development	8,336	4,865	72

⁵ See Appendix C: Study Variables for details about how each variable is defined and measured.

	Products	56,155	37,917	319
	Services	67,157	40,390	288
Industry	Agriculture, Forestry, Fishing and Hunting	421	283	1
	Mining, Quarrying, and Oil and Gas Extraction	385	284	1
	Utilities	1,092	582	4
	Construction	12,024	7,579	64
	Manufacturing	48,257	31,649	281
	Wholesale Trade	1,809	1,435	7
	Retail Trade	730	605	4
	Transportation and Warehousing	3,224	1,968	15
	Information	4,775	2,843	24
	Finance and Insurance	118	69	0
	Real Estate and Rental and Leasing	2,172	1,470	7
	Professional, Scientific, and Technical Services	22,816	12,237	159
	Management of Companies and Enterprises	6	3	0
	Administrative & Support and Waste Management & Remediation Services	10,346	5,964	34
	Educational Services	3,734	2,310	26
	Health Care and Social Assistance	2,618	1,861	9
	Arts, Entertainment, and Recreation	1,101	794	2
	Accommodation and Food Services	7,263	5,601	14
	Other Services (except Public Administration)	7,890	5,121	25
	Public Administration	611	289	1
<p>* Totals for each variable will not sum to the appropriate figures for each group due to instances of missing data not being included in the table.</p> <p>** Island areas include: Puerto Rico, U.S. Virgin Islands, Guam, American Samoa, and Commonwealth of the Northern Mariana Islands.</p>				

Primary Characteristics of Presumed Exits

Small contractors constitute the most significant loss to the DIB at 64.62% with 61,930 contractors in the exiting sub-population. This is in line with the overall reduction for the entire DIB (63.18%). Other-than-small contractors sustained a smaller overall reduction at only 59.31%; thus, they constitute a greater proportion of the remaining sub-population (30.06%).

The exodus of contractors has impacted every region in the United States.⁶ Contractors in the South experienced the largest decrease with 30,765 in the exiting sub-

⁶ The five states with the highest loss of contractors, South Dakota, Wyoming, Maine, West Virginia, and Arkansas, had an average reduction of 70.73%. In contrast, the five states with the lowest loss of contractors,

population. The other three primary regions (West, Midwest, and Northeast), experienced decreases of 19,007, 13,279, and 12,210, respectively. The South, West, Midwest, and Northeast all sustained similar reductions at 61.57%, 63.58%, 65.17%, and 63.44%, respectively. With slightly lower overall losses for the South, its proportion has grown in the remaining sub-population (39.61%).

Taxable corporate contractors experienced the largest loss of contractors with 36,525 in the exiting sub-population. Partnerships and Sole Proprietorships, the second and third largest cohorts, experienced decreases of 7,097 and 6,915, respectively. Taxable corporate contractors sustained an overall reduction of 53.71%. This was lower than the overall loss for Partnerships of 56.41% and much lower than Sole Proprietorships at 65.14%. These sizable differences in overall reductions are likely an artefact of the data. A sizable proportion of all contractors had missing data for organization type (24,151) with nearly all of them (23,508) being included in the exiting sub-population. Thus, the reported numbers, associated percentages, and overall reductions for each characteristic within organization type are likely undercounted.

Contractors providing services experienced a loss of 40,390 while contractors producing products experienced a loss of 37,917.⁷ Contractors engaged in R&D experienced a loss of only 4,865. Contractors producing products sustained larger reductions than contractors providing services at 67.52% and 60.14%, respectively. Contractors engaged in R&D sustained the lowest reduction at only 58.36%. Thus, R&D has grown as a proportion of the remaining sub-population and now constitutes 7.16% of the DIB. Furthermore, the lower reduction for contractors providing services versus contractors producing products has created a much wider spread for these two groups in the remaining sub-population (55.22% versus 37.62%).

Contractors in the Manufacturing industry constitute the greatest loss to the DIB. There are 31,649 in the exiting sub-population. The second greatest loss was in the Professional, Scientific, and Technical Services (PSTS) industry with 12,237 contractors in the exiting sub-population. The Manufacturing industry sustained a higher reduction than the PSTS industry at 65.58% and 53.63%, respectively. This relatively low reduction for the PSTS industry has resulted in its proportional growth in the remaining sub-population and now constitutes 21.82% of the DIB. The reduction of contractors across industries was particularly variable. The Retail Trade, Wholesale Trade, and Accommodation and Food Services industries sustained reductions of 82.88%, 79.33%, and 77.12%, respectively. In contrast, the Public Administration and Utilities industries sustained reductions of 47.30% and 53.30%, respectively.

Socio-Economic Characteristics of Presumed Exits

In addition to the characteristics discussed above, it is valuable to view the exiting sub-population from a perspective of high interest to defense market stakeholders—socio-economic classifications. Table 6 displays 16 classifications for the entire DIB, the exiting sub-population, and the usable responses. There is considerable variation in the experience of each group of contractors. For example, Alaskan Native Corporations and contractors in

Alaska, Virginia, Washington DC, Alabama, and Maryland, had an average reduction of 55.72%. There appears to be some value being in the national capital metro area.

⁷ Traditional defense related products, based upon Category Level 2 of Product and Service Codes, all sustained below average contractor losses. Ships and Submarines, Ammunition and Explosives, Aircraft, Guided Missiles, and Guns, experienced reductions of 44.19%, 50.57%, 50.94%, 52.00%, and 55.33% respectively. But these product levels are quite small within the DIB containing only 934 (0.71%) contractors. A second small subset of the DIB, slightly less than 1% of all contractors, experienced a very minimal loss of contractors. IT Professional Service (Labor) and Capability as a Service sustained reductions of only 8.09% and 9.31%, respectively.



the Ability One Program sustained very small reductions of only 30.71% and 29.41%, respectively. In contrast, Small Disadvantage Businesses sustained losses of 87.76%.

When viewing the loss of contractors for each socio-economic classification, the overall population reduction of 63.18% should be used as a benchmark for comparison. Woman Owned Businesses (WOB) sustained an overall reduction of 63.81% (similar to the entire DIB). WOBs and Economically Disadvantaged WOBs fared much better with reductions of only 51.94% and 50.92%, respectively. Joint Venture WOBs and Joint Venture Economic Disadvantaged WOBs fared even better with reductions of only 47.81% and 42.11%, respectively. Minority Owned Businesses experienced an overall reduction of 57.94% (better than the entire DIB). Black American Owned Businesses, Hispanic American Owned Businesses, and Asian Pacific American Owned Businesses sustained strikingly similar reductions at 59.37%, 59.95%, 59.97%, respectively. American Indian Owned Businesses fared slightly better with a reduction of only 55.03%. Native American Owned Businesses experienced much less attrition with a reduction of 45.18%. Veteran Owned Businesses sustained a reduction of 61.14%. Service-Disabled Veteran Owned Small Businesses fared much better with a reduction of only 53.42%.

Table 6. Socio-Economic Classifications

Classification	Entire DIB	Presumed Exits	Usable Responses
Alaskan Native Corporation Owned Firm	977	300	4
The Ability One Program	425	125	3
Small Disadvantaged Business	1,585	1,391	10
Woman Owned Business	20,343	12,980	140
Economically Disadvantaged Women Owned Small Business	4,723	2,405	41
Women Owned Small Business	12,539	6,513	94
Joint Venture Women Owned Small Business	594	284	5
Joint Venture Economic Disadvantaged Women Owned Small Bus	380	160	5
Minority Owned Business	19,662	11,393	98
Black American Owned Business	5,875	3,488	31
Hispanic American Owned Business	5,109	3,063	26
Asian Pacific American Owned Business	3,630	2,177	14
American Indian Owned Business	1,472	810	3
Native American Owned Business	2,738	1,237	11
Veteran Owned Business	15,565	9,516	106
Service-Disabled Veteran Owned Business	7,756	4,143	52

RQ 2: Why are contractors leaving the DIB?

The question of *why* contractors are leaving the DIB is perhaps the most central research question of this study. Expert coding (see Saldaña, 2021) was utilized in two steps *post-hoc* to make the initial survey results more meaningful for addressing this important topic.

Recoding “Other” Responses

Initially, there were 162 instances where a respondent reported “Other” as the primary reason for why the contractor no longer has an existing prime contract with the DoD.



This represented nearly a quarter of all explanations for exit, which would have made the results less informative overall. In many cases, the additional text response and sometimes the Final Comments of the respondent made it clear that the “Other” reason for exit warranted a recode into an already existing category. For example, the response “Simply too hard to work with the DoD” (ID:604) was readily interpretable as an unfavorable perception of working with the DoD, and therefore reclassified as “The entity stopped bidding for work with the DoD due to an unfavorable characteristic of working with DoD.” Alternatively, in those instances where it could not be determined if a reclassification was justified, the item remained as “Other.” For example, the descriptions “DoD rep asked us not to renew since we weren’t awarded very many jobs” (ID: 27) and “COVID stopped the services” (ID: 460) could not be easily recoded into another pre-existing category (the motivation and respondent’s reaction for not renewing was not clear, and it was not certain if COVID impacted the contractor beyond that contract), so these responses remained as “Other.”

Additionally, in instances where the item was reclassified as “The entity stopped bidding for work with the DoD due to an unfavorable characteristic of working with DoD,” the co-authors also coded the follow-on question that asked, “Why did the entity stop bidding for work with DoD?” if enough information was available for interpretation. For example, one contractor reported “Other” and “We are a small shop that can not [sic] comply with the NIST 800-171 requirements” (ID: 558). This response was recoded into the pre-existing category of “The entity stopped bidding for work with the DoD due to an unfavorable characteristic of working with the DoD.” and additionally coded as “Cybersecurity requirements” in the follow-up question. The open-ended responses to the Final Comments helped provide additional context in this regard. For example, in one instance “Hurtles with renewal process” (ID: 253) was originally thought to refer to contract renewal, but the Final Comments clearly indicated an issue with SAM.gov renewal instead.

The first step of reclassification was completed independently by the co-authors and a graduate research assistant (GRA). All three coders agreed on the new coding for 64 of the initial 162 “Other” responses, and the two co-authors initially agreed on another 28 reclassifications. If the two co-authors agreed on a recode but the GRA did not, it was assumed agreement had been achieved. This left 70 items to be reconciled, which was done after several rounds of discussion between the co-authors until all items had been agreed upon. The revised categorization resulted in the number of “Other” responses dropping from 24% (162 responses) to 10% (71 responses) of the overall sample. The other most significant change resulting from the recoding was that many of the “Other” responses were recategorized as a DIB exit due to an unfavorable characteristic of working with the DoD, thereby increasing that category from 16% (112 responses) to 24% (165 responses) of the sample.

Creating Additional “Other” Categories

A second round of coding was conducted by the co-authors to create additional categories not originally contained in the survey instrument. These categories reflected themes that arose in text responses, often corroborated by respondent Final Comments. For instance, a few respondents ($n = 11$) indicated issues with SAM.gov, not the DoD specifically, and so a new code was created to categorize these responses. Importantly, 14 respondents indicated that while they had not stopped bidding for DIB work (one of our responses), they did identify an unfavorable characteristic of working with the DoD that threatened their future participation. This second round of coding resulted in four new categories for the question of why contractors have left the DIB:

- The entity is still bidding for work but has identified an issue working with the DoD



- The entity “lost” a certain status and the work with it
- The entity has exited due to SAM.gov issues
- The entity has exited due to GSA issues

The additional categories resulted in the number of “Other” responses dropping from 10% (71 responses) to 5% (34 responses) of the overall sample. Table 7 shows the responses for this question contained in the original survey (“Original Answers”), changes based on the first round of recoding (“Revised Coding”), and the final set of all categories (“Revised Coding and New Categories”). All further discussion will reference only the final set of numbers.

Table 7. Primary Reason for DIB Exit

Response	Original Answers		Revised Coding		Revised Coding and New Categories	
	Number	Percent	Number	Percent	Number	Percent
The entity stopped bidding for work with the DoD due to an unfavorable characteristic of working with the DoD.	112	16%	165	24%	165	24%
The entity is still bidding for work but has not won anything current.	123	18%	127	19%	127	19%
The previous contract was only ever expected to be a single-time event (e.g., purchase order).	77	11%	78	11%	78	11%
DoD stopped issuing solicitations for the entity's product/service.	64	9%	78	11%	78	11%
The entity has become only a subcontractor to DoD prime contractors.	52	8%	59	9%	59	9%
Other (Please specify)	162	24%	71	10%	34	5%
The entity was originally set up to serve a single, specific contract that was completed (i.e., joint venture).	24	4%	25	4%	25	4%
The entity was party to a merger or acquisition but still conducts business with the DoD under a new name or through a parent entity.	21	3%	22	3%	22	3%
The entity changed strategic direction and is no longer seeking defense-related work.	13	2%	16	2%	16	2%
* The entity is still bidding for work but has identified an issue working with the DoD	N/A	N/A	N/A	N/A	14	2%
The entity closed the business due to reason(s) other than financial difficulties.	11	2%	13	2%	13	2%
* The entity has exited due to SAM.gov issues	N/A	N/A	N/A	N/A	11	2%
The entity no longer provides the product/service it once did for the DoD.	10	1%	10	1%	10	1%
The entity rebranded under a new name (not due to a M&A transaction) but still conducts business with the DoD under this new name.	6	1%	7	1%	7	1%
* The entity “lost” a certain status and the work with it.	N/A	N/A	N/A	N/A	6	1%
* The entity has exited due to GSA issues.	N/A	N/A	N/A	N/A	6	1%
The segment of the entity conducting work with the DoD was sold and this segment represented all defense-based business for the entity.	4	1%	5	1%	5	1%
The entity went bankrupt.	0	0%	2	0%	2	0%
The entity received a cure notice and is on probation.	0	0%	1	0%	1	0%
Total	679	100%	679	100%	679	100%
* Categories created by researchers during post-hoc analysis; not included in the original survey as an answer choice.						



Discussion: Primary Reason for DIB Exit

The top five reasons given by respondents account for nearly 75% of all responses (507 out of 679). The most frequently cited reason for a contractor exiting the DIB was an unfavorable working condition with the DoD (165 responses for 24% of the sample). This is concerning and will be addressed in more detail in the next section that addresses the follow-up question that only these respondents were asked in their survey.

More optimistically, the second most frequently cited reason for an apparent DIB “exit” strongly implies that certain contractors have not actually left the DIB. These respondents indicated that they are actively bidding for work but have not won anything current ($n = 127$ respondents for 19% of the sample). This means that they appeared to have exited the DIB in the USASpending.gov data by virtue of their not having won any current work, but they would not be considered a true “exit” if one is to consider willing and potential suppliers as part of a healthy DIB. This will also be discussed in more detail in the subsequent section answering Research Question #3 which sought to estimate the true rate of contractor exit from the DIB.

The next two top reasons, accounting for 78 responses (11% of the sample) each, are more agnostic in nature and should probably not be attributed directly to the DoD (positively or negatively) as they appear to be reasons circumstantial to business. There are plenty of business-legitimate reasons why a contract may only be a one-time event or the DoD has stopped issuing solicitations for specific products or services. As a further discussion point, this same agnostic nature applies to many of the other reasons for exit as well. For example, a contractor going bankrupt or shifting strategic direction away from defense work is probably beyond the DoD’s direct control. Even if the DoD stopped issuing solicitations for a contractor’s services/products or the contractor was established as a one-time joint venture for a specific solicitation opportunity, this should not be automatically construed as an unfavorable characteristic unique to the DoD because there are any number of legitimate reasons for a shift in purchasing behavior. How much responsibility the DoD should bear for ensuring its own supplier base through demand-side controls is a great debate topic but beyond the scope of this study.

The fifth most identified reason for departure was that the contractor had become only a subcontractor to DoD prime contractors ($n = 59$ responses for 9% of the sample). Respondents who selected this reason received a follow-on question eliciting more details in open-text response; 52 of the respondents provided such a response. Many of these respondents noted negative characteristics of working with the DoD as a prime contractor that prompted their decision to become only subcontractors. Some examples of such comments include: “We could do just as well as a subcontractor, and the larger prime contractors seemed to do better with bidding on RFPs” (ID: 231), “ease of contracting” (ID: 708), “The onerous paperwork required for each prime contract. We found the weight of the paperwork often outweighed the equipment being sold. We cannot support that level of effort for a limited return” (ID: 34), and “The current climate of only IDIQ opportunities prevents prime contract opportunities for a small company” (ID: 448). Therefore, most of the subcontractor-only respondents appear to have shifted away from being prime contractors due to an unfavorable characteristic of working with the DoD.

One of the newly created categories is also worth touching on for purposes of discussion. An additional 14 respondents (2% of the sample) indicated that while they continue participating in the DIB there are unfavorable characteristics that have forced them to change how they approach working with the DoD. For example, “The customer did not pay in time and your service was horrible. Now we deliver only by payment in advance if it is issued with SAM or the DoD” (ID: 724) and “We still supply the DoD with products but only



through direct negotiations with DoD purchasing representatives or third-party vendors to avoid the administrative issues that we normally run into when dealing with the RFP/RFQ system” (ID: 188). This category is highlighted because it represents another set of contractors experiencing specific unfavorable DoD characteristics.

In conclusion, three categories stand out as representing a negative “mark” on the DoD: contractors that 1) stopped bidding outright due to an unfavorable DoD characteristic, 2) become only a subcontractor⁸, and 3) are still bidding for work but have identified a negative characteristic of working with the DoD. Category one (1) and three (3) are very similar with the distinction being whether contractors are still actively bidding or ceased bidding altogether. When all three categories are combined to get a sense of the magnitude of the DoD’s responsibility for contractor departure, the results are sobering. The proportion of contractors exiting (or otherwise adjusting their contracting intentions) for negative reasons attributable to the DoD is approximately one-third ($n = 238$ respondents) of the overall responses (see Table 9).

Table 8. DIB Exits Due to Unfavorable Characteristics of Working with the DoD

Response	Number	Percent
The entity stopped bidding for work with the DoD due to an unfavorable characteristic of working with the DoD.	165	24%
The entity has become only a subcontractor to DoD prime contractors.	59	9%
* The entity is still bidding for work but has identified an issue working with the DoD	14	2%
Total	238	35%
* Category created by researchers during post-hoc analysis.		

Unfavorable Characteristics of the DoD

The unfavorable characteristics of working with the DoD identified by contractors are undoubtedly of key interest to DoD policy makers; therefore, more details were ascertained in the survey with a follow-on question. The same two-step expert coding process (recode and additional creation of categories) was followed for the “Other” responses to the follow-on question shown to these respondents: “Why did the entity stop bidding for work with DoD?”. Five new categories were created for the follow-up question of why contractors stopped bidding for work due to an unfavorable characteristic of working with the DoD (or if they were still bidding but had identified an unfavorable characteristic in their text response):

- Small business issues (including small business-specific policies)
- DoD acquisition/contracting policy issues
- Staff-related issues (e.g., expertise, racism, communication)
- Payment issues
- Not profitable or generally “worth it”

The total number of responses in the revised coding columns increased from 211 to 271 owing to the increased number of responses that had been recoded as unfavorable DoD characteristic in the preceding question. This first stage also resulted in most of those responses being identified solely as “Other” until the second stage of coding when new categories were created *ad-hoc* by the researchers. The last columns showing the final

⁸ Most of the reasons listed by contractors for becoming only a subcontractor related to a negative characteristic of being a prime contractor for the DoD, although it should be noted that not all the reasons were overtly disapproving of the DoD so describing this as a wholly negative mark on the DoD should be qualified.

categorization of responses show a large decline in the number of “Other” responses to only 5% (15 responses) of the total responses to this question. Table 9 shows the responses for this question contained in the original survey (“Original Answers”), changes based on the first round of recoding (“Revised Coding”), and the final set of all categories (“Revised Coding and New Categories”). All further discussion will reference only the final set of numbers. As a reminder, 179 responses were from contractors that had identified a specific unfavorable characteristic working with the DoD. Note that the totals shown in Table 9 are greater than 179 because multiple unfavorable characteristics could be identified by respondents.

Table 9. Reason(s) for Having Stopped Bidding for Work with the DoD

Response	<u>Original Answers</u>		<u>Revised Coding</u>		<u>Revised Coding and New Categories</u>	
	Number	Percent	Number	Percent	Number	Percent
DoD bureaucracy	63	30%	81	30%	81	28%
The solicitation process is cumbersome	65	31%	74	27%	74	26%
* Small business issues (including small business-specific policies)	N/A	N/A	N/A	N/A	34	12%
* Not profitable or generally “worth it”	N/A	N/A	N/A	N/A	28	10%
Cost and pricing issues (e.g., Truth in Negotiations Act)	23	11%	23	8%	23	8%
Accounting requirements (DCAA, CAS, etc.)	22	10%	22	8%	22	8%
Defense Federal Acquisition Regulation Supplement (DFARS) rules	19	9%	19	7%	19	7%
Cybersecurity requirements (CMMC)	17	8%	18	7%	18	6%
Other (Please specify)	34	16%	80	30%	15	5%
Security or facility clearance processes	10	5%	13	5%	13	5%
DoD profit policies	11	5%	11	4%	11	4%
DoD financing policies	9	4%	10	4%	10	3%
* Payment issues	N/A	N/A	N/A	N/A	8	3%
* DoD acquisition/contracting policy issues	N/A	N/A	N/A	N/A	5	2%
* Staff-related issues (e.g., expertise, racism, communication)	N/A	N/A	N/A	N/A	5	2%
Intellectual Property (IP) issues	1	0%	1	0%	1	0%
Total	211	100%	271	100%	286	100%
* Categories created by researchers during post-hoc analysis.						

Discussion: Unfavorable Characteristics of the DoD

In the follow-up question, DoD bureaucracy and a burdensome solicitation process were clearly the two biggest issues, representing over half of the rationale for why these contractors left (81 responses for 28% and 74 responses for 26%), respectively. Note that 45 contractors listed both as a reason, so their representation is slightly elevated in the overall counts, but they remain the top two reasons, regardless. These responses indicate that the DoD should focus on reducing internal bureaucracy and improving the solicitation process as these are the greatest unfavorable characteristics expressed by contractors that have exited the DIB. The next two most notable reasons for exit are *post hoc* categories; firstly, practical issues and policy issues related to small businesses (34 responses for 12%) and secondly statements that working with the DoD was generally not worth it or was an



unprofitable venture (28 responses for 10%). Both categories contained a myriad of issues and different ways of expressing it; page constraints prohibit going into detail here, but both categories reinforce the sometimes perception that the DoD might be a poor customer. Other items like payment-related issues and staff-specific issues are also other potential areas of improvement, even though they were ranked lower as contractor concerns (8 respondents for 3% and five respondents for 2%, respectively). All of these are issues that are likely to be within the DoD's direct ability to influence in the future.

A couple of other responses are worth highlighting. If profit, financing, and payment issues are combined since those issues are likely to be practically related to one another, they would cumulatively represent 29 respondents (10% of the sample), constituting a mid-level concern. Interestingly, while acknowledging they may be issues for contractors that are currently doing business with the DoD, cybersecurity and intellectual property issues did not rate highly in the results. Cybersecurity requirements remained a middle-of-the pack concern as it was represented by only 18 respondents (6% of the sample) and intellectual property issues appear to be practically non-existent as a concern for contractors that have exited.

RQ 3: *What is the extent of contractor exit in the DIB?*

This study identified 83,175 contractors that were presumed to have exited the DIB as prime contractors from FY2015 to FY2022. This (perhaps shockingly) equates to nearly two out of every three (63.18%) prime contractors during this period. This loss has been partially offset through new entrants or returning contractors, but the net impact has been a DIB shrinking almost 5% a year with approximately 2,756 contractors leaving per year. Although widely reported, it is worth investigating the extent to which the generally observed trend reflects the reality of contractor exit as evidenced by this study. The co-authors contend that the overall trend is exaggerated, and that several adjustments should be made to more accurately estimate the number of exiting contractors. The rationale for each adjustment is grounded in four categories, each of which are discussed in more detail along with an estimate for their relative impact:

- 1) Data artefacts
- 2) Definition of DIB: Transitory contractors
- 3) Definition of DIB: Subcontractors
- 4) Definition of DIB: Active bidders

Data Artefacts

There are several artefacts identified by the co-authors that seem likely to produce an inflation of the number of exiting contractors. First, the exiting sub-population (83,175) includes contractors that appear to still be in the DIB based upon a closer examination of some contractors by name (the recipient_name field in USASpending.gov). The co-authors identified 2,945 UEI from the exiting sub-population that have a contractor name identical to the name (but different UEI) of a contractor from the existing supplier base. This is particularly acute for the large primes. For example, "Lockheed Martin Corporation" has 44 UEI in the exiting sub-population and 49 UEI in the remaining sub-population. This set of 2,945 UEI with the appearance of exit should not be considered true exits since it is certain that the contractor still conducts businesses with the DoD, even under the same name, simply through another UEI.

Second, in addition to contractors that have multiple UEI both in the exiting and remaining sub-populations, there are contractors that appear to be represented multiple



times within just the exiting sub-population. The contractors considered here do not share an identical contractor name like the set above.⁹ Instead, these contractors have a near-identical name, and they were identified as likely to be the same entities because they share the same point of contact. This has heretofore not been visible to most researchers since this study uniquely matched USASpending.gov contractor data with SAM.gov contact information. The near-identical contractor name, coupled with identical points of contact, led the co-authors to realize this was a source of likely inflation for the number of exiting contractors. The co-authors identified the number of unique email domain names among this subset of contractors, resulting in 1,218 unique email domains and 4,336 unique UEI. This means that 3,118 UEI were probably erroneously counted as unique contractors in the exiting sub-population.

Third, based upon the method of calculating exiting contractors, it was a certainty that there would be some number of false positives recorded (i.e., contractors identified as having exited but that in fact still hold an active prime contract with the DoD). These are particularly likely from the recent cohorts since there were fewer subsequent years upon which to base the initial presumption of exit. The survey results allowed for an estimate of false positives. Ninety-five contractors (9.16%) that responded to the survey indicated through the filter question that they still hold an active prime contract with the DoD. The co-authors, using the real-time award search at USASpending.gov, were able to confirm that 32 of these contractors have prime contract actions with the DoD in FY2023. Thus, 33.68% of the stated false positives appear to be true false positives.

A final area of potential inflation in the data involves mergers and acquisitions. M&A activity has been rather significant in the defense market and often receives much attention and criticism. Unfortunately, this activity can create additional false positives in the data. The survey identified 22 contractors that were party to a merger or acquisition but still conduct business with the DoD under a new name or through a parent. Thus, these contractors have not truly exited the DIB. Since some M&A activity does rightfully remove a contractor from the DIB, we assume a haircut of 50% to this survey count when considering this effect on the exiting sub-population.

$$(2,945 / 83,175) + (3,118 / 83,175) + [(32 / 95) \times (95 / 1037)] + (11 / 679) = 12.0\%$$

Definition of DIB: Transitory Contractors

Some percentage of contractors should not reasonably be considered part of the DIB due to their transitory nature. The survey indicated that some contractors were established for a single use purpose and therefore should not necessarily be expected to remain as a fixture in the supplier base for future goods or services. Such contractors were identified from the survey as those that provided one of the following answers for the primary reason for their exit: “The previous contract was only ever expected to be a single-time event (e.g., purchase order)” and “The entity was originally set up to serve a single, specific contract that was completed (i.e., joint venture).” These two categories included 78 contractors and 25 contractors, respectively.

$$(78 / 679) + (25 / 679) = 15.2\%$$

⁹ The recipient_name field in USASpending.gov data is riddled with inconsistent use of periods, commas, contractor designations, and outright misspellings that create “unique” names for the same contractor from a strict data perspective; even though they have different UEI, under closer inspection they are in fact the same contractor.



Definition of DIB: Subcontractors

The co-authors contend that the DIB should be conceptualized as the collection of both prime contractors and subcontractors serving on DoD contracts. For many contractors there is certainly an overlap in membership of the two groups, as well as some migration between groups depending on the DoD's acquisition strategy for specific goods and services. While the former could not be estimated from this study's data, the latter was aptly represented by those 59 contractors that indicated they had transitioned from being a prime contractor to a subcontractor only.

Also, several contractors from the batch of 95 contractors who (perhaps mistakenly) said they still have a DoD prime contract appear to have transitioned to subcontractor work. Based on subcontracting data from USASpending.gov, eight contractors (distinct from the ones counted before as a true false positive) have subcontractor contract actions for DoD contracts in FY2022 and/or FY2023. Since they are still participating in the DoD's supply chain, these eight contractors should also be removed from the exiting sub-population count.

$$(59 / 679) + [(8 / 95) \times (95 / 1037)] = 9.5\%$$

Definition of DIB: Active Bidders

It could also be reasonably argued that the DIB should include those contractors willing to participate as suppliers, as best exemplified by those contractors that are actively bidding for work. The survey indicated that there is a rather large group of contractors who appear to still be actively participating in the defense marketplace, albeit without much success in terms of winning a contract award in recent years. The two categories that captured such contractors were those that gave one of the following answers: "The entity is still bidding for work but has not won anything current" and "The entity is still bidding for work but has identified an issue working with the DoD." These categories included 127 contractors and 14 contractors, respectively.

$$(127 / 679) + (14 / 679) = 20.8\%$$

Final Estimate of Contractor Exits

Calculating an estimate for the true extent of contractors exiting the DIB requires piecing together the observations noted above. The initial estimate for the amount by which the number of exiting contractors is inflated is 57.4%. One of the co-authors felt it wise to attenuate this by a factor of 0.85 to account for any missed overlap both within and between the four categories considered above. Applying this more conservative approach, the pool of contractors having exited the DIB is likely overstated by about 48.8%. This estimate could also be considered as the midpoint of a range. The range should have a rather large margin of error; for example, a back-of-the-envelope range favored by one of the co-authors would be +/- 15% such that the low end might be 34% and the high end be 64%. Figure 3 displays the final estimate and hypothetical range for the inflation in the count of contractors exiting the DIB.





Figure 3. Estimate of Inflation of DIB Contractor Exit

While the focus of this paper and the estimate above is based on the sub-population of exiting contractors, one observation about the overall decline of the DIB is worth noting. For a decline to exist, the number of exits must exceed the number of entrants. Thus, for a sizable decline, the gap must be relatively large. Therefore, if the exiting component of the equation is significantly inflated, as argued above, then the entrants component must also be significantly inflated for a decline to exist. Without such significant inflation to the entrants component, then the DIB may in fact be relatively stable. We do not have empirical evidence to comment on the nature of the entrants component, but the overall size and scale of the “shrinking” DIB can be called into question based upon the significant inflation of the exiting set of contractors.

Conclusion

A robust DIB is fundamental to ensure that proper and sufficient resources are available for warfighting capabilities and strategies. The continuing decline in the number of prime contractors is therefore a potentially worrisome trend. This study attempted to empirically examine the issue by conducting a survey of likely exited contractors to ascertain if they had left the DIB and, if so, why that was the case. The results provided unique, empirical insight into a critical area of concern to the defense acquisition community. In short, the DoD can do a better job of retaining contractors, which would place less pressure on its need to attract new contractors to compensate for exits and to achieve its overall desire for a resilient supplier base.

Contributions

The study makes several major contributions to the base of acquisition knowledge. First, to the best of our knowledge, this is the first study to empirically examine the issue of contractor departure from the DIB beyond simply noting the trend with broad numbers. The survey achieved a high threshold for statistical validity which is an improvement on most current research that relies on opinion, rhetoric, anecdotes, individual observations, or sample sizes too small to be generalizable. The rigor of the study means that its conclusions can be heavily considered for future policymaking and interventions. In the words of Grace

Hopper (computer programming scientist, mathematician, and United States Navy rear admiral), “One accurate measurement is worth a thousand expert opinions.”

Second, the results themselves provide several key insights into the composition of the DIB. The pool of contractors exiting the DIB has been broad based, impacting contractors across the entire United States, in nearly all organization types, and within all industries, albeit with considerable variation for different cohorts. The leading reason for contractors exiting the DIB (representing just over one-third of all survey respondents) was an unfavorable characteristic of working with the DoD. This means that the DoD has a direct ability to positively impact the health of its own supplier base if it handles certain hygiene issues such as a cumbersome solicitation process and financial policies (particularly regarding profitability). These are DoD-specific factors that go beyond the general circumstances that might affect the overall business community. The knowledge of the relative prevalence of specific unfavorable characteristics can inform the DoD as it seeks to introduce more targeted policy and acquisition interventions in the future. Finally, a deep dive into the pool of contractors that appear to be exiting the DIB suggests that there is likely some meaningful inflation to the numbers often reported. All this paints the “problem” of a declining DIB in a more favorable light than it is usually portrayed. In short, the trend of lower contractor participation is likely not as grim or extreme as it is often characterized. One caveat: it would behoove the reader to keep in mind that conclusions from this study are relative to contractors that may have left years ago (some as long ago as FY2016). Thus, some of the concerns noted by respondents may already have been or are being addressed by the DoD.

Limitations

In addition to its contributions, there are several limitations worth noting. First, the entire study had to rely on a single SAM.gov static file downloaded in 2021 because contractor contact information is no longer available in the current live system. This meant that points of contact could only be matched to roughly 60% of the presumed exiting contractors, skewing towards the years closer to the download date. This is unfortunate as it may have introduced systematic bias into the study, even though older contractors are more likely to be unreachable or to respond anyway. Second, some of the analyses relied on creating contractor “profiles” based on a single USASpending.gov contract action. Since many variables are contract specific and not entity-specific (to use SAM.gov parlance), a contractor can have contract actions with conflicting designations. For example, the same contractor can have contracts designating them as a small business and simultaneously have other contracts where they are designated as a not-small-business since that designation is contract-specific. While the likelihood is high that the most recent contract action is a fair enough representation of a contractor for the purposes of this study (and many exiting contractors had only a single contract), this was not determined conclusively by the co-authors.

Future Research

The raw data from the survey that informed this study offer several possible avenues for future research. First, there is a lot of relatively unexamined information in the survey’s Final Comments. For example, at cursory glance there are many specific mentions of small business, especially from those companies that became only subcontractors. In a similar vein, the co-authors barely scratched the surface on the subcontractor follow-on question, which also contains additional information. All of this could warrant a fruitful deeper dive.



There are also numerous email responses from recipients of the survey invite that should be examined more closely. A random sample of the undeliverable survey invitations, for example, might paint a more realistic picture of how many companies have ceased operations altogether and that is why they exited the DIB. It could also be worthwhile to parse through all contract actions, not just the most recent one, to build more accurate contractor profiles for use in analyses (e.g., create “Small,” “Mostly small,” “Balanced,” “Mostly not-small,” and “Not-small” distinctions in business size). An enhanced look into the data artefacts could provide helpful insights into the true size and characteristics of the entire DIB as the current data contain major inconsistencies and errors in contractor identifiers like recipient_name. There have been suggestions that the DIB decline is more of a reversion to the mean after a significant growth in contractors in the late 2000s and early 2010s (i.e., a popping of the DIB bubble). Therefore, expanding the research time frame to incorporate more historical years would be beneficial for understanding the extent of the “shrinking” DIB over time. The issue of DIB entrants should be addressed to assess whether the DIB might in fact be relatively stable even while it is shedding net contractors each year. Finally, 352 respondents to the survey indicated that they were willing to participate in a follow-up interview. This is an extensive set of participants for future surveys or in-depth interviews to continue exploring important topics related to contractor participation in the DIB.

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Mobilizing the Defense Industrial Base in the Event of Major Conflict

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Abstract

Increasing tensions in the Pacific, sudden conflict in the Levant, and continuing support for the war in Ukraine continue to strain the capacity of the U.S. defense industrial base. While some progress has been made increasing the production of munitions since Russia's invasion of Ukraine, challenges with acquisition approaches, budget processes, and other issues continue to stymie defense production despite significant leadership attention and resources focused on this issue. This condition will simply not suffice in the event of major conflict involving U.S. and allied forces in Asia or elsewhere.

This paper will examine past and recent efforts to dramatically increase defense production and address the research question, how can DoD truly mobilize the industrial base to rapidly scale production to support National Defense Strategy (NDS) objectives? Resources are certainly important, but the Ukraine experience has demonstrated the limits of resources alone to increase speed. DoD and Congress, working in partnership with industry, need to rethink acquisition policies and incentive structures to design and deliver capabilities at the speed required to meet today's challenges; reform elements of the Planning, Programming, Budgeting, and Execution (PPBE) process to enable the rapid insertion of capabilities to meet warfighter needs; foster contracting practices that incentivize and facilitate rapid production; and ensure that the right authorities are in place to accomplish these objectives.

From this analysis, the author will develop a set of recommendations for policies, incentives, process changes, practices, and authorities that enable effective industrial mobilization. Many of these activities are needed now, but they will be essential—even existential—in the event of a major conflict involving U.S. and allied forces. This paper will also complement and buttress the author's 2023 NPS ARS paper on a developing a Build Allied approach to increasing industrial base capacity.

Executive Summary

This paper examines how the United States can mobilize its defense industrial base in the event of major conflict. Increasing tensions in the Pacific and ongoing support to Israel and Ukraine continue to strain the capacity of the U.S. defense industrial base. This condition will simply not suffice in the event of major conflict involving U.S. and allied forces in Asia or elsewhere.

We examine why mobilization matters and how we have mobilized during World War II, the Mine-Resistant Ambush Protected (MRAP) experience in Iraq and Afghanistan, and providing support to Ukraine in its war against Russia. With this, we then identify elements of mobilization and establish a model for how these mobilization elements can work together to develop the capabilities and capacities needed to achieve the defense industrial base resilience necessary for success. We conclude with a series of recommendations to maximize the defense industrial base's ability to mobilize in major conflict.

Why Mobilization Matters

Increasing tensions in the Pacific and ongoing support to Israel and Ukraine continue to strain the capacity of the U.S. defense industrial base. While some progress has been



made increasing the production of munitions since Russia's invasion of Ukraine, challenges with sourcing, budget processes, and other issues continue to stymie defense production despite significant leadership attention and resources focused on this issue. This condition will simply not suffice in the event of major conflict involving U.S. and allied forces in Asia or elsewhere.

These events have led to an increased focus on industrial mobilization in the event of a prolonged major conflict involving the United States. Unfortunately, we have a somewhat checkered history with mobilization. During World War II, our industrial base ultimately was successful in developing and providing the ships, tanks, planes, and other systems that help our forces win on the battlefield, but the country and our industrial base was woefully unprepared for large-scale conflict. As both Arthur Herman and Mark Wilson show in their respective masterful books, it took some time for the arsenal of democracy to get rolling.¹ In the more recent case of the Mine Resistant Ambush Protected (MRAP) vehicle during conflicts in Iraq and Afghanistan, it took the secretary of defense acting essentially as the program manager to speed the development and fielding of MRAPs to save American soldiers being killed by the thousands by improvised explosive devices.² Finally, providing support to Ukraine in the wake of Russia's unprovoked invasion, our industrial base showed strength and resolve, but also brittleness.³

Our experience and the national security threats facing our nation make it clear that we need to do better. This paper addresses that challenge head-on through our research question: How can DoD truly mobilize the industrial base to rapidly scale production to support National Defense Strategy (NDS) objectives?

The Shape of the Defense Industrial Base

To answer this question, we must first look at the level of capabilities, capacities, and resilience in our defense industrial base. While the United States undeniably produces the highest caliber weapons and defense systems in the world, our industrial base has received increased attention in recent years as its vulnerabilities and limitations have been exposed through events such as Chinese industrial policy to seize critical areas such as rare earth elements processing and lithium batteries production, difficulties in surging production of munitions to support Ukraine, and wargames demonstrating dramatic losses of major weapons systems in the event of major conflict in Asia.

Our defense industrial base is comprised of the enterprises and institutions that provide the materials, products, and services to the Defense Department and other agencies related to national defense. The defense industrial base has two broad components. Both of these two components' defense-related operations are funded and provided tax benefits by Congress, and their work is contracted, regulated, and managed by the DoD.

One defense industrial base component consists of private businesses in the commercial sector. These businesses range from firms with publicly traded stock and large market capitalization to privately owned or venture capital-backed small companies.

¹ Arthur Herman, *Freedom's Forge: How American Business Produced Victory in World War II* (New York: Random House Trade Paperback, 2012); Mark R. Wilson, *Destructive Creation: American Business and the Winning of World War II* (Philadelphia: University of Pennsylvania Press, 2016).

² James Hasik, *Securing the MRAP: Lessons Learned in Marketing and Military Procurement* (Texas A&M University Press, 2021).

³ M. F. Cancian, A. Saxton, L. A. Bryan, and O. Helman, "Industrial Mobilization—Assessing Surge Capabilities, Wartime Risk, and System Brittleness," *Naval Engineers Journal* 132, no. 2 (2020): 39–49; Jerry McGinn, Breaking Defense.



Likewise, these businesses range from prime integrators and original equipment manufacturers to system, component, and parts suppliers as well as firms that provide all manner of services from classified intelligence analysis to office support. Not all these businesses limit themselves to the defense market.

The other component includes the modest organic industrial base of government-owned arsenals, shipyards, and depots as well as government, academic, and scientific entities. Government labs, such as the Defense Advanced Research Projects Agency and the Army Research Lab, conduct scientific and engineering research, development, and testing. Similarly, University Affiliated Research Centers and Federal Funded Research and Development Centers such as Johns Hopkins University's Applied Physics Lab and the Aerospace Corporation, provide engineering, research, and development services and facilities.

Inasmuch as both of these two components are dependent upon funding and tax benefits from Congress, their initiatives and incentives alike are determined by Congress. Equally, the DoD sets out the requirements, regulations, and contract competitions which steer and frame the components' work and revenue.

The interplay of these participants drives the resultant shape and outputs of our defense industrial base. These outputs can be summarized in three major components:⁴

- **Capabilities:** The types of products and services needed to meet current and future national security challenges;
- **Capacity:** The ability to produce systems or provide services at the scale and speed necessary to successfully address national security requirements; and
- **Resilience:** Maintaining an adequate balance of capabilities and capacities that enables the defense industrial base to equip and sustain U.S. forces to successfully deter or, if necessary, defeat adversary forces. Resilience, therefore, is a function of the other components and represents the ultimate end-state of the defense industrial base.⁵

It is these defense industrial base components that enable or inhibit mobilization. The recently released National Defense Industrial Strategy (NDIS) defines *mobilization* as

the legal and regulatory mechanisms that enable the United States government to rapidly expand, reconfigure, and draw on the defense industrial ecosystem in times of national emergency or war. Mobilization planning outlines how the government will work with the defense private sector and how the government will operate the [organic industrial base] OIB during times of crisis to ensure the timely production and distribution of essential materials, equipment, and services to support national security objectives.⁶

Using this definition, this paper will start with an examination of how we have mobilized in the past, looking at the cases outlined above. From the findings of these cases, we will then

⁴ This builds on analysis originally presented in John G. McGinn, "Building Resilience: Mobilizing the Defense Industrial Base in an Era of Great-Power Competition," Baroni Center White Paper series No. 6 (2020), pp. 2-3. Available at <https://business.gmu.edu/news/2021-10/no-6-building-resilience-mobilizing-defense-industrial-base-era-great-power> (accessed April 3, 2024).

⁵ The 2022 NDS defines resilience as the "ability to withstand, fight through, and recover quickly from disruption." The NDIS includes this definition as well, but the NDS definition was principally focused on the "cyber and space domains" (NDS, p. 8).

⁶ National Defense Industrial Strategy, Department of Defense 2023, pp. 39-40. Available at <https://www.businessdefense.gov/NDIS.html> (accessed March 30, 2024).



define the elements of mobilization. Finally, we build a roadmap for future mobilizations by making recommendations to strengthen each of the elements of mobilization.

How Have We Mobilized in the Past?

World War II

The mobilization, culminating in creating the industrial capacity that won World War II (WWII), commenced on January 28, 1938. President Roosevelt called for increased aircraft production and a 20% boost in the Navy's building program. The Fleet Expansion Act of May 1938 bolstered the Navy's building program, which injected \$1.1 billion into expanding the U.S. fleet, leading to significant naval construction.⁷ In January 1939, Roosevelt's budget proposal furthered his efforts to garner backing for rearmament, emphasizing key aspects of preparedness. Aligned with Roosevelt's agenda, Congress passed the Air Corps Extension Act on April 3, 1939, aiming to triple the existing fleet size. By August, the U.S. military had allocated \$100 million in new orders to the aircraft industry, marking the beginning of production for many of the bombers crucially utilized during World War II.⁸

Phase Two, Expansion, began on May 10, 1940, as German forces advanced into Europe. Roosevelt's urgent call for increased military spending and establishing GOCO facilities propelled industrial growth. The Lend-Lease Act of 1941 further facilitated aid to allies, significantly shaping the war economy. President Roosevelt's "Arsenal of Democracy" speech in December 1940 further underscored the nation's commitment to mobilization efforts. This speech served as a rallying cry, emphasizing the importance of the United States becoming a supplier of essential war materials to its allies.⁹

As the threat of war loomed after the attack on Pearl Harbor on December 7, 1941, the United States found itself thrust into full-scale mobilization. The War Production Board (WPB) was established in 1942 and further solidified efforts to coordinate industrial production for the war effort. Under the direction of the WPB, industrial output surged, with factories retooled to produce weaponry, equipment, and supplies at an unprecedented rate.¹⁰

Focusing on shipbuilding appealed to a broad spectrum of political and economic interests in the United States, including interventionists and isolationists. Unlike other forms of military production, such as aircraft or tanks, shipbuilding enjoyed bipartisan support because it aligned with America's historical identity as a maritime nation. The WPB differed from its World War I predecessor by being established earlier in the conflict and having broader authority to coordinate industrial production. Additionally, the WPB implemented innovative measures and fostered collaboration between government, industry, and labor to maximize industrial output and support the Allied war effort.¹¹

This mobilization effort marked a departure from the experiences of World War I. During WWI, the United States entered the conflict late, resulting in a rushed and less organized industrial mobilization. However, during WWII's buildup, Roosevelt's proactive measures ensured that industrial mobilization began well before the nation formally entered the war. This foresight allowed for a more structured and comprehensive approach, swiftly enabling the United States to transition into a wartime economy. Furthermore, Roosevelt oversaw a significant expansion of the U.S. military, including increasing the size of the Army

⁷ Cancian et al, "Industrial Mobilization," pp. 13-14.

⁸ Ibid., p. 14.

⁹ Ibid., p. 15.

¹⁰ Herman, *Freedom's Forge*.

¹¹ Ibid.



and Navy, modernizing equipment, and enhancing military infrastructure. These measures were crucial for strengthening America's defense capabilities in anticipation of potential involvement in the conflict.¹²

The substantial backing for the World War II endeavor in the United States is underscored, especially in the aftermath of the Pearl Harbor attack, which spurred the American populace into action and consolidated public opinion in favor of the war effort. This upsurge of patriotism and obligation to safeguard the nation and its principles permeated all segments of society, with workers, corporate leaders, and everyday citizens uniting to contribute to various capacities. Whether by enlisting in the military, laboring in war-related sectors, or aiding from the Homefront, there was a resolute sense of solidarity and commitment to supporting the war.

Furthermore, the significance of government propaganda and media campaigns in shaping public sentiment and fostering backing for the war is highlighted. Messages promoting patriotism, sacrifice, and the necessity of achieving victory were widely circulated through newspapers, radio broadcasts, and posters. The broad public support and unity behind the World War II effort in the United States underscore the collective determination of the nation to overcome obstacles and secure triumph. As an extension of the widespread support for achieving victory, the industrial sector also received widespread backing as it was perceived as a patriotic force-enabling success.¹³

A significant aspect of the U.S. industrial mobilization policy during World War II was government and private industry collaboration. Leaders from both sectors worked closely to mobilize the nation's industrial resources for the war effort. Through close cooperation, obstacles such as shortages in materials and labor were overcome, leading to increased production efficiency and effectiveness.¹⁴ The introduction of government-owned, contractor-operated (GOCO) plants significantly expanded industrial capacity, while collaborative efforts among firms ensured efficient production. The United States emerged as a prime example of full-scale economic mobilization, delivering vast quantities of weaponry and supplies.¹⁵ Collectively, they manufactured two-thirds of all Allied military equipment deployed during World War II, including the atomic bomb. Military equipment encompassed an astonishing array: 41 billion rounds of ammunition, 434 million tons of steel, 2.6 million machine guns, 2.5 million trucks, half a million jeeps, 286,000 warplanes, 86,000 tanks, 8,800 naval vessels, and 5,600 merchant ships. The ongoing partnership between government officials and prominent business leaders throughout World War II sustained a consistent expansion of industrial output until the conflict's conclusion on September 2, 1945.¹⁶

Findings

President Franklin D. Roosevelt's pivotal role in mobilizing American industry during World War II stands out. His leadership, strategic initiatives, and collaboration with influential business figures like Henry J. Kaiser and William S. Knudsen were instrumental in expanding industrial output during the war effort. Roosevelt's actions to prepare the United States for war, including establishing the Lend-Lease program, signing the Selective Service Act, and delivering the "Arsenal of Democracy" speech, were significant.

¹² Cancian et al, "Industrial Mobilization," p 13-14; Herman, *Freedom's Forge*.

¹³ Herman, *Freedom's Forge*.

¹⁴ Ibid.

¹⁵ Cancian et al, "Industrial Mobilization," p.10.

¹⁶ Herman, *Freedom's Forge*.



The remarkable feat of industrial mobilization during World War II, unfolding in rearmament, expansion, and total mobilization phases, demonstrated effective collaboration between the government and private industry. The substantial public support for the war effort, particularly following the Pearl Harbor attack, underscored a widespread sense of patriotism and dedication to supporting the war. Government propaganda and media campaigns played a crucial role in shaping public sentiment and fostering backing for the war. Additionally, the collaboration between the government and private industry in mobilizing the nation's industrial resources for the war effort led to increased production efficiency and effectiveness. The extensive output of military equipment, including the ongoing partnership between government officials and prominent business leaders in sustaining industrial output until the conflict's conclusion, marked a significant aspect of U.S. industrial mobilization policy during World War II.

American factories achieved unprecedented output levels, churning vast quantities of weaponry and supplies to support the military and Allied forces. Government and partnerships with influential business leaders played a crucial role in ensuring the continuous expansion of industrial output to support the war effort through the end of World War II. Sustained growth and adaptation of the U.S. industrial base throughout World War II demonstrated the nation's ability to mobilize its resources effectively in times of crisis. This mass production capability played a pivotal role in ensuring the eventual victory of the Allies by providing them with the resources needed to sustain their campaigns.¹⁷

MRAP

The Mine-Resistant, Ambush-Protected (MRAP) vehicle emerged as a program of record in 2007 in response to escalating casualties from improvised explosive devices (IEDs) in Iraq and Afghanistan. Secretary of Defense Robert Gates personally spearheaded an urgent initiative to ramp up the production and deployment of MRAPs based on existing foreign designs. MRAP vehicles presented a promising solution for offering sustained protection to our forces following the Joint Urgent Operational Need Statement (JUONS) pathway. Secretary Gates underscored this potential in a letter dated May 2, which included the following points:

The MRAP program should be considered the highest priority Department of Defense acquisition program. ... Any and all options to accelerate the production and fielding of this capability to the theater should be identified, assessed and applied where feasible. ... The urgency of the situation ... requires that we thoroughly examine all options to put as much of this enhanced capability in the hands of our troops as rapidly as reasonably possible. ... Speed is of essence.¹⁸

On May 30, 2007, the Defense Secretary issued further directives through a letter calling for establishing a department-wide task force. This task force integrated planning, analysis, and actions for acquiring MRAPs as comprehensively and judiciously as feasible within the coming year.¹⁹ Secretary Gates's direct leadership involvement and a simplified focus on improving soldier survivability were central to driving the MRAP program's success. The program adopted a rapid acquisition approach, soliciting bids in three categories tailored to different mission sets.

The Department of Defense's conventional modernization programs seek a 99% solution over a period of years. Stability and counterinsurgency missions require 75%

¹⁷ Ibid.

¹⁸ U.S. Secretary of Defense Robert Gates, "Speed is of Essence," memorandum for Secretaries of the Military Departments, Washington, DC, May 2, 2007.

¹⁹ Ibid.



solutions over a period of months. The challenge is whether these two different paradigms can be made to coexist in the U.S. military's mindset and bureaucracy. Given the types of situations the United States is likely to face, it is time to think hard about how to institutionalize the procurement of [critical] capabilities and get them to the field quickly.²⁰

The genesis of the MRAP concept traces back to earlier conflicts, such as the Rhodesian Civil War and conflicts in South Africa, where innovative designs like the V-shaped hull demonstrated remarkable success in mitigating blast impact. However, no single company held exclusive rights to the design, leading to a complex web of acquisitions and licenses over the years.²¹

In response to the urgent need for combat vehicles capable of withstanding high-threat environments, the CENTCOM Joint Urgent Operational Needs Statement (JUONS) was issued on October 26, 2006. This document underscored the critical requirement for vehicles that could survive mines, IEDs, and small arms fire. Subsequently, the Marine Corps Systems Command (MARCORSSCOM) awarded a sole-source contract to Force Protection Industries, Inc. (FPII) on November 9, 2006, for the procurement of up to 280 vehicles, with additional vehicles sought through an open Request for Proposal (RFP) issued simultaneously.²²

Multiple manufacturers responded with assorted designs, each offering unique features and capabilities.²³ Manufacturers' bids were managed inside the Pentagon, cognizant of the need for accelerated production timelines, prompting the MRAP program office to award multiple initial contracts swiftly. Designs that demonstrated superior maintainability, mobility, and survivability were further incentivized with additional contracts.²⁴ The government's decision to elevate the program's priority facilitated the expedited deployment of the vehicles. This initiative-taking stance encouraged industry investment in critical components before exercising delivery options while retaining integration responsibilities for mission equipment packages.²⁵ Such an approach was far from conventional. The U.S. military had not pursued such a multitude of parallel designs for a singular purpose since the dawn of nuclear submarine production in the late 1950s and early 1960s.²⁶

Secretary of Defense Ashton Carter later underscored the effectiveness of MRAPs, citing that troops in these vehicles were significantly more likely to survive roadside explosions compared to those in traditional Humvees.²⁷ Specifically, Carter highlighted that forces in MRAP vehicles were 14 times more likely to survive roadside explosions in Iraq

²⁰ Robert Gates, "A Balanced Strategy: Reprogramming the Pentagon for a New Age," *Foreign Affairs*, January-February 2009.

²¹ Jerry McGinn and Michael T. Roche, *A 'Build Allied' Approach to Increase Industrial Base Capacity* (June 26, 2023). Baroni Center Report No. 9, June 26, 2023. Available at <https://business.gmu.edu/news/2021-10/no-6-building-resilience-mobilizing-defense-industrial-base-era-great-power> (accessed April 20, 2024).

²² "USMC Doc Urgent Need for MRAP Vehicles." POGO, May 2007, https://pogoblog.typepad.com/pogo/2007/05/usmc_doc_urgent.htm; Urgent Change of Acquisition for Urgent Operational Needs." Defense Acquisition University. Accessed April 11, 2024. <https://aaf.dau.edu/aaf/uca/uons/>; Defense Acquisition University. "Urgent Operational Needs." July 7, 2016. <https://acqnotes.com/wp-content/uploads/2014/09/DAU-Urgent-Operational-Needs-7-Jul-2016.pdf>; U.S. Army Materiel Command. "ECOP Pocket Guide." Last modified March 4, 2020. https://www.amlc.army.mil/Portals/73/Documents/ECOP_POCKET_GUIDE.pdf?ver=2020-03-04-092340-860; McGinn and Roche.

²³ McGinn and Roche, *Build Allied*.

²⁴ Hasik, *Securing the MRAP*.

²⁵ GAO. (2009, October 8). *Rapid acquisition of MRAP vehicles*. <https://www.gao.gov/assets/gao-10-155t.pdf>

²⁶ Hasik, *Securing the MRAP*.

²⁷ McGinn and Roche, *Build Allied*.



and Afghanistan than forces riding in Humvees.²⁸ Guided by DoD directives, manufacturers reached a significant milestone by delivering an unparalleled quantity of MRAP variant vehicles, establishing it as the most substantial defense acquisition program of Fiscal Year (FY) 2010—a notable accomplishment considering its nonexistence in FY 2006. The MRAP program concluded when the last vehicle was produced in 2013, which led to the Joint Program Office (JPO), which managed the initiative, closing on September 30, 2013. As a result, the JPO’s responsibility for MRAP vehicles officially ended on December 19, 2013.²⁹

In under 3 years from the government’s proposal request, 16,204 vehicles were manufactured, and 13,848 were deployed.³⁰ As casualties from improvised explosive devices mounted by the fall of 2006, public support for the war dwindled. The MRAP vehicle program played a crucial role in sustaining the presence of U.S. forces in Iraq. From 2007 onward, the widespread introduction of MRAP vehicles brought about a fundamental shift in this situation.³¹ By 2007, the public perception was that MRAP vehicles saved the lives of U.S. troops.

Findings

Five critical determinants of the MRAP program’s success stand out: senior leadership sponsorship, utilization of established foreign designs, rapid development, fielding, flexibility in requirements, and a multi-sourcing strategy.

- **Senior Leadership Sponsorship:** The Secretary was at the forefront of championing the Department’s MRAP initiative, actively engaging to guarantee the swift delivery of critical, life-preserving equipment to our forces on the battlefield.
- **Utilization of Established Foreign Designs:** Leveraging foreign designs from previous decades, with minimal adjustments, proved highly effective for coalition forces during operations in Afghanistan and Iraq after 9/11. The U.S. acquisition system adopted this design approach and collaborated with the industry to generate diverse solutions, resulting in remarkable success.
- **Rapid Development and Fielding:** The MRAP program swiftly transitioned a proven foreign design into U.S. production by prioritizing established technologies and industry-provided non-developmental solutions. This approach, praised by the Government Accountability Office (GAO), defied typical DoD program delays, accelerating fielding during wartime.
- **Flexibility in Requirements:** The MRAP program was a model for demonstrating flexibility in requirement categories. It enabled firms to focus on providing specialized solutions for specific operational needs rather than applying a one-size-fits-all approach.
- **Multi-sourcing Strategy:** The MRAP program adopted a multi-sourcing approach to address capacity limitations, awarding contracts to nine commercial sources. This strategy allowed firms to specialize in providing optimal solutions for specific requirement categories.³²

²⁸ Vanden Brook, T. (2012, September 30). Officials say MRAPs made the difference in wars. *USA Today*. <https://www.usatoday.com/story/news/world/2012/09/30/mraps-saved-lives/160014>

²⁹ Friedman, Norman. *This Truck Saved My Life! Lessons Learned From the MRAP Vehicle Program*. Joint Program Office, Mine Resistant Ambush-Protected Vehicles, 2013.

³⁰ GAO. *Rapid acquisition*.

³¹ Friedman, *This Truck*.

³² The first three findings are derived from McGinn and Roche, *Build Allied*; the final two are from Hasik, *Securing the MRAP*.



Ukraine

While the United States had provided support to Ukraine since Russia's 2014 seizure of the Crimea, the United States intensified its commitment after the Russian February 2022 invasion of Ukraine. This support was crucial in strengthening Ukraine's military capabilities and resilience. Congress approved significant supplemental appropriations totaling \$48.7 billion to fund this assistance.³³

Providing support for the war in Ukraine exposed some significant shortcomings in the U.S. defense industrial base.³⁴ Initially, the United States provided Javelins, HIMARS, Stingers, and other munitions from existing stocks and used congressional appropriations to pay for the replenishment of these stocks. However, the rapid usage of munitions on the battlefield coupled with the inability to quickly increase production became quickly apparent. Long lead items, obsolete parts, systems no longer in production, and other factors underscored the urgent need for surge capacity in defense production.³⁵ Under Secretary of Defense for Acquisition and Sustainment, Dr. William LaPlante, began to stress the importance of production capacity over previous efforts to focus on cost reduction in defense acquisition. Potential threats in East Asia highlight the necessity of scaling up defense systems production.³⁶

Findings

Providing support to Ukraine exposed significant challenges in four facets of the defense industrial base:³⁷

- **Production capacity.** Defense industrial base production is driven solely by contracts between the DoD (or foreign countries) and industry. Thus, when demand fluctuates or ends, industry responds accordingly. Munitions production, in particular, has pitched and yawed significantly over time. Our Baroni Center analysis of 80 missile and ammunition accounts over 20 years found that funding levels could swing as much as 50% year over year, hardly a recipe for stability.³⁸ Moreover, because industry builds facilities to meet the terms of contracts, there is generally little readily available to quickly surge production despite available funding.
- **Acquisition practices.** DoD acquisition processes are heavily detailed to ensure precision of specifications and fairness to industry partners. This adds complexity and time. Budgeting processes, meanwhile, prioritize advanced planning that is inconducive to responding to crisis.
- **Supply chains.** Challenges with defense supply chains have been clear for some time, and COVID shone a bright light on this. As industry attempted to respond for increased demand for munitions in Ukraine, the limitations in existing supply chains became painfully evident.

³³ Congressional Research Service 2024. U.S. Security Assistance to Ukraine. Retrieved from <https://crsreports.congress.gov/product/pdf/IF/IF12040>.

³⁴ See, for example, Seth G. Jones, *Empty Bins in a Wartime Environment: The Challenge to the U.S. Defense Industrial Base*, January 2023. Available at <https://www.csis.org/analysis/empty-bins-wartime-environment-challenge-us-defense-industrial-base> (accessed April 15, 2024).

³⁵ Wall Street Journal Video, "How Arming Ukraine Exposed Cracks in the U.S. Defense Supply Chain," February 25, 2023. Available at https://www.youtube.com/watch?v=JEE_dJZtF1E (accessed April 15, 2024).

³⁶ McGinn and Roche, *Build Allied*, p. 2.

³⁷ This draws heavily from McGinn, "Four Steps."

³⁸ Eric Lofgren, "Year-to-year stability of munitions procurement funding," *Acquisition Talk*, February 15, 2023. Available at <https://acquisitiontalk.com/2023/02/year-to-year-stability-of-munitions-procurement-funding/> (accessed April 15, 2024).



- **Working with allies and partners.** Companies based in countries that are close allies and partners of the United States provide significant support to U.S. systems provided to Ukraine and these firms also had industrial capacity to develop systems to support Ukraine. While many NATO and other partner countries pledged support to Ukraine, they also struggled with increasing capacity.

Beyond the mechanics of developing and providing capabilities and capacity, maintaining public support within the United States for Ukraine has proven challenging. The recent budget showdown on Capitol Hill highlighted the contentious debate surrounding economic support and military assistance to Ukraine. Despite Congress passing appropriations for FY24, supplemental aid to Ukraine was conspicuously absent. This absence reflects a growing divide within the Republican party regarding U.S. support for Ukraine.³⁹ In the broader public, a Chicago Council on Global Affairs survey from September 7–18, 2023, indicates a notable shift in public sentiment towards Ukraine. While most Americans still supported economic assistance and military transfers to Ukraine, these majorities had decreased since November. Nonetheless, a slim majority believed the \$43 billion in military aid already sent to Ukraine had been worth the cost.

Elements of Mobilization

These cases demonstrate the tremendous capabilities and capacities of our industrial base over time. They also demonstrate the substantial challenges in ramping up mobilization efforts and, in some cases, the importance of factors such as public support. To chart a path for the future, it is therefore important to identify and examine the component parts, or elements, of mobilization. This decomposition helps identify the levers that policy-makers can impact today to facilitate faster mobilization in the future.

Building on these cases and an examination of the mobilization literature, we have identified seven elements that make up how the Executive and Legislative Branches, working with industry partners, mobilize to meet critical national security crises. These elements, their respective purposes, and the key required outcomes are outlined in Table 1.

³⁹ Smeltz, D. & El Baz, L. 2023, October 4. American Public Support for Assistance to Ukraine Has Waned, But Still Considerable. The Chicago Council on Global Affairs. Available at <https://globalaffairs.org/research/public-opinion-survey/american-public-support-assistance-ukraine-has-waned-still> (accessed February 6, 2024).



Table 1: Elements of Mobilization

Mobilization Element	Purpose	Key Required Outcomes
Authorities - Legal authorities and executive branch plans	Enable USG and industry to organize and execute	- Running start - Ability to marshal all elements of national power
Design - Types and nature of systems needed	Determine what we are going to buy	- Radically simplified requirements - Ability to rapidly iterate designs - Designing for production
Resourcing - Funding levels (i.e. appropriations) - Funding process (i.e. PPBE)	Determine how much we are going to buy and in what manner	- Consensus on funding levels - Flexibility in program execution
Acquisition - Program development - Prototyping and experimentation - Source selection & contracting - Production	Develop and produce what we buy	- Maximized industry involvement - Ability to rapidly scale production - Contracting strategies that enable speed and surge
Sustainment - Supply chains - Repair or replace systems in theater	Deliver, sustain, and replace U.S. forces and systems	- Secure supply chains - Succeeding in contested logistics environments - Robust stockpiles and sourcing capabilities
Public support	Gain and keep public support	- Favorable climate for mobilization actions
Allies and partners	Get a little help from our friends	- Co-development, co-production, FMS/DCS

Each of these elements require substantial coordination and cooperation across the government, both within the DoD and the Executive Branch as well as between the DoD and Congress. Industry partners are also central to most of the mobilization elements. As the cases clearly demonstrate, the involvement of industry partners as well as government officials with significant industry experience is critical from design through sustainment.

These elements of mobilization are distinct but obviously need to collaborate to achieve success. Figure 1 depicts a model for how these mobilization elements can work together to develop the capabilities and capacities needed to achieve the defense industrial base resilience necessary for success.

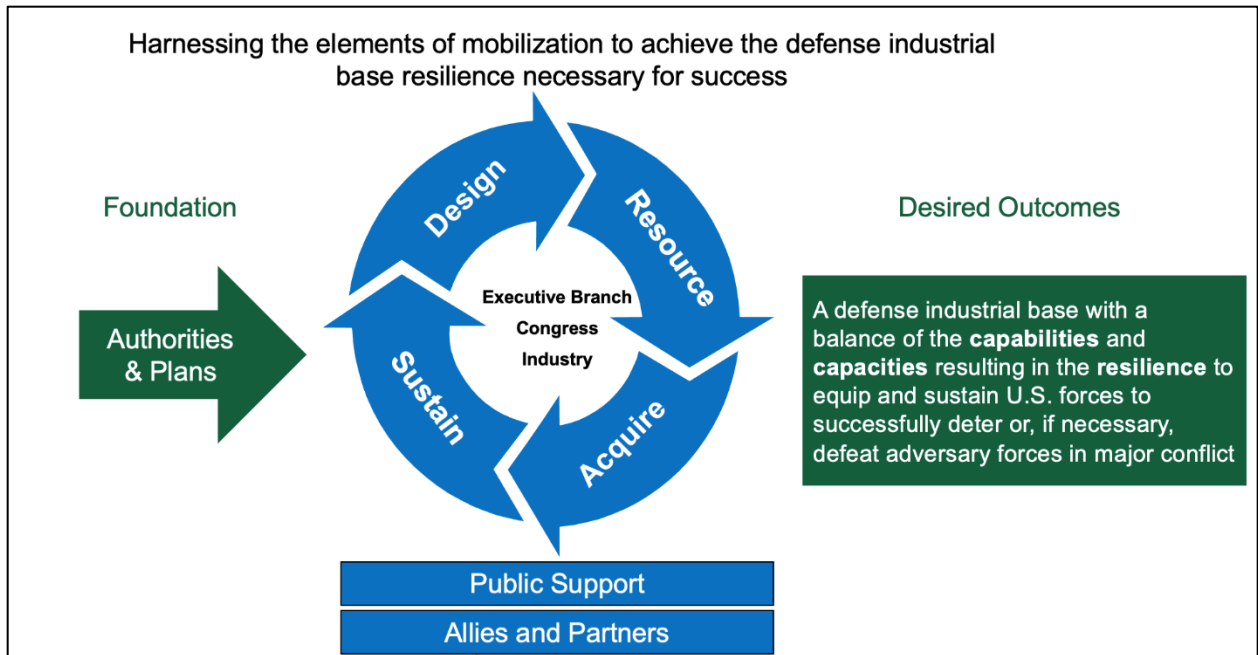


Figure 1: Mobilization Model for Major Conflict

Building a Roadmap for the Future

To execute this model, we must take a series of steps to strengthen the elements of mobilization and thereby maximize the defense industrial base's resilience in major conflict.

Authorities

The government's ability to mobilize its industrial base in many ways starts with the legal authorities and the agency plans and policies to facilitate production, reduce bottlenecks in the supply chain, and otherwise streamline how government and industry can develop the capabilities and capacities to meet the needs of the country in a crisis. The creation of the Office of Production Management and its better-known successor, the War Production Board, for example, helped FDR's Administration to organize government and industry for and facilitate mobilization.⁴⁰ In the MRAP case, uses of the Defense Production Act (DPA) in various manners demonstrated how the government could shortcut bureaucratic processes to meet exigent circumstances. Section 1244(c) of the FY 2023 NDAA gave DoD authority for multi-year procurement of numerous munitions in Ukraine to send a stronger demand signal to industry to support munitions production for Ukraine.⁴¹ This authorization was eventually accompanied by funding in the FY24 appropriations approved in March 2024.⁴² Overall, our legislative authorities are strong, but there are opportunities for strengthening their uses, coupled with agency planning, that will strengthen the nation's ability to respond to crises.

⁴⁰ Wilson, *Creative Destruction*, pp. 59-76.

⁴¹ Congressional Research Service, "Multiyear Procurement (MYP) and Block Buy Contracting in Defense Acquisition: Background and Issues for Congress," December 20, 2023, p. 13. Available at <https://sgp.fas.org/crs/natsec/R41909.pdf> (accessed April 11, 2024).

⁴² Valerie Insinna, Ashley Roque, Michael Marrow and Theresa Hitchens, "Replicator, planes and multi-year deals: What's in the new FY24 defense spending bill," *Breaking Defense*, March 21, 2024. Available at <https://breakingdefense.com/2024/03/replicator-planes-and-multi-year-deals-whats-in-the-new-fy24-defense-spending-bill/> (accessed April 8, 2024).

Recommendations for Strengthening

Keep the Defense Production Act strictly focused on national security needs.

The DPA was passed in 1950 and there are three active titles today.⁴³ It became widely known during COVID, but the MRAP case demonstrates how it has been used previously. Today, it is currently being used to great effect in reshoring and building industrial base capacity in areas such as rare earth processing, castings and forgings, and advanced batteries as well as countering foreign investment that impact national security.

The increased use of DPA is welcome but has also led to its recent invocation to support domestic production of solar panels and heat pumps, which has caused political controversy.⁴⁴ This was a focus at a recent House Financial Services Committee hearing focused on DPA reauthorization.⁴⁵ The hearing struck exactly the right tone. It is essential to keep DPA focused exclusively on essential defense and national security issues, in particular threats from our pacing competitor, China. Using DPA outside of direct national security purposes threatens “the viability of this unique tool for rebuilding a robust, resilient, and globally competitive American industrial base.”⁴⁶

DPA Title I – Update executive orders and regulations. The distribution and allocation authorities under DPA Title I are critical to get correct. However, at the national level, the DPA is governed by a mishmash of old and overlapping executive orders spanning numerous administrations that need to be refreshed and simplified. While detailed plans are not solutions by themselves, the Administration should conduct a thorough review of relevant executive orders and regulations to better orient DPA policies and practices to address future national security challenges.⁴⁷

DPA Title III – Delegate determination authority and use purchase commitment authority. Title III has been a tremendous tool to address aggressive and often illegal Chinese economic practices in areas such as rare earth processing, batteries, magnets, and microelectronics. The non-delegable requirement for the president’s signature on each DPA determination, however, has significantly slowed the process by which DPA projects are developed and executed. Allowing the delegation of that determination in the upcoming

⁴³ For a summary of the DPA’s history and usage, see Alexandra G. Neenan and Luke A. Nicastro, *The Defense Production Act of 1950: History, Authorities, and Considerations for Congress*. CRS Reports, **R43767**, updated October 6, 2023. Available at <https://crsreports.congress.gov/product/pdf/R/R43767> (accessed April 11, 2024). See also, McGinn, “Building Resilience,” pp. 5-7.

⁴⁴ <https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/06/fact-sheet-president-biden-takes-bold-executive-action-to-spur-domestic-clean-energy-manufacturing/> (accessed April 11, 2024); Press Release, House Energy and Commerce Committee Chair Cathy McMorris Rodgers, December 20, 2023. Available at <https://energycommerce.house.gov/posts/chairs-rodgers-and-duncan-decry-administration-s-use-of-war-time-authority-to-subsidize-radical-rush-to-green-agenda> (accessed April 11, 2024).

⁴⁵ March 12, 2024 hearing of the House National Security, Illicit Finance, and International Financial Institutions Subcommittee Entitled “Mission Critical: Restoring National Security as the Focus of Defense Production Act Reauthorization.” Hearing and background memorandum available at <https://financialservices.house.gov/calendar/eventsingle.aspx?EventID=409167> (accessed April 11, 2024).

⁴⁶ William Greenwalt, Jerry McGinn, and Christopher Zember, “The Defense Production Act is helping rebuild the U.S. industrial base. Let’s keep it that way,” *Defense News*, June 15, 2022. Available at <https://www.defensenews.com/opinion/commentary/2022/06/15/the-defense-production-act-is-helping-rebuild-the-us-industrial-base-lets-keep-it-that-way/> (accessed April 11, 2024).

⁴⁷ Jerry McGinn and Daniel Kaniewski, “Where does the Defense Production Act Go from Here? Key aspects need strengthening,” *Defense One*, November 24, 2020. Available at <https://www.defenseone.com/ideas/2020/11/where-does-defense-production-act-go-here/170301/> (accessed April 11, 2024).



2025 reauthorization of the DPA, perhaps to the Secretary level of those agencies with Title III authority,⁴⁸ would significantly streamline the development of Title III projects.

Another significant improvement would be the use of purchase commitments under Title III. All existing Title III projects are purchases under Section 303 of the DPA, but the authority also permits multiyear purchase commitments. Purchase commitments would allow the DoD to create a guaranteed demand signal for an industrial capability over a mutually agreed upon period of time, thereby reducing risks for industry to make their own investments.⁴⁹ Adding a number of purchase commitment projects could significantly help maintain capacity levels in areas such as critical materials to support future mobilization efforts. Purchase commitment projects, however, are not an option currently because Congress has appropriated DPA funds over the past 3 years using standard Procurement funds which expire in 2 years, contrary to traditional DPA appropriations which do not expire. That needs to change to start using this important authority.

DPA Title VII – Relook the use of voluntary agreements and the National Defense Executive Reserve (NDER). While CFIUS continues to do critical national security work evaluating foreign investment under the authority of Title VII, there are important aspects of the title that have been dramatically underutilized. The authority permits the government to establish voluntary agreements or plans of action with industry “to help provide for the national defense.”⁵⁰ The Administration, for example, could establish voluntary agreements to prepare stand-by industrial capacity for potential surge use during conflict. The NDER permits the President to establish a volunteer group of industrial executives like WWII’s WPB to advise on or support mobilization efforts. The Administration could similarly examine the utility of creating an active NDER unit to support industrial preparations for potential major conflicts.

Design

The design and development of the specific types and models of ships, tanks, airplanes, weapons, unmanned systems, and other capabilities used in war can evolve quickly over time. During WWII, it took a great deal of iteration to get to a standard and effective designs for the Liberty and Victory ships, tanks, and the B-29 Superfortress bomber.⁵¹ As shown during Ukraine, increasing or restarting the production of precision munitions such as Javelin and Stinger can take months or even years.⁵²

Complex, largely handmade munitions are inherently difficult to produce at scale. Part of these challenges begin with how these programs were designed. In the case of the MRAP, former Secretary Gates directed acquisition officials to use existing foreign designs to speed development and fielding. This greatly speeded MRAPs getting to the battlefield.

In a current shipbuilding program, unfortunately, the opposite situation occurred. The Navy selected the “mature design” of the Italian shipbuilder Fincantieri Marine Maritime for its future frigate program back in 2020. One of the major reasons for its selection was the

⁴⁸ Currently DoD, the Department of Homeland Security, and the Department of Health and Human Services have been delegated DPA Title III authority.

⁴⁹ Office of the Assistant Secretary of Defense (Industrial Base Policy) briefing, Defense Production Act Title III. Available at <https://www.businessdefense.gov/libr/mceip/dpai/dpat3/docs/DPA-TitleIII-Overview.pdf> (accessed April 11, 2024).

⁵⁰ 50 U.S.C. §4558(c)(1); Section 708(c)(1) of the DPA. See also, Neenan and Nicastro, *The Defense Production Act*, pp. 15-16.

⁵¹ Cancian et al, “Industrial Mobilization,” pp. 16-18; Herman, *Freedom’s Forge*, chapters 16-18.

⁵² Bryant Harris and Joe Gould, “Biden’s Javelin factory tour highlights struggle to backfill Ukraine munitions,” *Defense News*, May 2, 2022. Available at <https://www.defensenews.com/industry/2022/05/02/bidens-javelin-factory-tour-spotlights-struggle-to-backfill-ukraine-munitions/> (accessed April 12, 2024).



variant built for the U.S. Navy in a Wisconsin shipyard would have 85% commonality with existing models already in service in numerous foreign navies. Design alterations made by Navy engineers, however, dramatically reduced the commonality to 20% and added 3 years to construction timelines.⁵³ These experiences, among many others, demonstrate that the DoD needs to dramatically rethink how it designs future systems.

The venerable Joint Capabilities and Development System (JCIDS) is structured to develop validated “requirements” that the Services then use to design and develop systems. As Greenwalt and Patt have demonstrated, however, this JCIDS process adds at least 2 years to program development, hardly facilitating mobilization efforts.⁵⁴ The Joint Urgent Operational Need (JUON) was created to mitigate this when addressing exigent requirements identified by combatant commands, but our Center study for the PPBE Commission illustrates how difficult it is for JUONs to transition to programs amidst existing service priorities.⁵⁵

Recommendations for Strengthening

Design for production. Dramatic attrition in wargame scenarios in the East Pacific echo the case findings that, from munitions to platforms, service acquisition officials need to focus on

designing systems for producibility. The Air Force Program Executive Office for Weapons is pursuing just such an approach with its Enterprise Test Vehicle risk reduction effort that is being competed via the Defense Innovation Unit’s commercial solutions opening. The objective of this effort is to “demonstrate an aerial platform that prioritizes affordability and distributed mass production.”⁵⁶ Fostering this production-oriented approach to design, using digital engineering, modular open systems approaches (MOSAs), and similar methods will be critical for future mobilization.

Dramatically simplify requirements processes. An outcome-oriented focus must drive future capability design. JCIDS and even JUONs are inadequate for the current national security challenges. Replicator’s emphasis on speed, rapid iteration cycles, and mature technology mirrors the MRAP experience and clearly indicates that the DoD needs a new approach to requirements for mobilization and beyond.

Resourcing

Resources are of course essential to mobilization. Throwing a lot of money at the problem can make a big difference and the faster that you can do that, the better. The per capita dollars spent during WWII were astronomical, and the extraordinary funding and reprogramming efforts to acquire and field the MRAP, as well as the rapid bipartisan support for COVID supplemental bills were critical to meeting the exigencies of these respective situations.

⁵³ Jerry Hendrix, “The Navy’s Shipbuilding Doldrums have been Largely Self-Inflicted,” *National Review*, April 10, 2024. Available at <https://www.nationalreview.com/2024/04/the-navys-shipbuilding-doldrums-have-been-mostly-self-inflicted/> (accessed April 11, 2024).

⁵⁴ William Greenwalt and Dan Patt, *Competing in Time: Ensuring Capability Advantage and Mission Success through Adaptable Resource Allocation*, Hudson Institute, February 2021. Available at https://s3.amazonaws.com/media.hudson.org/Patt%20Greenwalt_Competing%20in%20Time.pdf (accessed April 12, 2024), pp. 41-43.

⁵⁵ Commission on Planning, Programming, Budgeting, and Execution Reform, *Defense Resourcing for the Future: Final Report*, March 2024, pp. 27-28. Available at https://ppbereform.senate.gov/wp-content/uploads/2024/03/Commission-on-PPBE-Reform_Full-Report_6-March-2024_FINAL.pdf (accessed April 12, 2024). Baroni Center Report to the PPBE Commission, forthcoming.

⁵⁶ sUAS News, “DIU – Enterprise Test Vehicle.” Available at <https://www.suasnews.com/2023/09/diu-enterprise-test-vehicle/> (accessed April 12, 2024).



As demonstrated in the more recent cases, the challenges with resourcing principally come with how the DoD, working with Congress, programs, budgets, and executes funding. That is governed in the Department by the Planning, Programming, Budgeting, and Execution (PPBE) process and between the Executive and Legislative Branches by the annual budgeting cycle. These challenges can be overcome with strong Departmental leadership and/or close collaboration as demonstrated in the MRAP case, but diverging perspectives or priorities can create challenges such as seen in the Ukraine case. The Congressional Commission on PPBE Reform has closely focused on these issues over the past 2 years and released their final report in March 2024.⁵⁷

Recommendations for Strengthening

Implement appropriate PPBE Commission recommendations.⁵⁸ The Commission's final report contains 28 recommendations for improving PPBE. All deserve close consideration by the DoD and Congress, but several recommendations are particularly relevant for future mobilization efforts:

- **Transform the budget structure.** This major recommendation to move to a new Defense Resourcing System is driven by the Commission's vision for "a more flexible and agile execution process";
- **Review and consolidate budget line items (BLI).** This consolidation will increase the DoD's ability to "adjust rapidly to changing circumstances in the year of execution and inject innovation or adopt new technology to address changing threats";
- **Encourage improved in-person communications.** Increased in-person updates and execution reviews will be essential to scale and expedite efforts when necessary.

Acquisition

The performance of the Arsenal of Democracy during WWII was truly extraordinary, but as the case shows, it took 2 years to really accelerate production. The Ukraine case has demonstrated the limits of how our current approach to acquiring most munitions and major defense systems has prioritized efficiency and cost savings over production. The inability to rapidly expand and scale production significantly hampers the capacity of the defense industrial base.

The system can move fast, however. The rapid deployment and deployment of MRAPs demonstrates this. Our experience during COVID also demonstrated this exigency. During the first month of COVID, for example, U.S. Government obligations went from less than \$5 million per day to over \$200 million per day.⁵⁹ That speed accelerated to the point where the United States obligated over \$40 billion within 7 months.⁶⁰

⁵⁷ The Commission final report and all supporting information about the Commission is available at <https://ppbereform.senate.gov> (accessed April 12, 2024). N.G. The Baroni Center provided research support to the Commission from May 2023 through March 2024.

⁵⁸ PPBE Commission Final Report. All subsequent quotes from the Report.

⁵⁹ Jerry McGinn, James Hasik, and Eric Lofgren, *COVID-19 Response: Contracting with Speed*, Baroni Center Report #3, April 22, 2020. Available at <https://business.gmu.edu/news/2022-03/covid-19-response-contracting-speed> (accessed April 9, 2024).

⁶⁰ Jerry McGinn and Eric Lofgren, *COVID-19: Federal Contracting Response and Industry Impact*, Baroni Center Report #5, November 6, 2020. Available at <https://business.gmu.edu/news/2022-03/covid-19-federal-contracting-response-and-industry-impact> (accessed April 9, 2024).



The Baroni Center has outlined a number of recommendations for shifting acquisition and contracting practices to facilitate mobilization over the past year.⁶¹ The DoD has also undertaken numerous initiatives along these lines drawing on the experiences in Ukraine and exercises in East Asia, from multi-sourcing 155mm ammunition production to Replicator.

Recommendations for Strengthening

Continue to prioritize open systems approaches. The use of continuous competition and modular open systems approaches (MOSA) during the life of a program has grown apace over the past several years and needs to remain a priority for future acquisition efforts. AM General's 2023 win on the Army's Joint Light Tactical Vehicle (JLTV) recompete contract is a prime example of that approach. Having multiple healthy producers in the wheeled vehicle industrial base, as well as other countless other DoD markets, helps move away from decades-long sole-source franchise programs and, more importantly, strengthens the ability to surge production when needed.

Where possible, pursue second sourcing. As outlined in our 2023 Center white paper on the subject, second sourcing played a significant role in maintaining additional industrial capacity, while substantially reducing costs, during the 1970s and 1980s in major sub-systems such as missiles and engines.⁶² Given the need for additional production capacity in mobilization, the DoD needs to relook second sourcing as a strategy going forward.

Maximize use of unmanned and autonomous systems to scale production. The focus of unmanned and autonomous systems to increase fielded capacity has grown significantly in recent years and must continue. The Baroni Center examined four service autonomy efforts during its recent research for the PPBE Commission and discovered that service prioritization and Congressional support have been critical to keep these efforts on track.⁶³ Publicly available information on Replicator has shown similar progress.⁶⁴

Contract for speed and surge.

- **Increase the use of follow-on production Other Transactions (OT) Agreements.** While research and prototype OTs have become standard practice in most parts of the DoD innovation ecosystem, transitioning to production—the so-called valley of death—is where many prototype efforts have struggled. Using more follow-on production OTs, in addition to FAR-based production contracts, will help speed the transition to production for appropriate innovation efforts.

⁶¹ Jerry McGinn, "America needs to grow its capacity to produce weapons. Here's four steps to do it," *Breaking Defense*, March 17, 2023. Available at <https://breakingdefense.com/2023/03/america-needs-to-grow-its-capacity-to-produces-weapons-heres-four-steps-to-do-it/> (accessed April 14, 2024). Olivia Letts, Jerry McGinn, Richard Beutel, "Back to the Future? Second Sourcing in Defense Acquisitions," Baroni Center for Government Contracting White Paper series #16, July 12, 2023. Available at <https://business.gmu.edu/news/2023-07/baroni-center-releases-white-paper-back-future-second-sourcing-defense-acquisitions> (accessed April 14, 2024). McGinn, "How to use the 'MRAP Mindset' to get U.S. industrial base on a wartime footing," *Breaking Defense*, January 3, 2024. Available at <https://breakingdefense.com/2024/01/how-to-use-the-mrap-mindset-to-get-us-industrial-base-on-a-wartime-footing/> (accessed April 14, 2024).

⁶² Letts, McGinn, and Beutel, "Back to the Future." See also, Ginny Wydler, Su Chang, and Erin M. Schultz, "Continuous Competition as an Approach to Maximize Performance," *Defense Acquisition Research Journal*, April 2013, Vol. 20 No 1, pp. 37-57. Available at <https://apps.dtic.mil/sti/tr/pdf/ADA583903.pdf> (accessed April 14, 2024).

⁶³ McGinn et al, *Case Studies of Technology Transition*, Report for the Commission on PPBE Reform, forthcoming.

⁶⁴ Brandi Vincent, "Counter-drone systems included in DoD's initial Replicator selections," *DefenseScoop*, April 9, 2024. Available at <https://defensescoop.com/2024/04/09/counter-drone-systems-replicator-selections/> (accessed April 14, 2024).



- **Establish surge CLINs.** Include surge tasks in program solicitations to create latent capacity. Contract for advance design and planning work for on-call surge production to greatly reduce the time for increased capacity if needed.⁶⁵

Sustainment

Contested logistics has been a major priority for the DoD given the experience in Ukraine and the daunting supply lines of a potential conflict in East Asia. Assistant Secretary of Defense for Sustainment (ASD(S)) Christopher Lowman recently noted that the shift to great power competition has required that the DoD needs to shift its sustainment approach to better “understand what we should be planning for upfront in the product support planning cycle.”⁶⁶

Supply chains have also been a major focus for the DoD and industry, particularly since COVID. Numerous supply chain illumination initiatives and investments coming from EO 14017 have prioritized DoD actions in the past several years.⁶⁷

Recommendations for Strengthening

Creating a tax on programs could help enable the second sourcing of parts to reduce supply chain bottlenecks. Shortages in parts often produce production bottlenecks for industry and the DoD. The Program Executive Offices across the DoD work with industry to mitigate these challenges, but the costs of establishing, qualifying, and maintaining a second source compete with other program priorities. One way to address this challenge would be to create a tax like that used for Small Business Innovation Research, which would go into a specific budget to help fund second sources where the need arises. The DoD could work with Congress to establish a pilot effort along these lines in the FY2024 NDAA.⁶⁸

Modeling surge requirements will be critical for future mobilization. ASD(S) has developed a repeatable objective model for surge capacity, and OSD has requested the Services to lay out an incentive structure for surge capacity with a focus on the Indo-Pacific theater in the current Defense Planning Guidance.⁶⁹ Building out these types of sustainment models will be critical to establish the needs and contract for the capacity necessary to sustain our forces in any major contingency.

Grow overseas sustainment capacity. Given the length of supply chains, the DoD needs to establish facilities in theater to repair and replace systems during conflict. The final assembly and check out (FACOs) facilities in Japan and Italy for the F-35 program are already established and chartered for repair and sustainment work.⁷⁰ There are also discussions underway to establish repair facilities for submarines and other initiatives developed under AUKUS in Australia.⁷¹ More of these efforts will increase the resilience of deployed systems.

⁶⁵ McGinn, “MRAP Mindset.”

⁶⁶ Laura Heckman, “Pentagon Developing Sustainment Strategies for Great Power Competition,” *National Defense Magazine*, February 6, 2024.” Available at <https://www.nationaldefensemagazine.org/articles/2024/2/6/pentagon-reassessing-rigid-sustainment-strategies-for-great-power-competition> (accessed April 14, 2024).

⁶⁷ See “Executive Order on America’s Supply Chains: A Year of Action and Progress,” The White House, February 7, 2022. <https://www.whitehouse.gov/wp-content/uploads/2022/02/Capstone-Report-Biden.pdf> (accessed April 14, 2024).

⁶⁸ Letts, McGinn, and Beutel, “Back to the Future,” p. 10.

⁶⁹ Lowman remarks at the NDIA Logistics Forum, Oklahoma City, OK, February 23, 2024.

⁷⁰ McGinn and Roche, *Build Allied*, p. 21.

⁷¹ John Grady, “AUKUS Partners Working Through Reality of a Submarine Pact, Official Say,” *USNI News*, April 9, 2024. Available at <https://news.usni.org/2024/04/09/aukus-partners-working-through-reality-of-submarine-pact-officials-say> (accessed April 14, 2024).



Public Support

Getting and maintaining public support is critical to mobilization efforts. As Herman and Wilson clearly illustrate in the WWII case, FDR carefully calibrated his mobilization efforts to meet the American domestic political environment. The Japanese attack on Pearl Harbor led to the all-out acceleration of the mobilization effort, but efforts starting in 1938 gave the industrial base a tremendous head start to develop the capabilities and the capacity needed to succeed when it mattered. For example, when domestic Congressional interests supported the development of navy shipbuilding, FDR seized that opportunity to start mobilizing that critical part of the industrial base. Later he used the Lend-Lease program to get equipment to Europe in the face of a skeptical Congress. Similarly, Secretary Gates's outsized role in the MRAP case helped maintain Congressional and public support throughout its development and deployment. In the ongoing Ukraine case, however, maintaining public support has become increasingly challenging as domestic political challenges have grown in the past year.

Recommendations for Strengthening

There is no substitute for leadership. It is hard to overstate the importance of leadership at all levels in mobilization efforts. Regularly stating and restating the rationale for and benefits of mobilization is essential to maintaining support across the branches of government and with the public.

Make the tangible benefits of mobilization clear. While mobilization's impact on domestic facilities and firms is well promoted, the impact of support to allies and partners like Ukraine is not as well understood or articulated to the public. Strong articulation of the benefits to the U.S. defense industrial base of foreign assistance, not to mention the significant contributions of U.S. subsidiaries of foreign-headquartered firms, will help blunt some of the political and public skepticism that can arise in mobilization efforts.⁷²

Allies and Partners – A Little Help from Our Friends

As the cases clearly demonstrate, mobilization efforts heavily involve U.S.-based production.

But at the same time, we have only so much manufacturing capacity. It is therefore critically important for the United States to harness and leverage the capacity of our allies and partners to supplement our production capacity. This has been evident with the use of foreign designs for the MRAPs that saved thousands of lives in Iraq and Afghanistan. Similarly, the dramatic expansion of 155mm munitions production to support Ukraine is coming from U.S. but also from Polish, Korean, and Indian-based firms.⁷³

This additive capacity is essential, particularly so in a potential two-front fight: if deterrence fails in the Western Pacific, the amount of destruction will be catastrophic. Russia could see that as an opportunity to attack the Baltics or conduct punishment strikes elsewhere. European production capacity, particularly for munitions, will help European

⁷² See, for example, Mark Thiessen, "Ukraine aid's best kept secret: most of the money stays in the U.S.A.," *Washington Post*, November 29, 2023. Available at <https://www.aei.org/op-eds/ukraine-aids-best-kept-secret-most-of-the-money-stays-in-the-u-s-a/> (accessed April 14, 2024). See also, McGinn and Roche, *Build Allied*, p. 45.

⁷³ Jen Judson, "U.S. Army awards \$1.5B to boost global production of artillery rounds," *Defense News*, October 6, 2023. Available at <https://www.defensenews.com/land/2023/10/06/us-army-awards-15b-to-boost-global-production-of-artillery-rounds/#:~:text=US%20Army%20awards%20%241.5B%20to%20boost%20global%20production%20of%20artillery%20rounds,-By%20Jen%20Judson&text=WASHINGTON%20—%20The%20U.S.%20Army%20said,production%20of%20155mm%20artillery%20rounds> (accessed April 13, 2024).



NATO countries defend themselves while the United States is busy slugging it out in East Asia.

The F-35 Final Assembly and Check Out facilities in Japan and Italy are an example of how existing cooperative efforts create additional capacity in potential operational theaters.⁷⁴ So too are the U.S. subsidiaries and investments in Poland.⁷⁵ We are fortunate that our treaty allies make up the most successful advanced economies in the world. Their manufacturing and their engineers are a valuable, important component of our alliance systems, just as their armed forces, diplomats, intelligence, air/seaports, and airspace are vital contributors to our alliance system.

Recommendations for Strengthening

Develop a true Build Allied approach. Our 2023 Baroni Center report laid out a series of recommendations to strengthen the ability of allies and partners to contribute to overall industrial base capacity that would significantly contribute to mobilization efforts.⁷⁶ Each of these deserve consideration, but fortunately the NDIS, other Administration actions, and the FY24 NDAA have addressed some of these recommendations. There is still work to be done, however, so here are some specific recommendations building off that report:

- **Prioritize international industrial collaboration.** International industrial collaboration has been central to programs such as the F-35, and this collaboration must continue to grow in the future. Recent progress in AUKUS Pillar I and II efforts focused on co-development and co-production are promising,⁷⁷ but this emphasis on international collaboration needs to be strongly promoted across the defense acquisition system through actions such as direct DoD leadership guidance, avoiding U.S.-only requirements development, and including international collaboration in performance evaluations for acquisition officials.⁷⁸
- **Promote and fund exportability.** The NDIS rightly emphasizes the importance of build exportability into systems during system design and development, rather than post-production.⁷⁹ The key is to make that happen, which requires policy and resourcing changes:
 - **Strengthen exportability incentives.** As the NDIS notes, DoD Instruction 5000.85 already directs programs to consider exportability during program development. Given the paucity of exportability efforts in current DoD programs, however, there needs to be more education and training on the benefits of exportability throughout the defense acquisition community.
 - **Dramatically increase funding of the Defense Exportability Features (DEF) program to spur increased exportability.** The DEF was established in 2013 to do exactly as the NDIS emphasizes. While it has contributed to important programs such as the U.S.–Norwegian collaboration on the Three-

⁷⁴ McGinn and Roche, *Build Allied*, pp. 19-21.

⁷⁵ “Poland – Country Commercial Guide.” International Trade Administration, U.S. Department of Commerce. Available at <https://www.trade.gov/country-commercial-guides/poland-defense-industry> (accessed April 13, 2024).

⁷⁶ McGinn and Roche, *Build Allied*.

⁷⁷ See, for example, AUKUS Defense Ministers’ Joint Statement, April 9, 2024. Available at <https://www.defense.gov/News/Releases/Release/Article/3733790/aukus-defense-ministers-joint-statement/> (access April 14, 2024). See also, Jen Judson, “Australian companies increasingly look to US following AUKUS pact,” *Defense News*, April 5, 2024. Available at <https://www.defensenews.com/land/2024/04/05/australian-companies-increasingly-look-to-us-following-aukus-pact/> (accessed April 14, 2024).

⁷⁸ McGinn and Roche, *Build Allied*, pp. 43-44.

⁷⁹ NDIS.



Dimensional Expeditionary Long Range Radar, it has limped along at \$10 million of annual funding. This needs to dramatically increase if the DoD is going to achieve its NDIS exportability objectives.⁸⁰

- **Ensure that technology transfer regimes facilitate increased collaboration.**
 - **Closely monitor the implementation of AUKUS export control reforms.**
The FY24 NDAA included significant export control reform relief for the United Kingdom and Australia to support AUKUS technology transfer. Given repeated failures in previous efforts, most notably the unsuccessful implementation of the defense trade treaties,⁸¹ the Administration must ensure that these export control changes help, not hinder, the close technological cooperation needed for AUKUS success.
 - **Technology disclosure and foreign disclosure (TSFD).** Similarly, DoD leadership needs to ensure that TSFD processes such as anti-tamper and electronic warfare do not hamper AUKUS or international cooperative efforts involving sensitive technology. The DoD has reviewed these policies for AUKUS, but the proof will come as Pillar II initiatives begin to mature.⁸²

Conclusion

The national security challenges facing the United States are profound. While the capabilities developed by our defense industrial base are the absolute best in the world, we must reposition our industrial base to meet today's challenges at the speed and scale necessary to ensure success. While further research and actions are needed, this paper lays out a roadmap to help government and industry to mobilize in the event of major conflict.

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⁸⁰ McGinn and Roche, *Build Allied*, pp. 8-9, 30-31, and 45.

⁸¹ Ibid., pp. 12-13.

⁸² Bryant Harris, "Congress lays groundwork for AUKUS export control reform," Defense News, March 22, 2023, <https://www.defensenews.com/congress/2023/03/22/congress-lays-groundwork-for-aukus-export-control-reform/> (accessed April 14, 2024).



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Defense Acquisition Trends 2023: Meeting the Challenge of Production?

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Abstract

The industrial-scale conflict of the war in Ukraine and the burgeoning production capacity of the People's Republic of China are reshaping the objectives of the defense acquisition system. This paper considers how acquisition trends have evolved in this environment, with special attention to the nation's first National Defense Industrial Strategy. After accounting, for inflation contract obligations rose 5.3% in Fiscal Year (FY) 2023, including increases in aircraft and shipbuilding, and a striking 58% 1-year rise in ordnance and missile obligations. A groundbreaking look at the number of defense vendors and the market share going to nontraditional defense contractors finds, skipping over the COVID-19 response in the past 2 years, that the \$94.7 billion spent in FY2023 was 9.3% above FY2020 levels. Other Transaction Authority usage has also increased with a diversifying group of customers and a near doubling of spending on production.

Introduction

In Fiscal Year (FY) 2023, the defense acquisition system faced the challenge of sustaining industrial-scale warfare. In response to Russia's expanded war in Ukraine, the U.S. took advantage of Presidential Drawdown Authority (PDA) to provide security assistance to Ukraine from existing U.S. stocks. Presidential drawdowns increased from a value of \$9.2 billion in FY2022 to \$14.6 billion in FY2023 (Arabia et al., 2022). Concurrently, the defense industrial base (DIB) began to increase and accelerate production to replenish transferred systems and to prepare for scenarios in which the war continues over multiple years. However, the DIB confronts an uncertain funding landscape, as proposed supplemental security assistance that would provide an influx of funds to the DoD was delayed for consideration to FY2024 and faces an uncertain fate at the time of writing.

Russian aggression is far from the DoD's exclusive focus; instead, the National Defense Strategy identifies China as the pacing threat. China's defense industrial capacity has expanded at a striking pace, with China's shipbuilding industry output dwarfing that of the United States (Jones & Palmer, 2024, p. 14). China produces a range of platforms, especially ships, at a pace difficult to imagine, let alone achieve, for the DoD's exquisite systems. Building the same systems, but at a faster pace, can be part of the solution. However, in the Western Pacific new submarines will be slow to arrive in optimistic scenarios. The DoD and its industry partners confront the challenge of both innovating new systems and ensuring systems arrive in the hands of the operators at a pace far exceeding that of traditional major defense acquisition programs.

To meet this daunting geopolitical environment, the DoD launched its first National Defense Industrial Strategy (NDIS) earlier this year (DoD, 2023). It outlined four strategic pillars, each with their own action items and metrics. The four pillars and some of the actions that are being taken in pursuit of the strategy are listed below:



- **resilient supply chains:** making capacity investments, increasing the visibility of lower tiers in the supply chain, and building resilience with the help of allies and partners
- **workforce readiness:** supporting the recruiting and training of public- and private-sector workers for a range of high-tech and industrial jobs
- **flexible acquisition:** pursuing standardization, open architectures, “access to intellectual property and data rights” (DoD, 2023, p. 34), and use of commercial off-the-shelf acquisition where possible¹
- **economic deterrence:** countering adversary efforts in the economic realm and strengthening science and technology sharing within alliances (DoD, 2023, pp. 16–17, 27, 34, 45; DoD, 2024)

While the strategy was released after the period covered in this report, it drew on longstanding best practices and recent work such as the February 2022 supply chain report (DoD, 2022). The NDIS calls out the importance of metrics: “Intermediate measures of success for the near-term actions over the next three to five years will be necessary to track progress toward the long-term goals” (DoD, 2023, p. 49).

Much of this will require information not available in the open source. For example, in February 2023 the deputy secretary of defense issued a data call to illuminate the supply chain for 110 weapons systems (DoD, 2023, p. 49). However, public data sets, such as the Federal Procurement Data Source (FPDS), can aid in identifying challenge areas and demonstrating progress towards the NDIS’s goals.

This paper examines FY2023 contract obligations to examine the extent to which recent shifts have anticipated the strategy’s direction and to better understand the baseline from which the U.S. government and industry, in cooperation with allies and partners, will face another demanding year in a marathon of industrial capacity building. The paper begins with an examination of overall contracting trends in the section titled What Is the DoD Buying? The next section, titled Production Capacity and Munitions, focuses on the parts of the NDIS most relevant to responding to the war in Ukraine. The following section, The Supplier Base and Nontraditional Defense Contractors, looks at DIB vendor counts and the market share won by the sort of nontraditional vendors the NDIS seeks to attract into the base. The penultimate section, The Range of Contracting Approaches, looks at the mix of Federal Acquisition Regulation (FAR) and non-FAR arrangements the NDIS seeks to encourage, with a deeper dive on Other Transaction Authority (OTA). International cooperation and production diplomacy is also central to the NDIS but beyond the scope of this paper for space reasons. The paper concludes with findings regarding the relevant illustrative outcomes and outputs identified by the NDIS.

What Is the DoD Buying?

This analysis starts by looking at the demand signal for industry, as measured by DoD contract obligations as shown in **Error! Reference source not found..** Contact obligations rose from \$433.1 billion in 2022 to \$456.2 billion in 2023, a 5.3% increase after accounting for inflation.² This contract obligation growth outpaced the overall 2.1% increase in DoD outlays. Foreign funding bolstered spending as contracts that include foreign military sales (FMS) jumped from \$40.5 billion to \$65.8 billion. The dramatic increase is partially

¹ Flexible acquisition pointedly does not include “broad-based acquisition reform, which ... is beyond the scope of this strategy” (DoD, 2023, p. 34).

² Unless otherwise specified, all dollar figures in this paper are converted to constant 2023 dollars using gross domestic product deflators from the Office of Management and Budget’s 2025 presidential budget.



attributable to \$36.5 billion in spending on the F-35 project, 86% of which was for contracts that include FMS.³ The substantial increase in FMS provides evidence of the budgetary and often supply chain support that allies and partners provide for DIB production capacity.

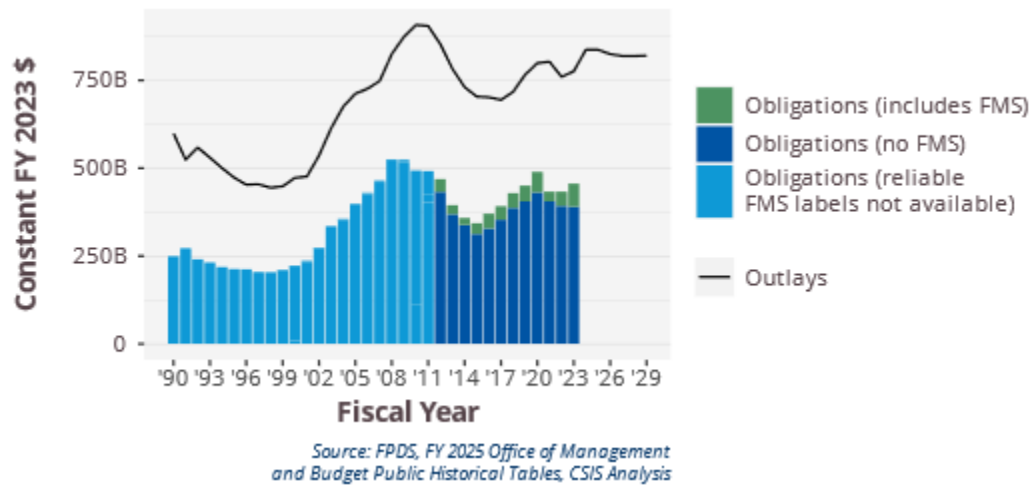


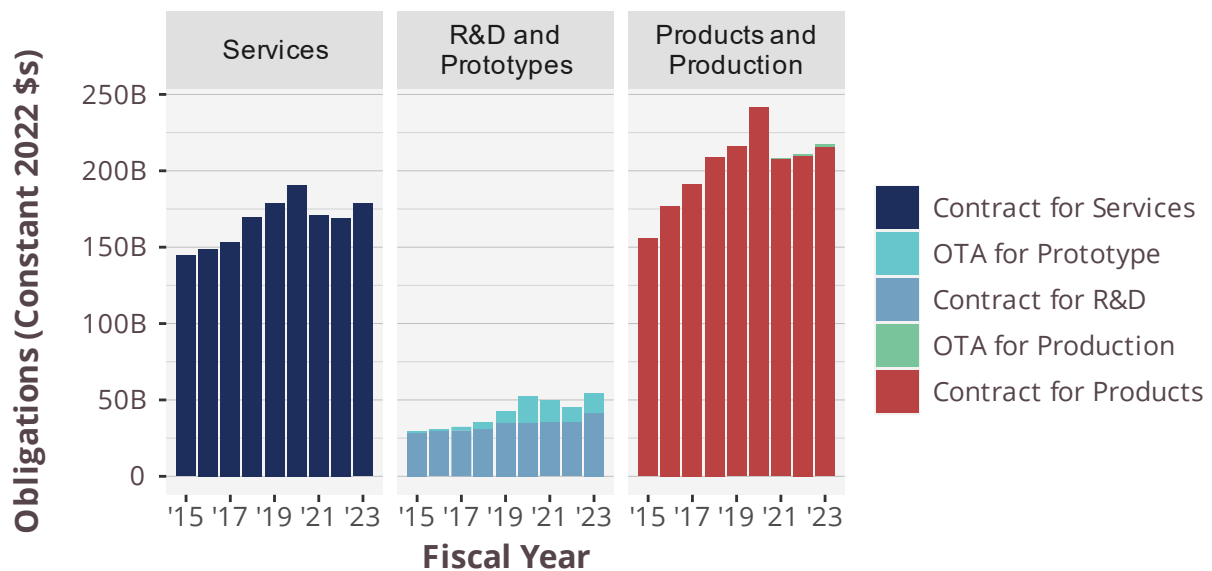
Figure 1. Defense Contract Obligations and Total Obligation Authority, FY1990 to FY2024 Oct–Nov

Obligations by Area

To understand how the DoD balances competing priorities of production, technology and innovation, and maintenance of existing equipment, this paper now turns to obligations for products, research and development (R&D), and services. These three categories, although not precisely aligned with DoD funding accounts, provide a helpful view of the DoD's shifting priorities over time.

This section introduces a second form of funding, the innovation-oriented OTA. While OTA is only reliably available back to FY2015, these arrangements play a substantial role in R&D and thus must be considered to give a complete picture. The data show that product along with OTA procurement spending continues to account for the largest share of obligations, accounting for 48.25%, followed by services (39.7%) and then R&D along with OTA prototypes (12.05%).

³ The F-35's fluctuations are broken out below in the Navy section of Figure 4.



*Note: Unlabeled contract product, service, and R&D areas as well as unlabeled OTA agreement types not shown.
Source: FPDS and CSIS analysis.*

Figure 7. Defense Contract Obligations by Product, Service, and R&D and OTA Obligations by Agreement Type, FY2015 to FY2023

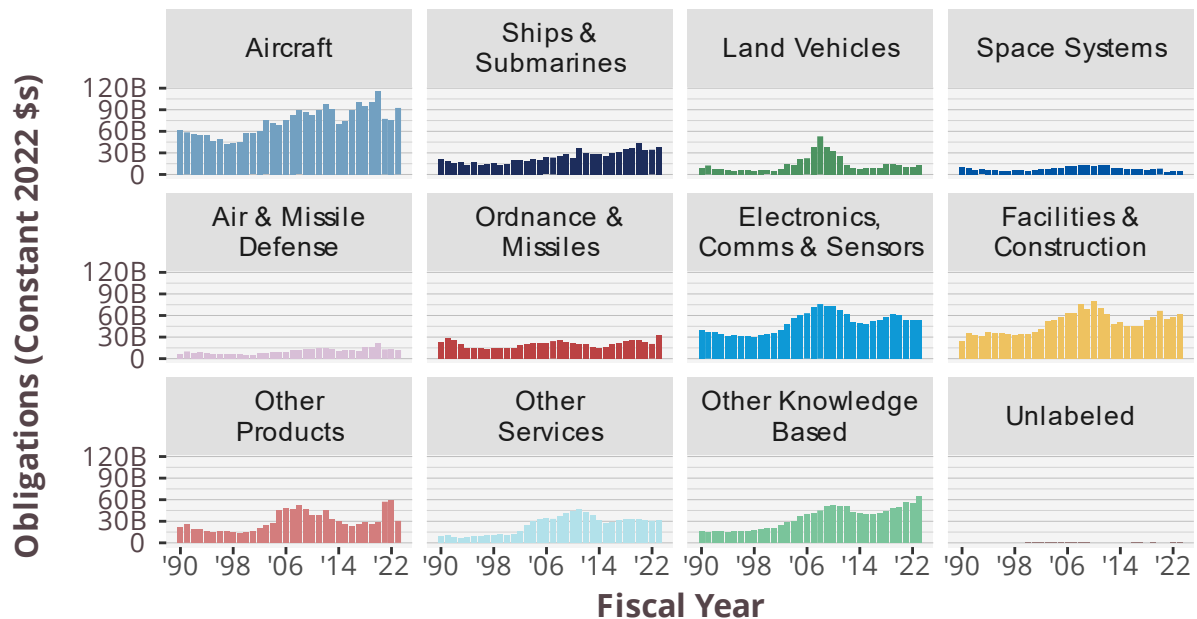
Figure 2 depicts the trajectory of DoD spending across these three areas from FY2015 to FY2023, showing an increase from FY2022 to FY2023 across the board, with the largest increase seen in R&D. However, despite significant increases in FY2023, both product and services contract obligations remained over 6% lower than the recent peak in FY2020. When considering both contracts and OTAs, total spending remained 7% below FY2020's total of \$507.9 billion, a figure largely attributable to increases in major air systems programs, notably the F-35, increases in naval ship spending, and COVID-19–related spending.

Obligations for services fell slightly from FY2021 to FY2022 but rose sharply in FY2023 by 5.9% to \$187.4 billion in FY2023. R&D and prototype obligations saw the most significant hike, leaping by 20.0% from \$47.4 billion in FY2022 to \$56.8 billion in FY2023. Finally, the largest contract spend category of the three, product and production obligations, experienced the smallest growth, rising 3.4% from \$220.3 billion in FY2022 to \$227.8 billion in FY2023. For both R&D and Prototype and Product and Production obligations, spending rose at a faster rate for OTAs than for contracts.

To understand the trends shaping the DIB, one must also look not only at what and how much the DoD buys, but *how* it buys, particularly given the department's stated objective of increasing acquisition flexibility. OTAs, distinct from than contracts, grants, or cooperative agreements, are an acquisition approach that pursues innovation and flexibility by enabling certain federal entities, including the DoD, to procure goods and services outside of the traditional acquisition system. However, although OTAs enable flexibility of payment arrangement, promote the utilization of nontraditional vendors, and can advance new technologies, their relative newness and the need to tailor agreements mean that the usage of OTAs is often more demanding on the acquisition workforce and requires additional training.

In the past fiscal year, OTA obligations rose for both prototypes and production. The increased use of OTA for prototypes was dramatic, up 30.4% to \$13.6 billion from FY2022. Yet, despite this increase, OTA for prototypes remained significantly lower than the peak in FY2020. While OTA use had fallen markedly after peaking in 2020 as part of Operation Warp Speed and the larger U.S. COVID-19 response (Schwartz & Halcrow, 2022, pp. 19–20), 2023 re-establishes their importance as over 3 in 10 dollars spent on R&D or prototypes use the OTA mechanism. Similarly, OTAs increased for production, nearly doubling from a small baseline at \$1.1 to \$2.1 billion in FY2023. While still a tiny portion of product spending, OTA for production is worth watching closely as it indicates one path for OTA prototype experiments to transition to systems that are deployable in the field.

Obligations by Platform



Source: FPDS and CSIS analysis.

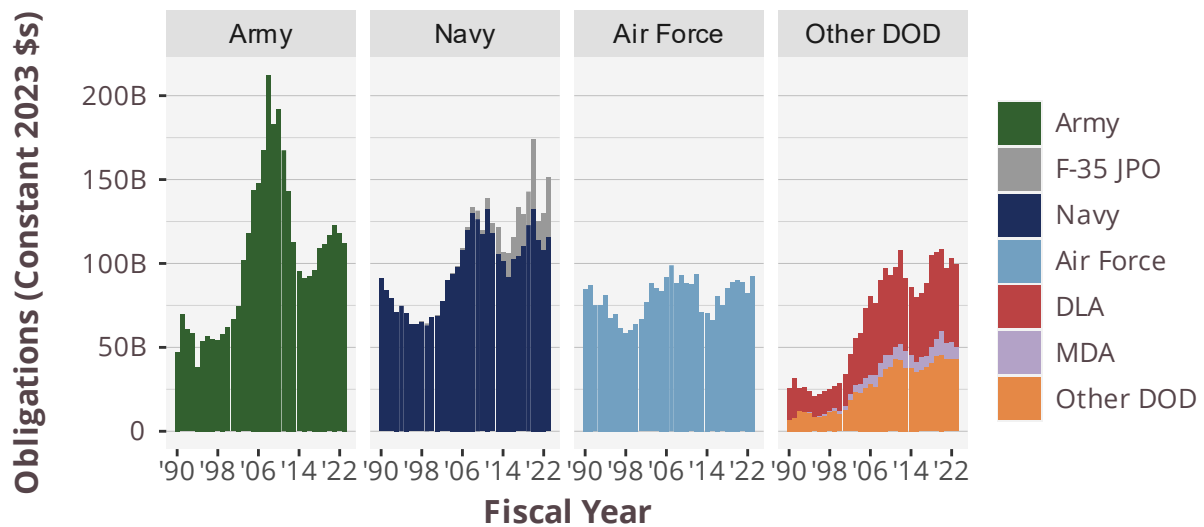
Figure 8. Defense Contract Obligations by Platform Portfolio, FY1990 to FY2023

Obligations by Component

The 5.3% increase in spending was concentrated in a short list of weapon systems categories, primarily ordnance and missiles, as seen in Figure 13. That category, central to refilling stocks diminished by the war in Ukraine, surged from \$21.4 billion to \$34.1 billion, a 59.3% increase to the highest obligation amount this century. Surprisingly, despite their similar relevance, air and missile defense equipment fell by 13% to \$12.6 billion. This is the lowest spending level since FY2017. Land vehicles, aircraft, other knowledge-based services, and submarines all experienced double-digit growth (28.8%, 23.4%, 17.0%, and 11.5% increases respectively). However, the gain in other knowledge-based services is somewhat deceptive as it is in part a consequence of decreasing granularity in the product and service codes used by the FPDS. Those codes once distinguished defense R&D by platform type but in recent years only specify the phase of R&D for a range of platforms.

Understanding the landscape of contract spending across DoD components provides further insight into how and to what extent DoD strategic priorities are reflected in its acquisition efforts. **Error! Reference source not found.** shows DoD obligations from 1990 to FY2023 organized by component. The data show that in FY2023, the services together

accounted for 78% of the department's spend, with the Navy at 25.3% (32% including F-35 Joint Program Office obligations), Army at 24.6% and the Air Force at 20.3% of total contract obligations.



Source: FPDS and CSIS analysis.

Figure 9. Defense Contract Obligations by DoD Component, FY1990 to FY2023

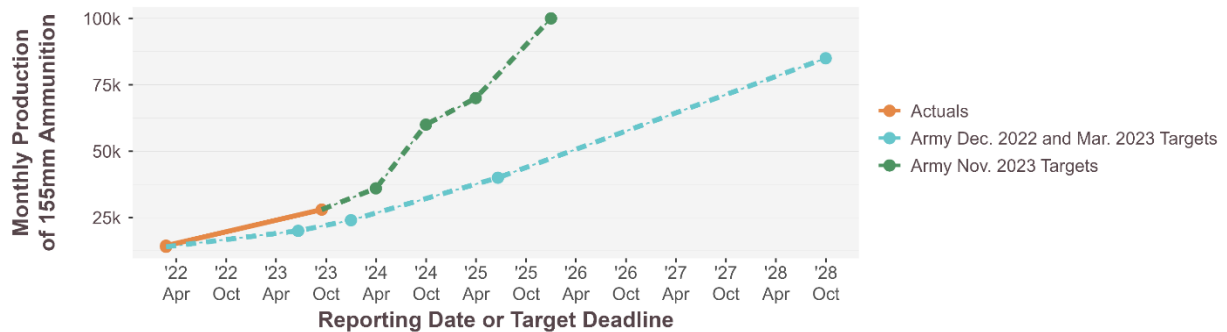
This represents a significant dip in obligations from non-service components, such as the Missile Defense Agency (MDA), whose contract obligations dropped 31% from FY2022 to FY2023 and halved since FY2020. The MDA's 50% decline in contract obligations corresponds to the 43.9% decline in missile defense platforms highlighted in Figure 13.

Among the DoD services, the Air Force experienced the most significant increase in contract obligations, up from its dip to \$82.5 billion in FY2022 to \$92.7 billion in FY2023, a 12.3% rise. This growth was driven by a steady rise in spending in the other knowledge-based services portfolio. The Navy also increased its contract obligations, climbing 7% from \$107.9 billion in FY2022 to \$115.5 billion in FY2023. However, at \$115.5 billion, obligations still represent a 12% drop from the service's contract obligations in FY2020, which saw greater DoD spending on naval platforms, including ships and submarines. The Army, unlike the Air Force and the Navy, decreased contract obligations from FY2022 to FY2023, dropping by 4.7% from \$117.8 billion to \$112.3 billion. This decline occurred despite the increase in ordnance missiles and land vehicles, both portfolios associated with the Army due to the wrapping up of the Army's extensive spending in FY2021 and FY2022 as part of COVID-19 response efforts.

Production Capacity and Munitions

In support of a larger mantra that production is deterrence, the industrial strategy plainly identifies an "increase in DIB capacity" (DoD, 2023, p. 24) as a key metric for success and seeks to pursue multiple routes to that goal. This can mean direct investments, especially in government owned facilities that are operated by the government (GOGO), operated by contractors (GOCO), or leased to contractors (such as most of the Alleghany Ballistics Laboratory). For data availability in FPDS reasons, this report focuses on private sector industrial base rather than the organic industrial base, but as shown in Figure 15, based on public reporting, the ramp in the Army artillery shell production had exceeded initial projections and has grown more ambitious in response to the ongoing operational

need by Ukrainian forces. Meeting future targets, however, will depend on whether a supplemental spending bill is passed (CSIS, 2024).



Sources: Bryan Bender and Lara Seligman, *Politico*, Dec., 4, 2022; Jen Judson, *DefenseNews*, Mar. 28, 2023; Noah Robertson, *DefenseNews*, Sept. 15, 2023; Sam Skove, *Defense One*, Nov. 27, 2023; initial chart by Govini; and CSIS analysis.

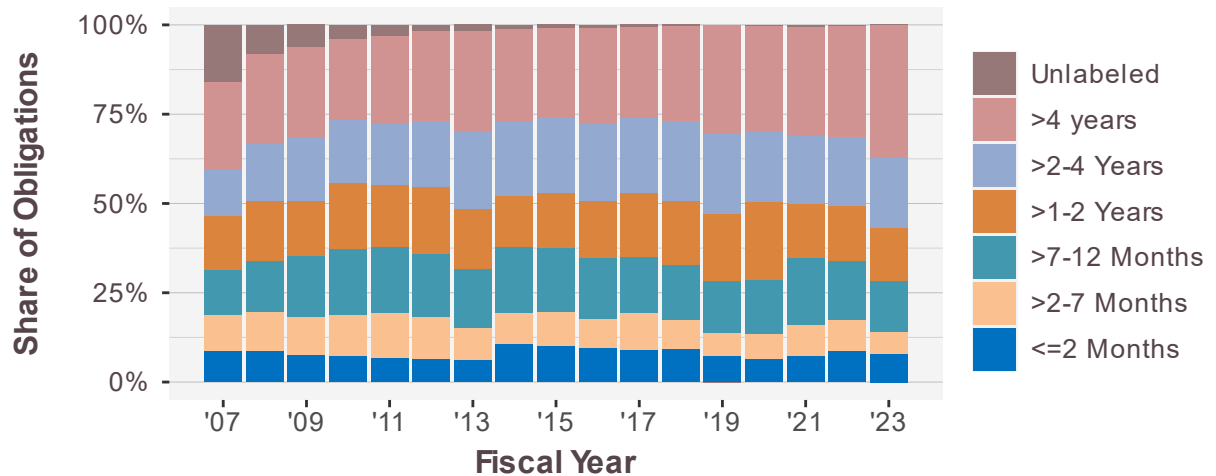
Figure 10. Army 155 mm Ammunition Production Rates and Targets

Deputy Secretary of Defense Kathleen Hicks listed five key investments by the administration since its first budget to boost the DIB:

- \$2.4 billion for casting and forging, batteries, kinetics, and critical minerals;
- \$10.3 billion in microelectronics, augmented by historic funds in the CHIPS and Science Act;
- \$12.9 billion for industrial base infrastructure and facilities, including shipyards;
- \$9 billion alone in submarine industrial base investments to support both our domestic production goals and [Australia, United Kingdom, and United States (AUKUS)] commitments; and,
- \$24.7 billion for multi-year procurement of key munitions, from PATRIOTs to Long-Range Anti-Ship Missiles. (Hicks, 2024)

Both direct support and attempts to incentivize industry to make further investment are one of the places where the strategy becomes most explicit about specific contracting approaches.⁴ Specifically, increasing multi-year procurement is a goal in its own right, which requires not just funding but also program-by-program authorization by Congress. Historically, industry has been hesitant to make major investments in capacity, especially in the ordnance and munitions, because of the boom and bust cycles of spending and a longstanding peace-time emphasis on lowering unit costs by maximizing efficiencies (Cook, 2023).

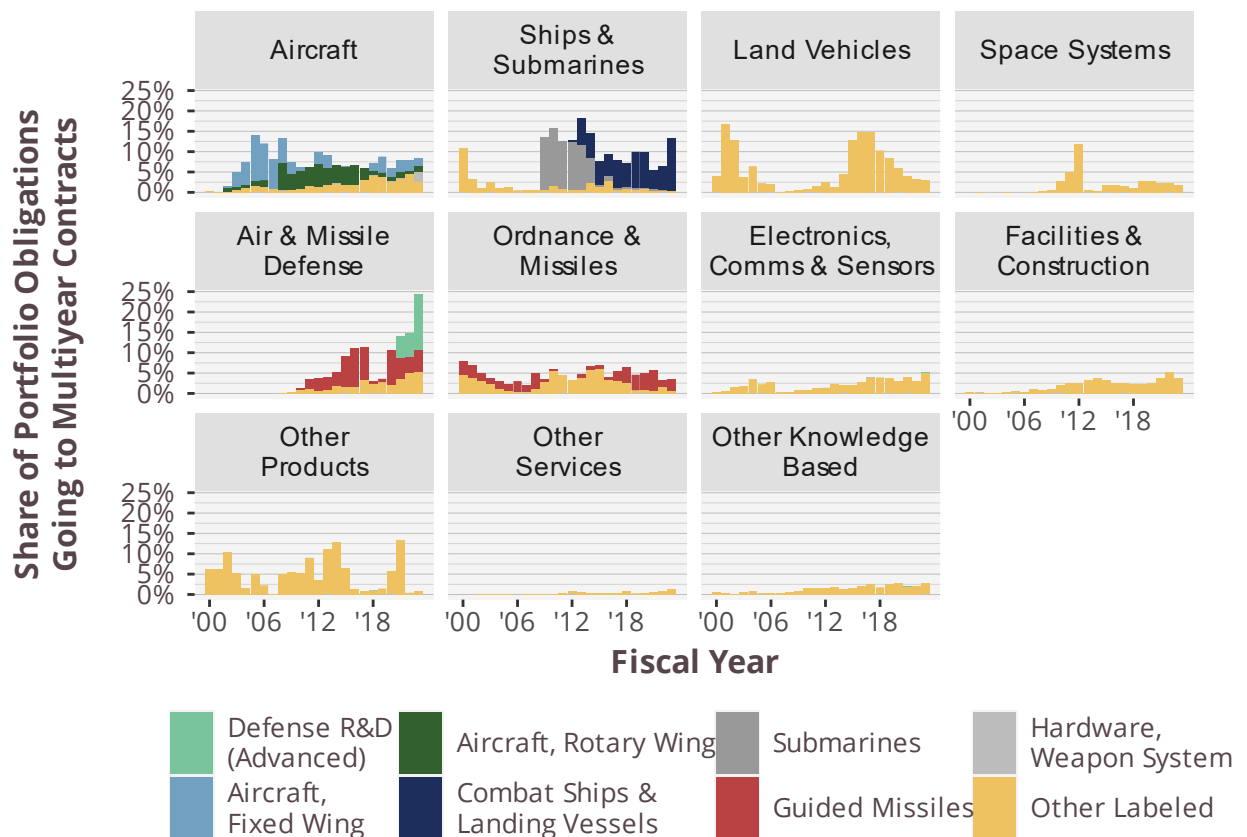
⁴ Capacity boosting actions include 2.1.2.1 (incentivizing industry to boost and sustain spare production capacity); 2.1.2.3 (revitalizing the [organic industrial base] with “innovative funding mechanisms including GOGO and GOCO sites”); and 2.3.2.6 (“The DOD will seek to expand the use of multi-year procurement [MYP]”; DoD, 2023, pp. 17, 19, 38).



Source: FPDS and CSIS analysis.

Figure 11. Share of Defense Obligations by Initial Contract or Task Order Ultimate Duration, FY2007 to FY2023

Contract funding, which markedly rose for ordnance and missiles as shown earlier in **Figure 13**, is the most powerful demand signal to industry to ramp up production. Boosting capacity is a slow process that leads the strategy to point to longer-term contracts and program duration as ways both to incentivize industry and build up the domestic production base (DoD, 2023, pp. 17, 19). This does come with challenges in an environment where high inflation is a recent memory and a potential future risk. As seen in **Figure 16**, in the wake of inflation the use of contracts with a duration of 7 months or less rose in FY2022 to the highest level since FY2018. However, the share for shorter-term contracts fell to just 14.1% in FY2023 with contracts with an anticipated ultimate duration of 4 years or more rising to 37%, the highest level of the period with reliable data available.



*Note: When the multiyear column is blank, transactions are treated as not multiyear.
Source: FPDS and CSIS analysis.*

Figure 12. Share of Contract Obligations Employing Multi-Year Procurement by Platform and the Top Seven Products or Services, FY2000 to FY2023

However, many contracts are shorter term or only placed in batches at a time and thus address present demand and stockpiles but do not assure industry that this demand will recur in the future. Multi-year procurement is a powerful means to incentivize industry to boost capacity in ways that will have long-term benefits but may take years to achieve a return on investment. This method lays out expected future buys and includes reimbursement to industry for investments made should those future buys fall short of expectations. This approach inherently limits DoD's future flexibility to shift priorities should a system no longer be relevant to urgent strategic needs, which is why explicit congressional authorization is required.

Multi-year contract spending rose to nearly \$26.0 billion in FY2023, exceeding the previous high of \$25.8 billion in FY2021. **Error! Reference source not found.** shows the share of contracting for a given platform using multi-year procurement. These shares are lumpy as a given program moves into and then out of the acquisition pipeline, but air and missile defense and ships and submarines have both shown marked increases. The doubling in multi-year ship and submarine contracts, going from \$2.3 billion to \$5.3 billion due to the DDG-51 is especially noteworthy. While air and missile defense obligations are not yet rising, multi-year procurement has increased from \$2.15 billion to \$3.05 billion, a promise of steady funding in the future. By comparison, multi-year procurement rose 78%

for ordnance and missiles, but the \$1.2 billion in obligations in FY2023 are still below FY2020's \$1.4 billion.

The Supplier Base and Nontraditional Defense Contractors

The DIB is proportionally smaller than its Cold War peak: the 3.2% share of U.S. GDP going to military expenditures is a bit over half the rate of 1973 and a bit over a third of the 1963 rate. In absolute terms, there are “1.9 million fewer people” in the DIB relative to 1985 and in the larger economy “7.1 million fewer people in US manufacturing jobs since 1979” (DoD, 2023, p. 21). Even with expanding budgets, this difference results in fundamental restraints that prevent any industrial strategy from simply replicating the strengths of the Cold War DIB.

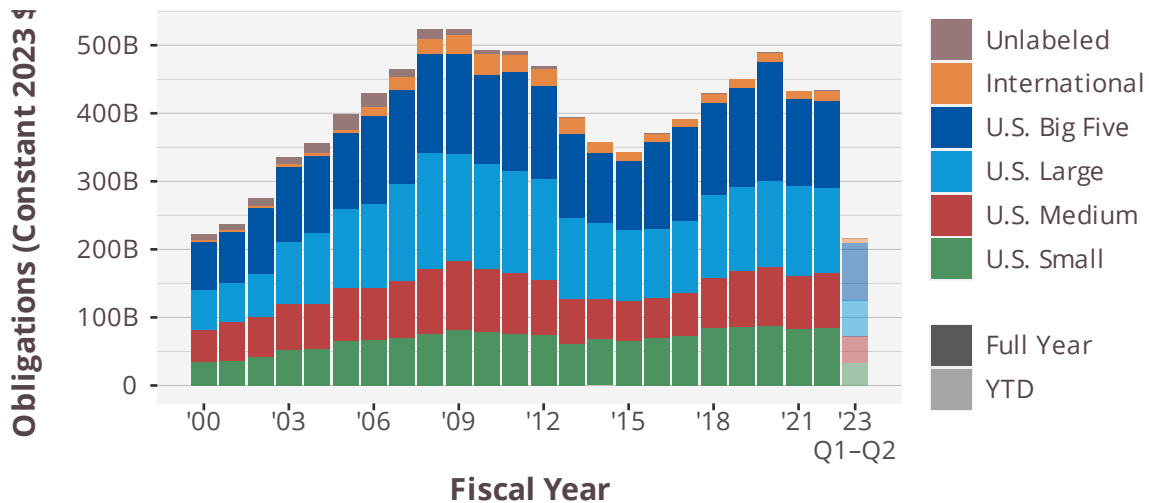
Instead, the NDIS builds on past rounds of acquisition reform and seeks to take advantage of the larger U.S. economy by increasing the diversity of DIB vendors. Two categories of vendors are especially important for this end: small businesses, categorized using definitions set by the U.S. Small Business Administration, and those larger companies that have not adopted DoD cost accounting processes, referred to as nontraditional defense contractors. The strategy plans on DoD acquiring products and services employing “an appropriate level of customization that can balance efficiencies and speed of fielding from commercial off-the-shelf (COTS) capabilities with resilience, scale, and effectiveness through the life cycle of platforms” (DoD, 2023, p. 34). A sign of success would be an “increase in number of suppliers newly doing business with the Department” (DoD, 2023, p. 24).⁵

Figure 18 shows DoD contract obligations from FY2000 to FY2023 Q1–Q2 with a breakdown between U.S. contractor size and a distinction between U.S. vendors and international vendors.⁶ The U.S. Big Five vendors—Lockheed Martin, RTX, Boeing, General Dynamics, and Northrop Grumman—held a 29.3% market share in FY2022. Pfizer briefly joined their ranks as a top contractor because of the Army’s role in contracting in response to COVID-19. In FY2022 U.S. large vendors had 29.0% market share, and U.S. medium vendors had an 18.4% market share. International vendors, which does not include the U.S. subsidiaries of international companies, had only a 3.5% market share, though the \$6.7 billion they received in FY2022 was a 29.3% increase over FY2021, which may have been influenced by production diplomacy efforts.

⁵ Four different NDIS action items directly involve considerations for expanding the supplier base: 2.1.2.4 seeks to “expand relationships with companies and industries not traditionally in the DIB,” including socioeconomic diversity; 2.3.2.1 considers standards and interoperability with reference to small business and nontraditional suppliers; 2.3.2.3 calls for using a preference COTS to access an “expanded supplier base”; and 2.3.2.6 advises “helping” small businesses navigate the complex defense acquisition process (DoD, 2023, p. 19, 36–38).

⁶ CSIS has classified by parent company for all vendor identifiers receiving \$250 million in one year or \$1 billion over the study period. That classification is still ongoing for the latter half of FY2023, so only the data for which classification is complete is shown.





Source: FPDS and CSIS analysis.

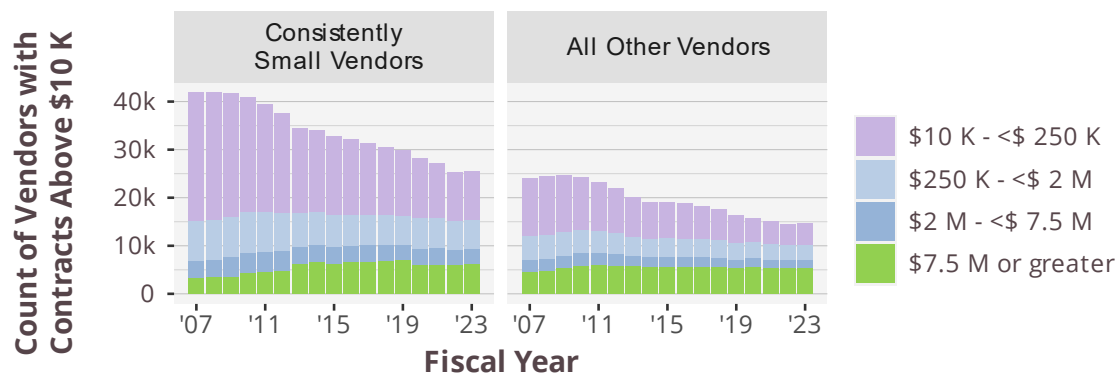
Figure 13. Contract Obligations by Vendor Size, FY2000 to FY2023 Q1-Q2

Promoting U.S. small vendors is a priority of the NDIS, and they start in a comparatively strong position with a 19.6% market share in FY2022. From FY2020 to FY2023, small businesses only had a 16.3% or lower market share, but a decline in internationally located contracting as the overseas contingency operations drew down and concerted promotion efforts, U.S. small businesses have had an 18% share or higher since FY2014.

Figure 19 turns from market share to the count of vendors.⁷ The contractors on the left are consistently classified as small businesses. This means they operate only as small businesses in each sector amongst which they do business. There may be other sectors where their employee count or revenue would mean they would be larger than small, but they did not win any contracts in those sectors in that given fiscal year. Another reason a vendor might be inconsistently classified is if they graduated beyond small business status or were acquired but still received legacy credits they won as a small business.

The contractors on the right include large and medium contractors as well as vendors with a variable classification as a small business. These contractors may qualify in some sectors as a small vendor, but they also surpass thresholds in other sectors or on more recent contracts, but for some contracts, they qualify as small businesses. The graph shows the number of players within the DIB over time. There has been an overall 39% decline in the number of contractors in the defense industry from FY2007 to FY2023, with the largest decline occurring in areas where contractors are exclusively winning small contracts, between \$10,000 and \$250,000. These vendors with small contractors declined by 62% to 63% regardless of small business status. As can be seen in Table 1, the magnitude of decline was inversely proportionate to the largest contract won by the vendor; that is to say that vendors winning small contracts declined markedly while those winning larger contracts were less likely to exit.

⁷ The threshold for reporting contracts in FPDS has changed repeatedly over the period. To provide a consistent baseline, only those contractors with a contract above \$10,000 in 2018 dollars, the year reporting threshold last changed, are included in these counts. These vendor counts employ unique entity identifiers (UEI) and parent UEI identifiers provided by FPDS. To reduce counting multiple subsidiaries as different entities, this analysis groups UEIs with their parent UEIs, when one is provided for that fiscal year.



*Note: Threshold values are adjusted for inflation (in 2018 \$).
Source: FPDS Unique Entity (UEI) reporting and CSIS analysis.*

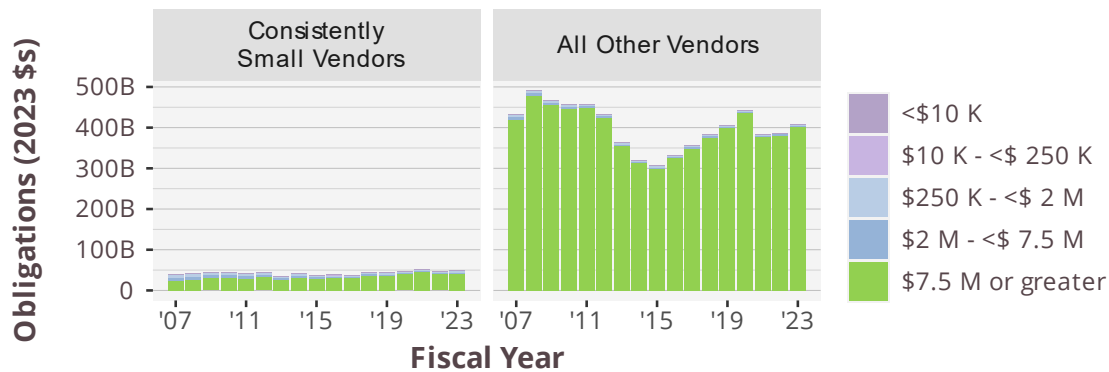
Figure 14. Number of Defense Contractors by Annual Small Business Status and Size of Largest Federal Contract

		2007	2015	2020	2023	'07– '23	'15– '23	'20– '23
Consistently Small Vendor	\$10 K- <\$250 K	26.7K	16.5K	12.5K	10.2K	-62%	-38%	-18%
	\$250 K - <\$2.0 M	8.3K	6.5K	6.3K	5.9K	-29%	-10%	-7%
	\$2.0 M - <\$7.5M	3.7K	3.7K	3.6K	3.4K	-8%	-9%	-8%
	\$7.5 M or greater	3.2K	6.1K	5.9K	6.1K	90%	0%	5%
	Subtotal	41.8K	32.8K	28.3K	25.5K	-39%	-22%	-10%
Variably Small or Large Vendor	\$10 K- <\$250 K	12.1K	7.7K	5.1K	4.5K	-63%	-41%	-11%
	\$250 K - <\$2.0 M	4.9K	3.8K	3.3K	3.1K	-37%	-18%	-6%
	\$2.0 M - <\$7.5M	2.5K	2.2K	1.9K	1.8K	-29%	-18%	-8%
	\$7.5 M or greater	4.5K	5.5K	5.5K	5.2K	15%	-5%	-4%
	Subtotal	24.0K	19.1K	15.8K	14.6K	-39%	-24%	-7%
Total		65.9K	51.9K	44.1K	40.1K	-39%	-23%	-9%

Table 1 compares FY2023 with three snapshots: FY2007 with overseas contingency operations supported by contractors, FY2015 as a low point in contract spending due to the budget caps, and FY2020 as the recent high-water mark in real contract spending. Despite FY2020's higher spending, there was a drop in consistently small vendors with contracts over \$7.5 million in that year. That category of contractors went from 6,100 in FY2015 to 5,900 in FY2020. The drop occurred entirely between FY2019 and FY2020, and in FY2023 count had recovered to 6,100 vendors, which suggests that the COVID-19 pandemic may have temporarily suppressed the number of vendors.

As suggested by Figure 18, a reduction in the number of vendors winning small contracts does not imply a reduction in market share going to small vendors. Indeed, the number of consistently small vendors with contracts above the \$7.5 million threshold increased from FY2007 to FY2015. The share of obligations going to small businesses was rising from FY2007 to FY2015 even amidst a general decline in the number of vendors (Bipartisan Policy Center, 2021). As a result, it is important to look at multiple measures or changes at the periphery of the DIB could swamp out shifts that may be more consequential to the core.

Figure 20 further emphasizes this point. Since FY2012, no more than 5% of contract obligations were awarded to contractors winning only contracts under \$7.5 million, and less than 2.5% of contract obligations went to contractors winning only contracts under \$2 million. A comparison of defense and federal contracting by Edward Hyatt (2023) suggested that federal and DoD consolidation and competition move in parallel in sectors not specific to a single agency. As a result, the decline in these total vendor counts may be shaped by larger policies such as federal category management or best-in-class contracting, which may result in greater reliance on a smaller pool of vendors qualified for pivotal multi-award contracts (Miller, 2019).



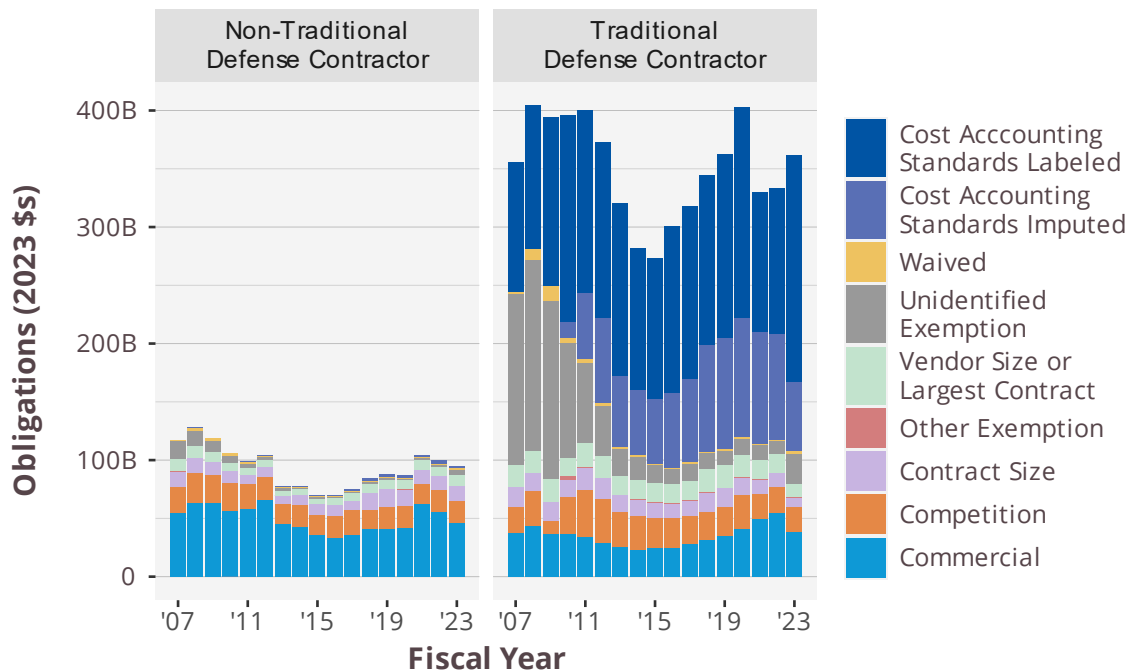
*Note: Threshold values are adjusted for inflation (in 2018 \$s).
Source: FPDS Unique Entity (UEI) reporting and CSIS analysis.*

Figure10. Defense Contract Obligations by Annual Contractor Small Business Status and Size of Largest Federal Contract

Nontraditional Defense Contractors

This paper breaks new ground by overcoming a crucial limit in contract reporting: nontraditional status is not tracked directly in FPDS. The analysis presented here makes some simplifying assumptions; for example, vendors are classified as nontraditional based on whether or not they have any contracts employing defense cost accounting standards in a given fiscal year rather than assessing their status at the start of each individual contract.⁸ When possible, this defers to FPDS's "Cost Accounting Standards Clause" to learn whether a contract has such a clause, is exempt, or has been granted a waiver. Unfortunately, this field ceased reporting for task orders in FY2011, so the study team attempted to replicate the field based on cost accounting standard applicability rules in the Code of Federal Regulations (CAS Applicability, 2018). As an additional simplifying assumption, when FPDS labels are not available, the study team applied the current regulations, which entered into force in August 2018, rather than accounting for the changes in the rules before 2018 over time.

⁸ Nontraditional defense contractors are defined in statute as "an entity that is not currently performing and has not performed, for at least the one-year period preceding the solicitation of sources by the Department of Defense for the procurement or transaction, any contract or subcontract for the Department of Defense that is subject to full coverage under the cost accounting standards prescribed pursuant to section 1502 of title 41 and the regulations implementing such section" (Nontraditional Defense Contractor, 2022).



Source: FPDS and CSIS analysis.

Figure 15. Defense Contract Obligations by Nontraditional Status and Reason for Exemption from Cost Accounting Standards, FY2011 to FY2023

The breakdown of defense contract obligations for nontraditional defense contractors is shown in **Error! Reference source not found.**. The graph includes two classifications for cost accounting standard clauses: *labeled* refers to those contracts confirmed to apply cost accounting standards by FPDS, and *imputed* refers to those contracts that were unlabeled but do not appear to qualify for any exemptions. *Waived*, shown in yellow, refers to contracts that have been authorized to not apply cost accounting standards despite not qualifying for an exemption. Multiple exemptions could apply to a single contract; they are classified in the order of this list by the first exemption that applies. This order is reversed in the graph, to make it easier to track categories most relevant to the NDIS. *Commercial* refers to use of commercial products and service acquisition procedures under the FAR Part 12. *Competition* refers to seal bids as a solicitation procedure or firm-fixed-price contracts with sufficient competition that did not require cost and pricing data. *Contract size* covers contracts below the \$2 million Truth in Negotiation Act threshold. *Other exemptions* capture lesser-used exemption categories (i.e. for foreign governments). *Vendor size or largest contract* covers those vendors that are consistently small or have no contracts greater than \$7.5 million. When FPDS categorized a contract as exempt, but the study team could not determine the reason, that is categorized as an *unidentified* exemption. Unclassified exemptions overwhelmingly appear on contracts held by traditional defense contractors, which limits their impact on classification. Nonetheless, their prevalence is troubling and will be further examined by the study team in future iterations of this research.

Nontraditional contractors won an estimated \$94.7 billion market share in FY2023, below the COVID-19 boosted magnitude of the prior 2 years but up 9.33% above the FY2020 obligations of \$86.65 billion. Obligations to nontraditional were higher in FY2007 to FY2010, with the last peak at \$104.1 billion in FY2012, suggesting that the drawdown of overseas contingency operations followed by the budget caps led to consolidations. Because vendors with no contracts over \$7.5 million and consistently small vendors are

potentially exempt from cost account standards, they actually make up the majority of all defense contractors by count, as is implied by **Figure 19**. By looking at obligations, **Figure 20** can demonstrate the addressable market for nontraditional entities. Regardless of the nontraditional status of the awardee, commercial contracts and qualifying competed contracts had \$84.0 billion and \$40.65 billion respectively in FY2023 obligations. Commercial contracts obligations were lower than the past 2 COVID-19 response years but still 1.5% above the FY2020 level. Qualifying competition is up 1.6% from FY2022's level but down 15.9% from the \$48.3 billion obligated in FY2020.

Standardization and Interoperability

Increasing commonality through standardization and interoperability are recurring themes in the NDIS.⁹ This is in line with a longstanding emphasis on MOSA, an attempt to make DoD acquisition more like Android phones or IBM personal computers through the use of open interfaces that allow a broader range of vendors to provide solutions (Sanders, 2022). The strategy posits that this suite of approaches “benefits DOD by reducing the risk of lock-in to a single supplier by allowing small businesses to offer components or systems that can be integrated into larger defense systems, which by extension, and together with multi-year contracts, mitigate business execution risk” (DoD, 2023, p. 36).

There are no simple ways to measure the extent of adoption of common standards or the higher bar of modular open systems, but there are signs to watch. From 2017 to 2021, an increasing number of budget lines for procurement and research, development, testing, and engineering for the Army, and to a lesser extent the Air Force, saw mentions of open systems or open architectures (Sanders, 2022, p. 6). Neither of those services matched the more than a dozen each research, development, test, and evaluation (RDT&E) and procurement lines from the Navy, whose sonar boosting Advanced Processor Build and Technology Insertion (APB/TI) is a success story of incorporating quickly developed commercial chip technology going back to 2013 (Guertin et al., 2018). The Army's Future Long-Range Assault Aircraft (FLRAA) placed considerable emphasis on MOSA in both guidance documents and in competitive criteria (Freedberg, 2020; GAO, 2023; PEO Aviation MOSA Transformation Office, 2021). For the presently under development uncrewed aerial system Collaborative Combat Aircraft, the government reference architecture developed as part of the Next Generation Air Dominance program has been a point of emphasis for Air Force leadership (*Air Force, Fixed-Wing Tactical and Training Aircraft Programs*, 2023; Luckenbaugh, 2024).

The industrial strategy puts forward as an illustrative outcome “increase in adoption of open systems architectures across critical programs” (DoD, 2023, p. 40). This is an area where FPDS reporting, perhaps in the government-furnished equipment or property field or via another mechanism, would ease tracking progress and also advertise to vendors both presently in the DIB and beyond about the addressable market should they produce a compliant hardware or software product.

The Range of Contracting Approaches

As covered above, multi-year procurement is called out in the NDIS, similar to the way incentive fee contracting was highlighted by a previous DoD-led acquisition policy shift, the Better Buying Power 3.0 initiatives (Kendall, 2016, p. 9). But as the name indicates, the flexible acquisition pillar seeks to manage shifting priorities resulting from an evolving

⁹ Citations include action items 2.3.2.1, calling for broadened platform standards and interoperability; 2.3.2.4, seeking “Increase Access to Intellectual Property (IP) and Data Rights to Enhance Acquisition and Sustainment”; and 2.4.2.2, which involves participating in standard setting bodies to increase interoperability (DoD, 2023, pp. 35–38, 46).



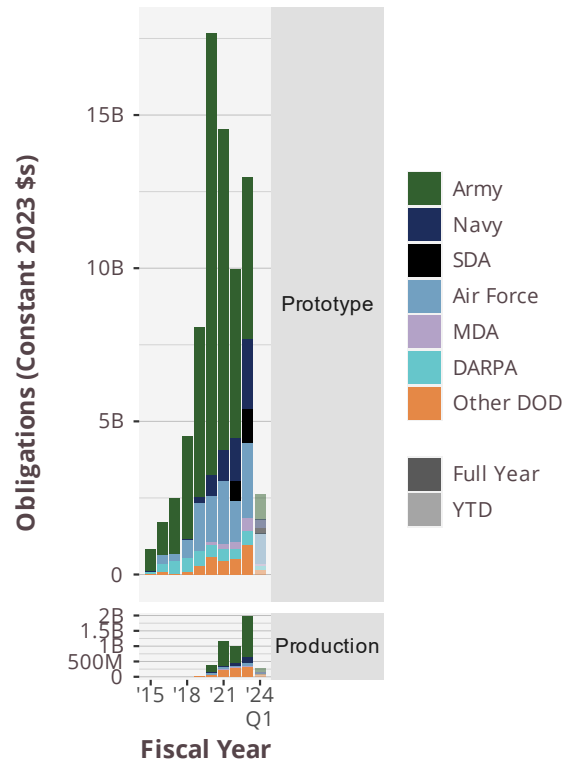
geostrategic situation, including by adjusting requirements. The software acquisition pathway merited special mention as an example of a modern means of delivering software implementable with existing authorities. The yet-to-be-released operational annex may contain more details, as the NDIS announced that the DoD “will look to use greater FAR- and non-FAR-based contract types, as appropriate, and seek to ensure contracting authorities align with present defense priorities” (DoD, 2023, p. 38). As a metric for evaluating that goal, the NDIS puts forward an “increase in range of contracting types and authorities used” (DoD, 2023, p. 40).¹⁰ Time will also tell whether the operational annex will address critique raised by Caverley et al. (2023) that the NDIS would benefit from disaggregating different strategies for different contexts.

The objective of increasing the range of contracting types might have implementations for the pricing mechanisms used by the DoD. For example, use of fixed price–incentive firm contracts has greatly expanded use after the Better Buying Power reforms and time and materials, labor hours, and fixed-price level of effort contracts have been largely suppressed (Sanders et al., 2023, pp. 6–7). However, while not explicitly mentioned in the NDIS, an increasing range may have greater implications for OTAs and commercial solutions openings (CSO; Office of the Under Secretary of Defense for Acquisition and Sustainment, 2022, p. 13). A CSO launched in January 2024 seeking uncrewed surface vehicles as part of the consequential Replicator uncrewed aerial systems initiative (Katz, 2024). CSOs will be important to track going forward, but an initial review found only 34 labeled award or indefinite delivery vehicles for CSOs, only two of which had ceilings over \$7.5 million in size.¹¹

¹⁰ Acquisition approach action items include 2.1.2.6 with reference to encouraging collaboration and 2.3.2.5, “Consider Greater Use and Policy Reform of Contracting Strategies” (DoD, 2023, pp. 22–23, 38).

¹¹ These two include an indefinite delivery vehicle to Deloitte (USASpending, n.d.-b) and L3-Harris (USASpending, n.d.-a). The labeling for CSOs only dates to October 2022, so this list almost certainly misses larger historical CSOs.





Note: Unlabeled values not show.
Source: FPDS and CSIS analysis.

Figure 16. Defense OTA Obligations by Customer and Type, FY2015 to FY2024 Q1

While not mentioned by name in the NDIS, OTAs are directly relevant to the action item to “Promote Accelerator Programs to Foster Innovation” (DoD, 2023, pp. 18–19).

Since FY2020, over 90% of OTA obligations go to vendors with significant participation by nontraditional entities. As seen in Figure 22, OTA use has jumped 36.2% from 2022 to 2023. While the Army is still the plurality user, a wide range of customers, including the Army, the Navy, the Air Force, the Defense Advanced Research Projects Agency, the Missile Defense Agency, and the Space Development Agency, have \$400 million or more in OTA spending. While the Army is still the leading employer of OTA arrangements for production, both the Navy and Air Force have increased their use, admittedly only to \$204 million and \$102 million, respectively, in 2023.

Findings

Production Capacity and Munitions

DoD took time to ramp up, but the rise in shipbuilding and ordnance and missiles, as well as an uptick in multi-year contracting, shows that the demand signal to industry has arrived. This growth is not sufficient to ensure sustained capacity, as munitions are notorious for spikes in spending followed by rapid declines. However, the combination of multi-year procurement and direct investments in capacity incentivize sustained capacity.

Relevant NDIS Illustrative Outcomes and Outputs:

- **“Increase in DIB capacity” (Action Item 2.1.2.1):** The organic industrial base has increased its production of 155 mm ammunition, as shown in Figure 15. From FY2022 to FY2023, priority portfolios *ordnance and missiles as well as ships and*

submarines have increased by 59.3% and 11.5% respectively, but obligations for air and missile defense has declined 6.7%, as seen in Figure 13.

- **“Expand the use of multi-year procurement (MYP)” (sub-bullet under Action Item 2.3.2.6):** Multi-year contracting has *surged 41% to nearly \$26.0 billion* in FY2023. As seen in **Error! Reference source not found.**, *ships and submarines and air and missile defense were notable drivers, reaching \$5.3 and \$3.1 billion respectively.* Multi-year contracting for ordnances and missiles grew by 78% to just \$1.2 billion but remains below the FY2020 level.
- **“Increase in adoption of open systems architectures across critical programs” (Action Item 2.3.2.1):** Rising adoption can be seen in the Army emphasis on MOSA in the FLRAA competition and the centrality of government reference architectures to the upcoming multi-competitor procurement stage of the Collaborative Combat Aircraft, but good measures are lacking.

The Supplier Base and Nontraditional Defense Contractors

The total number of defense contractors has dramatically declined, but this would be misleading as the primary indicator of DIB health. As shown in Figure 19, since FY2007 there has been a marked decline in the number of defense contractors, with those vendors in categories whose maximum contract value was smallest suffering the largest declines. This helps explain why the number of vendors can decline even as the share of obligations to small vendors rose since FY2013, as is seen in Figure 18. As a result, any metrics that focus on the total number of new vendors, or the total number of vendors overall, will likely be dominated by shifts in vendors whose largest contract is between \$10,000 and \$2 million. This group may be a key indicator of barriers of entry to federal contracting, but these tens of thousands of firms have a collective market share of less than 2.5%. Thus, additional metrics are likely to be necessary to have a sense of commercial participation, production capacity, and the ability of small vendors to traverse the valley of death, or the extent of DIB consolidation. The extent of obligations going to nontraditional vendors is a valuable supporting metric, and it shows the DIB is beginning to recover to pre-budget cap levels.

Relevant NDIS Illustrative Outcomes and Outputs

- **“Increase in number of suppliers newly doing business with the department” (Action Item 2.1.2.4):** As shown in Figure 19, the number of contractors *fell by 9% from FY2020 to FY2023*, but the *number of vendors with contracts over \$7.5 million fell by only 0.2% to 11,400*. However, in a positive sign, the \$94.7 billion in obligations to nontraditional market shows growth is 9.3% above the FY2020 levels.

The Range of Contracting Approaches

Both commercial contracting approaches and OTAs played key roles in response to COVID-19, but OTA subsequently blossomed across multiple dimensions. OTAs are still overwhelmingly focused on prototyping rather than production and rightly receive less attention from the NDIS than multi-year procurement. However, FY2023 shows that the mechanism has not gone out of style since Operation Warp Speed but instead shows a blossoming to sustained and diversified use, implying a growing confidence of the acquisition workforce.

Relevant NDIS Illustrative Outcomes and Outputs

- **“Increase in Off-the-Shelf acquisition supporting critical programs” (Action Item 2.3.2.3):** As seen in **Error! Reference source not found.**, use of commercial authorities for COVID-19 has receded, but the nearly \$84.0 billion spent in FY2023 is still 1.5% above FY2020's level.



- **“Increase in range of contracting types and authorities used” (Action Item 2.3.2.5):** As shown in Figure 12, OTAs for prototypes are up 30.4% to \$13.6 billion and OTAs for production have nearly than doubled to \$2.1 billion, the latter a new high. As seen in Figure 22, OTAs have also diversified. The state of CSO is still too early to tell.

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