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Creating Synergy for Informed Change: Transitioning Technology to the Warfighter

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Preface & Acknowledgements

The purpose of the “Creating Synergy for Informed Change: Transitioning Technology to the Warfighter, 22nd NPS Annual Acquisition Research Symposium and Innovation Summit” is to provide a forum for the presentation of scholarly acquisition research, as well as for dialogue between scholars and acquisition policy-makers and practitioners. Research papers and presentations are given on recently completed and on-going Departments of Defense and US Navy (DoD/DON)-sponsored projects conducted by researchers at a variety of research institutions. Senior DoD/DON acquisition officials serve as panelists or keynote speakers to present their critiques and comments on research papers and priorities.

This year our symposium is coupled with an Innovation Summit and takes up the theme of “Transitioning Technology.” The goal of this dual event is to explore and promote innovative ways to transition technology from research and development to programs of record to support the warfighter.

Although attendees come from many U.S. locations, as well as from some international locales, a large number are from Naval Postgraduate School (NPS) where faculty members and graduate students engage in acquisition-related research. In particular, NPS graduate students are an integral component of research and dialogue. The Symposium serves an essential part of their graduate learning experience and provides them with the opportunity to meet with senior policymakers, practitioners, and distinguished scholars.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the Acquisition Research Program:

- Assistant Secretary of the Navy for Research, Development and Acquisition (ASN(RDA))
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WELCOME: DR. JAMES H. NEWMAN, VICE PRESIDENT, PROVOST AND CHIEF ACADEMIC OFFICER, NAVAL POSTGRADUATE SCHOOL

Dr. James H. Newman—is the Vice President, Provost and Chief Academic Officer (Acting) of the U.S. Naval Postgraduate School (NPS), where he also serves as Professor, Space Systems. He previously held the position of Chair and Professor, Space Systems Academic Group (SSAG).

In 2006, Newman came to NPS after three years serving NASA in Moscow, Russia. He joined the SSAG as a NASA Visiting Professor and in 2008 he subsequently transferred from NASA to the Department of the Navy to accept a tenure-track professorship at NPS. His teaching has included orbital mechanics and launch systems, payload design, and introduction to programming for space applications. He has performed applied infrastructure research in the use of very small satellites for focused projects of national interest and for motivating hands-on, officer student educational opportunities. This applied research has included launching several very small satellites and satellite deployers and he is currently assisting with a payload on satellites developed by other faculty in the SSAG.

NASA selected Newman into its astronaut program in 1990. Newman's space flight experience included four missions aboard the Space Shuttles Discovery (STS-51), Endeavour (STS-69, STS-88), and Columbia (STS-109). Notably, he logged a bit more than forty-three days in space, including six spacewalks totaling a little longer than forty-three hours and assignment as the robotic arm operator. On the spacewalks, he installed mission critical equipment on the International Space Station and worked on the Hubble Space Telescope. His office assignments included progressively more responsible positions in leadership and management, culminating in his assignment as the Director, NASA's Human Space Flight Program, Russia.

Newman received a Bachelor of Arts degree in Physics from Dartmouth College in 1978 and a Master of Arts degree and Doctorate in Physics from Rice University in 1982 and 1984, respectively. After graduating from Rice University in 1984, Newman performed post-doctoral research prior to starting at NASA in 1985 as an instructor in Control and Propulsion. He is a member of the Association of Space Explorers, the American Physical Society, Sigma Xi, and the American Institute of Aeronautics and Astronautics.

KEYNOTE SPEAKER: HON. SEAN J. STACKLEY, FORMER ASSISTANT SECRETARY OF THE NAVY FOR RESEARCH, DEVELOPMENT, AND ACQUISITION (ASN RD&A)

Sean Stackley—spent four decades in public service, including a 27-year career in the U.S. Navy where he served at-sea in engineering and combat systems assignments, and subsequently as an Engineering Duty Officer performing design, construction, maintenance & modernization across all Surface Combatant ship classes. From 2001 to 2005, he served as the Navy's LPD 17 Amphibious Ship major program manager.

Upon retirement from the Navy, Stackley served on the Seapower Subcommittee of the Senate Armed Services Committee, responsible for formulating budget and legislative provisions and performing oversight of Navy, Marine Corps, and Maritime Administration programs.

Appointed as Assistant Secretary of the Navy for Research, Development and Acquisition by President George W. Bush in 2008, Stackley continued through the Obama administration, surpassing Franklin D. Roosevelt as the nation's longest-serving ASN. After serving as (Acting) Secretary of the Navy under President Trump, he transitioned to the private sector.

From 2018-2024, Stackley served as L3Harris Technologies President, Integrated Mission Systems, and Senior Vice President for Strategy, Business Development, Engineering and Programs, providing advanced weapon systems and services to US and Allied forces.

Stackley graduated from the U.S. Naval Academy in 1979. He holds the degrees of Ocean Engineer and M.S., Mechanical Engineering from the Massachusetts Institute of Technology, and is a certified professional engineer in the Commonwealth of Virginia. Awards include the Defense Medal for Distinguished Public Service, Secretary of the Navy Award for Distinguished Public Service, the Legion of Merit, and the USNA Distinguished Graduate Award.

PANEL 14. INNOVATING DEFENSE: A ROUNDTABLE ON NAVY AND ARMY ACQUISITION

Thursday, May 8, 2025	
0715 – 0815 PT 0915 – 1015 CT 1015 – 1115 ET	**Chair: Michael Williamson, LTG USA (ret.) President of Lockheed Martin International and Senior Vice President for Global Business Development & Strategy at Lockheed Martin Corporation** **Panelists:** **Lieutenant General Robert Collins, USA,** Principal Military Deputy to the Assistant Secretary of the Army (Acquisition, Logistics and Technology) and Director, Army Acquisition Corps **Rear Admiral Kurt J. Rothenhaus, USN,** Chief of Naval Research **Geoffrey Bryce (SES),** Chief Deterrence Technology Officer, Strategic Systems Programs

Michael Williamson, LTG USA (ret.)—is the president of Lockheed Martin International and senior vice president for Global Business Development & Strategy at Lockheed Martin Corporation. In this role, Williamson is focused on bringing integrated solutions to customers who rely on Lockheed Martin's capabilities and technologies to support their missions and address their most pressing needs. His responsibilities also include establishing comprehensive strategies across the enterprise that will enable future growth.

Previously, Williamson served as vice president and general manager for Lockheed Martin Missiles and Fire Control (MFC), where he was responsible for operational excellence, a diverse portfolio of products and business enabling initiatives.

He also previously served as vice president of Tactical and Strike Missiles for MFC. In this capacity, he managed significant programs in the areas of Hypersonic Weapon Systems, Close Combat Systems, Strike Systems, Precision Fires and Advanced Programs.

Williamson joined Lockheed Martin in 2017 following a distinguished career as a lieutenant general with the U.S. Army. He served as the principal military deputy to the assistant secretary of the Army for Acquisition, Logistics and Technology and director of Acquisition Career Management. He also served as a congressional fellow on Capitol Hill.

Williamson holds a bachelor’s degree in business administration from Husson University, a master’s in systems management from the Naval Postgraduate School, and a Ph.D. in business administration from Madison University. He is also a graduate of the Advanced Management Program at the Harvard Business School.

Lieutenant General Robert Collins, USA—In January 2024, LTG Collins was appointed as the Principal Military Deputy to the Assistant Secretary of the Army (Acquisition, Logistics and Technology) and Director of the Army Acquisition Corps. He previously served as the Deputy for Acquisition and Systems Management.

LTG Collins was assessed into the Acquisition Corps in 2000 and assigned to the U.S. Army Signal Center as a Training and Doctrine Command Systems Manager and Combat Developer. He then served as an Assistant Product Manager (APM) for Warfighter Information Network-Tactical (WIN-T) and APM for Software Integration with Future Combat Systems. He was nominated to serve as a

Department of the Army Systems Coordinator (DASC) for Tactical Army Communications systems, and later as the Executive Officer for the Army Acquisition Executive and Assistant Secretary of the Army (Acquisition, Logistics and Technology).

LTG Collins was selected as the Army's Product Manager for Warfighter Information Network - Tactical. Following Senior Service College, he was selected as the Army's Project Manager for Distributed Common Ground System - Army. LTG Collins then served as the Assistant to the Program Executive Officer for Intelligence, Electronic Warfare and Sensors (PEO IEW&S) and later as the PEO IEW&S. LTG Collins then served as the Program Executive Officer for Command, Control, Communications-Tactical (PEO C3T).

LTG Collins holds a Bachelor of Science in Criminal Justice, a Master of Arts in Computer Resources and Information Management, a Master of Science in Human Relations, and a Master of Science in National Resource Strategy. He is a graduate of the Eisenhower School of Strategic Studies, Combined Arms Services Staff School, Command and General Staff College, the Armor Officer Basic Course, Signal Advanced Course, and Systems Automation Course.

His military awards and decorations include the Parachutist Badge, Air Assault Badge, Army Staff Identification Badge, the Legion of Merit Medal, the Meritorious Service Medal (four awards), the Army Commendation Medal (four awards), the Army Achievement Medal (five awards), National Defense Service Medal (two awards), Armed Forces Expeditionary Medal, Kosovo Campaign Medal, Iraq Campaign Medal, Global War on Terrorism Expeditionary Medal, Global War or Terrorism Service Medal, Army Service Medal, Army Overseas Medal, NATO Medal and Army Superior Unit Award.

Rear Admiral Kurt J. Rothenhaus, USN—is a native of New York City, New York. He received his commission in 1992 upon graduating from the University of South Carolina where he earned a Bachelor of Science degree. He also earned a Master of Science in Computer Science and a Ph.D. in Software Engineering from the Naval Postgraduate School and transferred into the Engineering Duty Officer community in 2003.

He assumed command of the Office of Naval Research as the 27th Chief of Naval Research in June 2023.

From May 2020 until May 2023, he served as Program Executive Officer, Command Control Computers Communications and Intelligence (PEO C4I).

His operational assignments include serving as the combat systems/C5I officer on USS Harry S. Truman (CVN 75) and chief engineer on USS O'Brien (DD 975). Additionally, he served on the staff of Destroyer Squadron 15 and on USS Fife (DD 991). He completed an Individual Augmentee tour in Baghdad, Iraq.

He completed numerous acquisition tours including program manager for the Navy's Tactical Networks Program Office (PMW-160) and commanding officer of Space and Naval Warfare Systems Center Pacific. He also served as the deputy program manager for the Navy Communications and GPS Program Office (PMW/A 170).

He is the recipient of the Legion of Merit, Meritorious Service Medal and various unit and sea service awards.

Geoffrey Bryce (SES) currently serves as the Chief Deterrence Technology Officer (CDTO) for the Department of the Navy's Strategic Systems Programs (SSP) and is responsible for overseeing the development and dissemination of technology for nuclear weapons systems.

He is also responsible for establishing and directing research and exploratory development programs in support of follow on sea-based Strategic Weapon Systems and provides executive leadership for the Navy for all matters relating to Arms Control Treaty implementation.

In his previous role he served as the Assistant for System Integration and Compatibility for SSP, where Mr. Bryce was responsible for management of the overall systems engineering process for the TRIDENT II Strategic Weapon System (SWS) installed on OHIO-class SSBNs and all conventional weapons systems assigned to SSP's oversight. Additionally, he oversaw platform modernization, test evaluation, requirements and accuracy assessment, and weapons safety associated with the Trident II SWS. Most notably, Mr. Bryce was responsible for implementing Model-Based Engineering within SSP and its industry partners through a System Engineering Transformation initiative.

Mr. Bryce entered the Senior Executive Service in April 2017 and has more than 19 years of federal service. Mr. Bryce began his career at BAE Systems in 1997 supporting the Navy's Fleet Ballistic Missile (FBM) and Attack Weapon System (AWS) Programs. In this post, he acted as an engineering supervisor, developing system engineering best practices for the TRIDENT D-5 Life Extension (LE) Program and consulting the UK Ministry of Defense on interface management for the Astute Class attack submarine program.

In 2004, Mr. Bryce transitioned to civil service with SSP in the Office of the Chief Engineer, where he was a Technical Program Manager responsible for system requirements and performance assessments of SWS and AWS Programs. He then went on to assume various roles within the Guidance branch, leading to the assignment as Guidance Production and Repair Section Head, his last position before selection as Assistant for System Integration and Compatibility. As the Guidance Production & Repair Section Head, he was directly responsible for the acquisition, production, supply chain management, and operational support of the Trident Missile Guidance System.

Mr. Bryce attended the University of Rochester, where he earned a Bachelor of Science in Mechanical Engineering. He is an Acquisition Corp Member, and is DAWIA Level III in System Planning, Research, Development, and Engineering and Program Management. Mr. Bryce received the Department of Navy Meritorious Civilian Service Award for his efforts that culminated in the initial flight of the MK6 Mod 1 Guidance System from the USS TENNESSEE in February 2012.

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PANEL 16. STRATEGIC SPACE ACQUISITION: RESEARCH, PRODUCTION, AND AGILE PRACTICES

Thursday, May 8, 2025	
0825 – 0940 PT 1025 – 1140 CT 1125 – 1240 ET	**Chair: Maj Gen Steve "Bucky" Butow, USAF, Military Deputy and Director, Space Portfolio, Defense Innovation Unit (DIU), Office of the Secretary of Defense** **Discussant: Gary "Grinch" Thomason, Chair Space Systems Engineering & Acquisition, Naval Postgraduate School** ***State of Non-Geostationary Satellite Orbit Communications and SATCOM Terminal (transportable) Non-Geostationary*** Vince Squitieri, Technical Director, PEO C4I PMW/A 170, US Navy Communications and GPS Navigation Programs, U.S. Navy ***Balancing Operational Utility and Repeatability for Defense Space Systems*** Andrew Berglund, Sr. Analyst, The Aerospace Corporation ***Accelerating Satellite Development: A Comparative Simulation of NASA's Waterfall Process and Agile Process Using Innoslate Life Cycle Modeling Language*** Robin Yeman, Senior Director of Engineering, Leidos

Maj Gen Steve "Bucky" Butow, USAF—is the Military Deputy of the Defense Innovation Unit (DIU), Office of the Secretary of Defense.

General Butow joined the team in 2015 as an early plank owner when DIU was known as the Defense Innovation Unit Experimental (DIUx). He initially served as West Coast Military Lead and helped establish the organization's operating locations in Silicon Valley, California; Boston, Massachusetts; and Austin, Texas. In 2016, he was was selected as DIU's first Space Portfolio Director. Upon promotion to brigadier general, Butow continued this role at DIU as a DoD civilian.

General Butow continues to serve as the Commander of the California Air National Guard in a dual Title 10/32 status where he leads 4,900 Airmen assigned to five wings and a headquarters staff performing air, space and cyber operations as part of the Total Air Force. He commanded the 129th Rescue Wing at Moffett Field, CA, from 2011 to 2014.

General Butow's previous Title 10 leadership assignments include Deputy Director of the Joint Search and Rescue Center for U.S. Central Command in 2005, and as Chief of Personnel Recovery for U.S. Air Forces Central in 2007 supporting Operations IRAQI and ENDURING FREEDOM. Prior to joining DIU, Butow was the Vice Chief of the Joint Staff, California Military Department with responsibilities including cybersecurity, incident awareness and innovation. He has deployed ten times to support combat and contingency operations across Southwest Asia, the Middle East, the Horn of Africa and other global locations.

Butow graduated from San Jose State University with a B.A. in Physics & Astronomy and earned a M.S. in Management with specialization in Air and Space Strategic Studies from the University of Maryland. He has also completed executive courses at Harvard's John F. Kennedy School of Government, and was a member of the National Leadership Preparedness Initiative (NPLI) Cohort 16. Butow is a lifetime member of the Honor Society of Phi Kappa Phi for academic achievement.

As a researcher with the Search for Extraterrestrial Intelligence (SETI) Institute, Butow worked on instrument concepts for Mars surface soil analysis at NASA Ames Research Center in Mountain View, CA. He later served as co-principal investigator for a series of airborne science missions for which he was recognized for outstanding achievement and contributions to the Space Science Division in 1999 and received an Ames Honor Award as a member of an Astrobiology Mission Project Team in 2000.

Mr. Gary "Grinch" Thomason—lectures in the Naval Postgraduate School's Space Systems Academic Group as the sponsored Space Systems Engineering and Acquisitions Chair and Lecturer, educating the next generation of space-enabled warfighters. As the inaugural Space Warfighting Chair, he established the position with NPS's Naval Warfare Studies Initiative.

In his past roles, 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 his contributions to planning the new service and its components.

Internationally, he consulted with the United States Military Training Mission Transformation Action Group to Saudi Arabia, advising on the development of a new Royal Saudi Space Force. With this experience, he developed the NPS thesis fieldwork program for Institutional Capacity Building (ICB) in the space domain, working with combatant command partners in Chile and Peru in 2024 and 2025. Additionally, as a founding member of the space ICB community of practice, he helps develop processes for successful international engagement.

Domestically, Mr. Thomason collaborates with NAVWAR PMW-170 to create and co-host the Space Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) Technical Information Exchange (SLaM TIME). This event fosters dialogue among industry, government, and academia on developing military and government capabilities using commercial Non-Geostationary Orbit (NGSO) constellations. The success of SLaM TIME, attended by the Secretary of the Navy, led to the creation of the Naval Space Summit, which brings together senior leaders to collaborate on space domain equities. The Naval Space Summit attendees include Combatant Commanders, Service Chiefs, and other high-ranking dignitaries.

Mr. Thomason's experience includes serving as Chief of Staff/Executive Officer at MCAS Iwakuni, managing program costs up to $4.5 billion and overseeing $3 million/day in construction. At the National Reconnaissance Office (NRO), he was the USMC Service Chief Representative in the User Engagement Office and held roles such as NRO Field Representative to the Joint Chiefs of Staff, J39; combat deployment with Joint Special Operations Command; Field Representative to the Joint Inter-Agency Task Force – National Capital Region; and USMC Service Chief Fellow to DARPA. He has been a member of the Marine Corps Gazette Editorial Panel from 2006 to 2025. His program management experience spans large-scale construction projects and space-based operational implementation of advanced technologies, collaborating with military, national, and inter-agency organizations including the NRO, intelligence agencies, special operations, DARPA, space systems operations, data management, and C4ISR training and application.

During multiple combat deployments, he served as HMH-362 Squadron Operations and Maintenance Officer in OIF and OEF. He led the Command and Control Training and Education Center of Excellence, training Marine Corps C2 systems at five locations worldwide and conducted combat operations center studies during OIF 06 after serving as the Modeling and Simulations Officer at the MAGTF Staff Training Program. Prior to attending the Naval Postgraduate School, he served and deployed with HMH-362 conducting operations during OEF-P in 2002.

From deployments with the Unit Deployment Program in the Pacific to major combat operations in OIF and OEF at the squadron and SPMAGTF levels to combat deployments with JSOC, Mr. Thomason served across the DoD and IC Enterprise at the tactical, operational, and strategic levels with service, component, and inter-agency activities.

Balancing Operational Utility and Repeatability for Defense Space Systems

Andrew Berglund—is a Senior Policy Analyst in the Center for Space Policy and Strategy at The Aerospace Corporation. In his role, he focuses on national security space, defense acquisition and budget policy, and emerging technologies. Prior to joining Aerospace, Berglund was a Senior Defense Acquisitions Analyst at the U.S. Government Accountability Office, where he earned a meritorious service award for leading work on national security space systems, acquisition policy, and cybersecurity. Berglund earned a bachelor's degree in political science from Christopher Newport University and a master's degree in global policy studies from the LBJ School of Public Affairs. [andrew.berglund@aero.org]

Abstract

The Department of Defense and the U.S. Space Force seek to develop and field a more proliferated space architecture based on greater numbers of smaller satellites in lower orbits to counter space threats and deliver warfighting capabilities more quickly. This shift is forcing a reexamination of acquisition practices and approaches. Prototypes will need to demonstrate operational utility at the system-of-systems level. Similarly, acquisition programs will need to be designed for repeatability, since successful follow-on efforts will be critical for sustaining the system's capabilities. This paper explores some of the tensions within these different goals, offering strategies for how decision makers and acquisition program offices can design and execute space acquisition programs to deliver positive outcomes.

Introduction

The United States faces a dynamic environment for national security space. Government budgetary pressures are forcing difficult funding choices just as an increasingly contested space environment are exposing the lack of innovation, speed, and resilience within both the defense acquisition system and the industrial base. The U.S. Space Force (Space Force) is still evolving as an organization as it seeks to "transform into a warfighting service" (Secretary of the Air Force Public Affairs, 2025). On the commercial side, the space sector has experienced rapid technological and financial growth yet still faces challenges as it matures.

The Space Force seeks to field a resilient and capable space architecture both by transitioning to a more proliferated constellation of smaller satellites in diverse orbits and by leveraging commercial innovation and new suppliers. This effort represents a departure from the large, multipurpose, custom-built, and expensive satellites that were developed and produced by defense contractors with long-established ties to the Department of Defense (DoD). While the DoD's total demand for smaller satellites in low Earth orbit (LEO) is not yet fully known, its future space architecture could require a sustained pace of several hundred units per year. The DoD and the Space Force will need to 1) foster and maintain some level of competitiveness amongst its vendors, 2) routinely incorporate technological innovations that respond to new threats and requirements, and 3) ensure that its selected vendors are able to repeatedly deliver quality at scale.

The Space Force's long-term success in transitioning to and then sustaining a more proliferated space architecture depends on achieving balance between two overarching goals: operational utility and repeatability. The paper will explore some of the natural tension between these goals, describe some of the ways that acquisition programs are navigating these tensions, and offer suggestions for how decision makers and acquisition program officials should consider and make trade-offs. Although proliferation is an approach that can be applied to any orbit, the focus in this paper is large LEO constellations (LLC) for national security space missions. Employing hundreds or even thousands of satellites, LLCs represent significant departure from legacy space systems and carry important and distinct implications for the defense acquisition community and the space industrial base.[1]

LLCs Proving Value for Commercial and Government Customers

In 2019, SpaceX and OneWeb (now Eutelsat OneWeb) each launched their first operational satellites in LEO. Although these were not the first commercial space-based broadband services, they helped raise aspirations for what commercial space companies could achieve, particularly with large constellations of small satellites enabled by falling launch costs. Both these and other LEO constellations have demonstrated commercial success. SpaceX's Starlink, in particular, has exceeded expectations for subscribers, revenue, and number of operational satellites (Erwin, 2024). Anticipating significant increases in demand for these types of space-based services, a growing number of both U.S. and foreign companies have announced plans to launch their own large LEO constellations.

Although revenue from commercial companies now exceeds global government space spending, the U.S. government, and the DoD in particular, play an important role in shaping and supporting the commercial space sector (Reber, 2024). A clear demand signal from government about its future capability needs can help drive commercial investment, and companies that secure defense contracts can show investors a diversified revenue forecast. For its part, the DoD increasingly recognizes the value of commercial innovations. For example, in addition to citing direct economic benefits to the United States, the Space Force's 2024 Commercial Space Strategy states that "[the] Space Force and the Nation become stronger through the effective integration of commercial space solutions during times of peace, competition, crisis, conflict, and post-conflict" (U.S. Space Force, 2024).

Commercial space companies that have not historically pursued defense space acquisitions have recently shown that they can compete effectively with traditional defense contractors on price and schedule. Many of these non-traditional vendors design and build satellite buses and other systems or components that can be readily modified for government or commercial applications. These dual-use technologies have been championed by industry as a way to break down barriers between commercial and government technologies and systems, reversing the trend of defense industry consolidation that started in the 1990s (Palantir, 2023).

Despite impressive growth over a short period, many commercial space companies are still searching to prove out their business models with consistent revenue. Compounding this challenge, venture capital investment in commercial space has fallen from its peak in 2021, in part due to inflation and higher interest rates (Chen et al., 2024). Venture capital investment remains a critical source of support for the commercial space sector, but this recent decline highlights the fact that venture capital is often seeking a shorter timeline for financial returns than even promising commercial space technology is likely to deliver. Overall, there is not yet a broad, established, and competitive market of companies that have proven both the utility of their technology for consumers and their ability to manufacture at scale. Government spending on commercial space products and services remains a vital part of the sector's growth plan.

DoD's Future Space Architecture Driving Changes to Acquisition

The DoD's shift to LLCs is forcing rapid changes to the defense acquisition system. Decades after abandoning earlier attempts like the Strategic Defense Initiative and the Space-

[1] As a point of comparison, the Global Positioning System operates in medium Earth orbit (MEO) and has historically been the DoD's largest military satellite constellation. At that altitude—approximately 20,000 km—a minimum of 24 satellites are required to meet operational requirements. The GPS satellite constellation, and subsequent replenishment efforts, were largely completed under traditional acquisition processes.

Based Infrared System-low (SBIRS-Low), the DoD is again pushing to employ LLCs for national security missions.[2] Since 2023, The Space Development Agency (SDA), an independent acquisition unit within the U.S. Space Force, has launched 27 prototype satellites built and operated by several different vendors. SDA plans to launch hundreds more in the coming years as part of LEO architecture to support missile warning and tracking, data transport, and other missions (Berglund, 2024a). While this is the DoD's most visible and advanced LLC acquisition effort, there is a growing interest in expanding this approach to serve other missions, potentially including navigation, space situational awareness, and communications. The shift to LLCs is also occurring amidst a renewed interest in defense acquisition reform. Acquisition cycle time—roughly the period between program initiation and capability deliver—has been a primary target of reform efforts for decades, and traditional space system acquisitions have often struggled to meet cost and schedule targets (GAO, 2017).

Space systems have long faced unique acquisition challenges. They rely on specialized components, operate in a challenging environment, and cannot be readily retrieved for upgrades and repairs. In the years after Congress established the middle tier of acquisition (MTA) approach, the DoD explored the creation of a "alternative acquisition system" for space acquisitions. This alternative system was meant to tailor standard practices and processes to better account for space systems' acquisition needs (Department of the Air Force, 2020). In particular, the pathway was intended to account for the differences in how space systems were typically developed and fielded, which was through a long development phase followed by a production of just a few satellites. The space acquisition pathway effort was abandoned before it could be implemented, though elements of the proposal have been incorporated by the DoD (Defense Business Board, 2023). Among other things, the "typical" process for space system acquisitions was being upended by a new model, championed by SDA, that upended the typical approach by creating acquisition programs with short developmental phases followed by production of many satellites.

The shift to a more proliferated space architecture carries long-term acquisition and funding implications. An LLC requires more satellites to provide equivalent Earth coverage compared to more distant constellation, making it imperative to control the cost of each satellite to manage total system cost. Because of this emphasis on unit cost, each satellite is designed and built to have a shorter operational life, lacking many of the redundancies and protections that increase costs but also allowing a larger, more expensive satellite to operate for a decade or more. At the same time, the shift to a proliferated system implies a long-term commitment. Satellites in the constellation must be regularly decommissioned and replenished to sustain operations. Abandoning the LLC and shifting the architecture back to using fewer, larger satellites could be both costly and operationally risky. Therefore, in approving the development of a proliferated space acquisition program, decision makers, including Congress, are committing resources beyond the 5-year projection that makes up the annual budget request. This provides a level of stability far greater than other acquisition programs where the hardware's projected end-of-life is known from the beginning.

Achieving and Sustaining Success

To be successful, an LLC acquisition program must strike an appropriate balance between two broad goals: operational utility and repeatability. Because an LLC operates as a system-of-systems, in that each satellite node is only as effective as its integration in the

[2] Proponents of the DoD's increased use of LLCs, and proliferated systems generally, argue that in addition to other benefits, these systems are more resilient against certain types of threats. For example, a recent report found that proliferated constellations "directly and significantly undermine the (People's Liberation Army's) preferred method of conducting operations" by reducing the number of critical nodes that can be targeted in a precision strike (Wang et al., 2025).

broader network, it must measure its performance differently than other space acquisition programs. An LLC acquisition program demonstrates operational utility by proving that its technologies work individually and collectively as intended to provide capabilities that support warfighting missions. An LLC acquisition program demonstrates that it is repeatable by, among other things, effectively controlling cost, accessing or supporting a robust and resilient industrial base, and allowing for technology insertion.

Operational Utility

Prototyping is central to the DoD's plan for demonstrating progress toward and achieving operational utility for LLCs. The DoD's 2022 *Prototyping Guidebook* defines a prototype as "a model (e.g., physical, digital, conceptual, and analytical) build to evaluate and inform its feasibility or usefulness." Because of the limited utility of a single satellite within an LLC, the measurement of operational utility must primarily occur at the network, or system-of-systems, level. Therefore, a prototype system must field a sufficient number and diversity of satellites to "evaluate and inform" options about the future operational constellation. This adds complexity to prototyping efforts, since acquisition program offices will need to establish system-level performance goals to evaluate the prototype's success. This is also consistent with prior research showing that identifying and resolving conflicting definitions of success is a key challenge for prototyping efforts (Seraphin et al., 2025).

For its primary acquisitions, the SDA has utilized the MTA rapid prototyping pathway to streamline acquisition processes and help deliver capabilities more quickly. As of March 2025, SDA has 27 prototype satellites on orbit made by several different vendors. Together, these satellites composing the agency's Tranche 0 efforts, which are intended to "demonstrate the feasibility of a proliferated architecture in cost, schedule, and scalability toward necessary performance" (Space Development Agency, n.d.). SDA leadership recently stated that they continue to test and learn from Tranche 0 as they prepare to launch the next round of satellite, Tranche 1, later this year (Hadley, 2025).

Although system-level performance is the key metric, testing and verifying an individual satellite's functionality remains a vital part of the acquisition process for LLCs. While proliferated satellites require many of the same kinds of components as traditional satellites, there are important differences, mainly due to the need for LLCs to rapidly, flexibly, and efficiently pass large volumes of data across different nodes. For example, optical communications terminals (OCT) are a key component for many LLCs that enable rapid, secure space-to-space and space-to-ground communications. Instead of using radiofrequency communications, OCTs transmit and receive in the infrared spectrum and are a low size, weight, and power option capable of much higher data rates. However, because the DoD has not previously deployed this technology at scale, it has been a challenge for SDA and its vendors to obtain a sufficient number of reliable OCTs, demonstrate technology interoperability through ground testing, and verify the full range of required capabilities (GAO, 2025). Other important technologies include software algorithms and on-board computer processing so that the constellation is able to perform more of its tasking without sending data back to a ground station.

While SDA is likely to use the MTA rapid prototyping pathway for future acquisition programs, recent legislative changes have granted increased flexibility for how MTAs are executed. Specifically, the National Defense Authorization Act for Fiscal Year 2025 included a provision that allows for "continuous iterative prototyping and fielding under the same program or project for an unlimited number of subsequent periods, where each period is intended to be five years" (National Defense Authorization Act, 2024). Prior to this change, each rapid prototyping or fielding effort had to be executed as a standalone acquisition program. It remains to be seen whether and how acquisition programs will use this new authority for national security space acquisitions, including LLCs; however, it could greatly help reduce administrative burden when transitioning from one effort to the next.

Repeatability

Whereas most acquisition programs are evaluated primarily by the degree to which they meet cost, schedule, and performance goals, repeatability is another valuable metric for evaluating LLC's success. The initial acquisition program or programs that deliver the operational system must be followed by future rounds of development, production, and fielding to sustain the constellation and its capabilities. Here again, the overall system is the appropriate unit of measurement, and assessments of an acquisition program's repeatability provide insight as to whether the system's operational utility can be sustained.

There are several different ways to evaluate whether an acquisition program is repeatable, but three specific ways deserve special attention: affordability, industrial base capacity and capability, and mechanisms for technology insertion.

Affordability. Controlling LLC's unit cost is critical for acquisition success. Because of the large satellite quantities involved and the need to periodically replenish the constellation, unit cost increases can quickly add up to a significant amount. In addition to increasing budgetary pressures, these cost increases could also erode the program's support within the DoD and Congress. Program offices can help control costs by leveraging commercial capabilities that require little to no additional development work or modifications to meet government requirements. They may also use fixed price contracts to limit the government's financial risk on any cost overruns, as the Space Force has increasingly prioritized over the past several years.

Industrial base capacity and capability. The capacity and capability of the space industrial base are vital to the long-term success of LLC acquisitions. Vendors must be both willing to pursue and able to execute government contracts. SDA has been successful in developing a diverse and large number of vendors that are competing for and winning its contracts. However, the rapid transition to LLCs has revealed some signs of stress within the space industrial base, including delays, missed deliveries, and quality issues (Berglund, 2024b). Some of these challenges are likely to be resolved as the government's LLC efforts mature and more satellites are successfully fielded, but continued assessments of the space industrial base and supply chains are needed. On short acquisition timelines, even small delays can have a significant operational impact.

Mechanisms for technology insertion. An LLC that fails to provide opportunities for technology insertion and refresh will fail to keep pace with innovation and threats. In the context of weapon system acquisitions and repeatability, this idea is somewhat counterintuitive. Technology development is typically the highest risk component of any acquisition program, and keeping requirements stable has long been identified as important to successful acquisition outcomes (Anton et al., 2020). However, an LLC cannot be successful over the long-term if it fails to take advantage of the predictable cycle of satellite replenishment with improved hardware. This process can and should be done incrementally, avoiding the temptation to take large technology leaps between satellite generations. Recognizing this, the SDA has outlined some of its capability goals as part of a "technology roadmap," providing an important signal of the agency's long-term plans to drive technology development within industry (Berglund, 2024a, p. 10).

Scaling Manufacturing and Building Resilient Supply Chains

There is a critical scaling challenge for the space industrial base to overcome in meeting the DoD's needs for LLCs. The shift from low- to high-volume production of satellites not only increases the number of components, subcomponents, and parts required, it also necessitates a fundamentally different approach to manufacturing. For national security space acquisitions, low-volume satellite production—often 0–10 units—utilizes customized, labor-intensive manufacturing techniques often performed by specialized personnel. In contrast, high-volume satellite production—50–100 units or more—borrows principles from the automobile, commercial airplane, and consumer electronics industries to rapidly and efficiently manufacture satellites that relies more on processes than personnel to achieve quality and consistency.[3]

Companies that are able to reach and sustain high-volume production will have a sizeable advantage over companies that are unable to do so. This advantage may be particularly important for LLCs, in that vendors that are able to secure a significant portion of the early acquisition efforts will be able to reinvest their profits into capital improvements. These improvements will further reduce manufacturing costs and increase efficiencies, strengthening their competitiveness for future awards, either for a comparable government or commercial LLC.

The size and composition of the DoD's future space architecture will help shape the number and diversity of satellite manufacturers that are able to compete for future LLC acquisition programs. To promote efficiency, rapid delivery, and lower costs, the government can encourage companies to design and implement high-volume production by designing LLC acquisition programs have include production quantities greater than 50 satellites. This is still applicable if the acquisition program's total quantities are divided amongst several vendors, as the SDA has typically done. For example, a total quantity demand of 250 satellites could be split among two to five high-volume satellite manufacturers.

While high-volume production promotes efficiency and cost savings, there are other factors acquisition decision makers should consider. Most notably, promoting innovation and competition may require creating opportunities for vendors that have not yet fully developed or institutionalized high-volume production. When it was created, part of the SDA's initial tasking was to foster growth within the U.S. space industrial base, and the agency has consistently divided its contract awards amongst a diverse range of contractors is consistent goal. For the Space Force overall, balancing its commitment to fostering the growth of the space industrial base against greater efficiencies from more winner-take-all contract awards may become increasingly difficult. However, if this balance can be achieved, LLCs can be an important mechanism for the DoD to both deliver its operational capabilities and support the continued maturation of the space industrial base.

Strategies for Building Resilience Throughout the Space Industrial Base

There are several strategies the DoD and Space Force could pursue for LLC acquisition programs to balance high-volume production, and the benefits it provides, with innovation, including competition and opportunities for diverse vendors. Employing a mix of these strategies will help promote the overall resilience and dynamism of the space industrial base.

Create tiers of competition for potential vendors. Acquisition programs could intentionally carve out a portion of their production awards for newer, smaller vendors. This would provide access to companies that have demonstrated promising technologies but have not had access to prior contract awards, commercial opportunities, or private capital to scale their manufacturing processes. Vendors performing these awards would then be able to demonstrate increasing levels of manufacturing maturity as their production units increase.

[3] Prior research has identified roughly 100 units as the quantity that separates low- and high-volume production. Discussions with the authors of this research suggest that this is an estimate. Flow processing can be achieved with fewer units, roughly 50, but production benefits increase as quantities increase (Eccles et al., 2020).

Connect low-volume producers with scaling opportunities. Manufacturing scale is not the only challenge smaller vendors need to overcome, and the government should continue to engage with companies to promote early-stage technology development that may provide warfighting capabilities over the next 5–10 years or more. Service or department-wide opportunities exist: Small Business Innovation Research, Small Business Technology Transfer, Strategic Funding Increase, Tactical Funding Increase, the Office of Strategic Capital domestic manufacturing loans, and the Small Business Investment Company Critical Technologies Initiative. Some of these opportunities are explicitly designed to support scaling and commercialization. On the acquisition program side, SDA created the Hybrid Acquisition for Proliferated Earth Orbit to identify and support companies for prototyping and experimentation efforts that might support long-term needs (Space Development Agency, 2024). Connecting these efforts to LLCs, with sustained funding and long-term support, can help create a pipeline of innovation for warfighting capabilities.

Invest in diversity across tiers. Access to parts and components has been an acute supply chain challenge for the defense industrial base over the past decade, contributing to schedule delays for national security space acquisition programs (Berglund, 2024b). While some well-funded companies are able to take steps to insulate themselves from supply chain disruptions through vertical integration, many companies will not be able to make these investments prior to receiving customer orders. The DoD and Space Force can continue to make strategic investments in technologies and inputs, such as critical minerals, semiconductors, and solar cells. The government should also redouble its efforts to identify and take action to resolve weaknesses within its supply chain, particularly diminishing manufacturing sources and material shortages.

Facilitate hybrid space solutions. Efforts to increase the interoperability of government and commercial space systems can further enhance the DoD's capabilities as well as the resilience of the space industrial base. These hybrid solutions expand opportunities for nontraditional vendors to participate in national security missions, building trust between the vendor and the government that can facilitate future engagement. Moreover, just like LLCs overall, greater path diversity for sending and receiving information increases mission resilience. Because LLCs are structured at a system-of-systems level and many commercial companies operate assets in LEO, government LLCs are well-positioned for this kind of approach. Recent government efforts to develop hybrid solutions include the Defense Innovation Unit's Hybrid Space Architecture program to develop networking and other backend services to facilitate hybrid communications transmissions. On the hardware side, the Defense Advanced Research Projects Agency (DARPA) is developing a reconfigurable OCT that would serve as a connection point between disparate constellations that would otherwise not be able to communicate (DARPA, n.d.).

Opportunities for Commercial Services

One possibility that could further upend the future of space system acquisition is that the DoD increasingly adopts a more service-based model for national security space capabilities that have previously been considered primarily within the purview of government systems. The DoD's 2024 *Commercial Space Integration Strategy* identifies 13 mission areas for national security space, including environmental monitoring, missile warning, nuclear detonation detection, and satellite communications (p. 5). The strategy organizes each of these missions under one of three categories based on whether the responsibility for executing the mission relies primarily on the government or the commercial sector: government primary mission areas, hybrid mission areas, and commercial primary mission areas.[4] In the coming years, as commercial space services expand, the DoD could decide to place more missions in the "commercial primary" category.

Signs of this shift are already visible, as the DoD and Space Force officials have repeatedly stated their interest in integrating commercial companies and procuring commercial space services (Erwin, 2025). This rhetoric has been matched by action. In late 2024, the DoD raised the ceiling on its proliferated LEO Satellite-Based Services program from $900 million to roughly $13 billion (Luckenbaugh, 2024). The success of this program, and the continued challenge to meet aggressive cost and schedule targets for national security space acquisition programs, could create further momentum for commercial space services. However, some government missions are likely to remain specialized enough that the government will continue to lead, particularly in areas that lack a clear commercial corollary.

Conclusion

The DoD's efforts to proliferate its space architecture and harness commercial space innovations will be two of the dominant trends in national security space over the next decade. These goals immense promise to improve space warfighting capabilities as well as improve acquisition outcomes. However, they also challenge existing processes and approaches. To be successful, the space acquisition community will need to adapt its approach to things like prototyping and manufacturing, while also finding new ways to promote competition and innovation. Finally, the extent to which the DoD demonstrates its commitment to pursuing proliferation and utilizing commercial space capabilities will help spur industry to continue developing the space warfighting capabilities that the United States needs.

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[4] Government primary mission areas are those where "a preponderance of functions must be performed by the government, which include more traditional and sensitive national security capabilities, like missile warning and command and control. Commercial primary mission areas are those where companies "have demonstrated technological maturity and met the Department's requirements and capability needs for mission assurance," which include emerging missions like in-space servicing, assembly, and manufacturing (ISAM).

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Accelerating Satellite Development: A Comparative Simulation of NASA's Waterfall Process and Agile Process Using Innoslate Life Cycle Modeling Language

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Abstract

Large-scale, safety-critical cyber-physical (LS/SC/CP) systems, such as satellites, face significant challenges in balancing the need for safety, regulatory compliance, and documentation with the demand for faster development cycles. This study examines the impact of applying Agile methodologies to the LS/SC/CP system by modeling the development of a fictional mid-size Low Earth Orbit (LEO) satellite using Innoslate. We created two development models: one following NASA's traditional Waterfall process from Phase A to Phase D, and another using an Agile approach with incremental Minimum Viable Products (MVPs). The models were compared regarding schedule and cost, revealing that the Agile approach delivered the satellite two times faster with reduced costs. However, applying Agile to safety-critical systems introduced several challenges, including regulatory compliance, safety assurance, integration complexity, bi-directional traceability, documentation requirements, and cultural barriers. We applied specific adaptations to the Agile model to address these challenges, including automated compliance checks, integrated hazard analysis, added traceability mechanisms, and streamlined documentation practices. Our findings suggest that these adaptations significantly mitigate the risks associated with Agile adoption in LS/SC/CPS. The study concludes that a tailored Agile approach—augmented with industry-specific adaptations—can improve development speed and flexibility while maintaining compliance, safety, and quality standards, thus providing a viable alternative to traditional Waterfall processes for future satellite development projects.

Keywords: Agile Large-Scale Safety-Critical Cyber-Physical

Introduction

In recent years, product development has increasingly become more volatile, uncertain, complex, and ambiguous (Ciric, 2018). To remain competitive in the marketplace, many businesses building cyber-physical systems are looking at alternatives such as Agile to reduce delivery times. The two most common approaches in product development are Waterfall, a linear stage gate process, and Agile, an iterative incremental approach. This paper focuses specifically on NASA's Waterfall process and scaled Agile approach.

Problem

A fundamental problem exists with traditional development processes. They only work well when requirements and risks are stable and well understood in advance (Heeager & Nielsen, 2018). As systems have become increasingly complex there has been a growing interest in applying Agile methodologies to large-scale, safety-critical cyber-physical (LS/SC/CP) systems across multiple domains due to the need to be able to adapt to changing requirements, increase the speed up delivery cycles, reduce life cycle costs, manage increasing complexity, and increase maintain quality (Yeman & Malaiya, 2023). The space industry struggles with multifaceted requirements, leading to complexity, long project timelines, and stringent safety requirements. Therefore, the application of Agile methods has the potential to impact schedule and cost significantly (Bart, 2024). The challenge is objectively evaluating the impacts of development process implementations in the context of complex systems (SoS) such as a satellite system.

Purpose

This research aims to objectively compare two distinct process implementations regarding cost and schedule when building an LS/SC/CP system, such as a satellite. The first implementation is NASA's life cycle approach to space and ground system development, documented in NASA's Systems Engineering Guidebook (NASA, n.d.). The second implementation is an Agile approach to building the system, utilizing a series of minimum viable products (MVPs).

Research Objectives and Question

Compare Agile and Waterfall approaches for LS/SC/CP system development. Highlight challenges and propose adaptations for Agile in these domains.

- RQ1: How does the application of Agile principles influence the system development process for LS/SC/CP systems compared to NASA's traditional systems engineering approach?
- RQ2: What are the primary challenges in applying Agile to developing safety-critical systems such as satellites?
- RQ3: What adaptations are necessary for Agile methodologies to be effective in LS/SC/CP system development?

Methodology

System Context

The mid-size Low-Earth Orbit (LEO) satellite under development is designed to provide high-resolution Earth imagery and weather monitoring capabilities. With a launch mass of 250 kg, this satellite is equipped with a 1 kW solar array to support its operational power needs. It also features dual band communication via S-band (125 Kbps uplink, 2 Mbps downlink) and X-band (650 Mbps downlink) for efficient data transmission.

The satellite's mission objectives focus on capturing Earth imagery for environmental monitoring, disaster response, and resource management while supporting weather observation and atmospheric data collection. The spacecraft is designed to operate in LEO, optimizing its orbital characteristics for frequent revisit times and continuous global coverage. This satellite aims to deliver critical data to researchers, meteorologists, and government agencies by leveraging advanced sensor payloads and high-speed communication links, contributing to improved forecasting, climate studies, and geospatial intelligence.

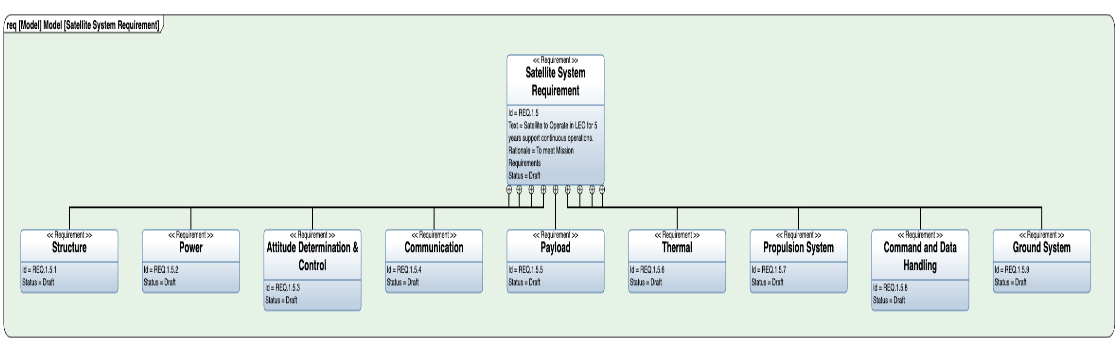

Figure 1. Satellite Requirements Diagram

Each model started with a detailed breakdown of each subsystem's inputs (components, requirements) and outputs (verified functionality). The inputs described in Table 1 were identical for both the Agile and Waterfall models to maintain consistency.

Table 1. Modeled Subsystem

	Subsystem	Inputs	Outputs
1.	Structure	Primary & Secondary Structures	Verified Structural Integrity
2.	Power	Battery, Solar Arrays	Power Distribution Verified
3.	Attitude Determination, Control	Reaction Wheels, Star Trackers, Software	Attitude accuracy verified
4.	Communications	Transmitters, Receivers, Antennae	Reliable communication link established
5.	Payload	Scientific Instruments, Payload Specifications	Data collection and processing operational
6.	Thermal Control	Radiators, Heaters, Insulation, sensors	Thermal Controls Verified
7.	Propulsion	Thrusters, Fuel Thanks, Piping	Basic maneuver capability established
8.	Command & Data handling	Onboard Computer, Software, Sensors	Command/Data Handling Verified

Subsystems

Developing a mid-size LEO satellite requires integrating multiple interdependent subsystems, each critical to mission success. These subsystems work together to provide structural integrity, power generation, attitude control, communication, payload operation, thermal regulation, propulsion, and command and data handling.

Structure

The structural subsystem is the satellite's backbone, providing mechanical support and protection for all internal components. It is designed to withstand the stresses of launch, the space environment, and on-orbit operations. The primary and secondary structures are lightweight yet durable materials, such as aluminum alloys and composite materials, ensuring rigidity and strength while minimizing mass. The structure also houses the payload and ensures proper alignment of sensors and antennas.

Power

The power subsystem generates, stores, and distributes electrical power to all onboard systems. The satellite has a 1 kW solar array, which collects and converts solar energy into electrical power. Lithium-ion batteries store excess energy during eclipse periods when the satellite is not exposed to sunlight. A power distribution unit (PDU) regulates and distributes power efficiently, ensuring uninterrupted operation of critical subsystems.

Attitude

Determination and Control System The Attitude Determination and Control System (ADCS) ensures the satellite's precise orientation and stability to maintain proper pointing for imaging, communication, and orbital maneuvers. The system includes reaction wheels, magnetometers, gyroscopes, and star trackers for attitude sensing and control. Magnetorquers or thrusters may be used for momentum management and stabilization after deployment. The ADCS enables accurate positioning for Earth observation and data transmission, ensuring optimal performance of the payload and antennas.

Communication

The communication subsystem provides command, telemetry, and data transmission capabilities between the satellite and ground stations. It operates in S-band (125 Kbps uplink, 2 Mbps downlink) for telemetry, tracking, and control (TT&C) and X-band (650 Mbps downlink) for high-data-rate payload transmission. The subsystem consists of high-gain and low-gain antennas and software-defined radios (SDRs) for efficient frequency modulation and adaptability to mission requirements.

Payload

The payload subsystem comprises high-resolution imaging sensors and weather monitoring instruments designed for Earth observation. The imaging system captures multispectral and thermal imagery for environmental monitoring, disaster response, and resource management. Weather instruments collect atmospheric data, cloud cover, and temperature variations, contributing to meteorological forecasting and climate studies. The payload is optimized for high spatial and temporal resolution to maximize scientific and operational benefits.

Thermal Control

The thermal control subsystem ensures that all components operate within their required temperature ranges in the extreme space environment. It includes passive thermal elements such as radiators, multi-layer insulation (MLI), coatings, and active thermal management using heaters and heat pipes. The system prevents electronic components from overheating and ensures that the payload, batteries, and communication systems function reliably across day-night temperature cycles in LEO.

Propulsion

The propulsion subsystem provides orbital maneuvering, attitude corrections, and station-keeping capabilities. It consists of thrusters, fuel tanks, piping, and valves for controlled thrust generation. The propulsion system supports collision avoidance maneuvers, deorbiting, and precise station adjustments, extending the satellite’s operational lifetime and ensuring compliance with space debris mitigation guidelines.

Command and Data Handling

The command and data handling (C&DH) subsystem acts as the satellite’s central processing unit, managing data flow between subsystems and executing mission operations. It includes an onboard computer, data storage units, and fault tolerant software. The system processes telemetry data, executes onboard autonomy algorithms, and ensures real-time decision-making. It also interfaces with the ground control center, executing commands and coordinating data collection, storage, and transmission.

Modeling Environment

Life cycle modeling is a structured approach to visualizing, analyzing, and managing the development, deployment, operation, and retirement of complex systems (Vaneman, 2016). It enables engineers and project managers to model the entire system life cycle using standardized methodologies such as SysML, LML, and UAF, ensuring alignment with industry standards. To effectively compare the Waterfall and Agile life cycles. Life cycle modeling in Innoslate is valuable for our fictional case study because it provides an integrated modeling environment capable of clearly visualizing, simulating, and analyzing differences in these methodologies. LML covers the entire system’s life cycle, from conceptual development to disposal. The approach involved creating detailed activity and action diagrams, running simulations, and evaluating outcomes to objectively determine the effectiveness and suitability of Agile versus Waterfall for satellite development. Innoslate is a cloud based and on-premises platform that supports requirements management, modeling and simulation, verification and validation, risk analysis, and collaboration within a single digital environment.

Table 2 summarizes key assumptions underlying the satellite development models using both Waterfall and Agile methodologies. Multiple assumptions were made to simplify the modeling process and effectively compare these two distinct approaches. These assumptions focus on critical aspects such as requirements management, workflow structure, resource availability, integration, testing, compliance, and risk management. Clearly defining these boundaries ensures a consistent and fair comparison of each methodology within the context of satellite development.

Table 2. Modeling Assumptions

Category	Waterfall Model Assumption	Agile Model Assumption
Workflow	Follows NASA defined approach	Iterative and Incremental with Continuous Assurance Plugin (CAP)
Planning	Complete Integrated Master Schedule is defined before work starts.	Multiple Horizons Roadmap with Years decomposed into Quarterly Increments into 2-week sprints.
Materials/Components	All required materials and components are available from the start and cause no delays.	All required materials and components are available from the start and cause no delays.
Labor / Skill Availability	Skilled workforce available	Skilled Workforce Available
Integration / Test	Access to Test Environments readily available	CI/CD Pipeline
Regulatory Compliance and Safety	Validated at the Phase Gates	Automated and continuously validated at each sprint and Increment.
Material Cost	Fixed 5 million	Fixed 5 million
Labor Cost	$120 per hour	$120 per hour

We leveraged NASA's Cost Estimating Guide (NASA, 2015) to estimate the satellite build costs under both Waterfall and Agile models. Our approach combined analogy cost estimating with an engineering build-up. We created work breakdown structures for each model for the engineering build-up. After comparing our estimates with subject matter experts and adjusting for their experience, we refined them to a rough order of magnitude.

Development Models

NASA Development Approach

The NASA Systems Engineering Handbook, initially published as SP-6105 in 1995, provided the foundation for the NASA Waterfall life cycle process (Hirshorn et al., 2017). NASA's process for developing air and ground systems follows a linear approach, segmented into distinct project life cycle phases. The life cycle begins with Pre-Phase A: Concept Studies, where ideas and feasible alternatives are generated and evaluated for cost, technical feasibility, and risk. This leads into Phase A: Concept and Technology Development, which refines mission concepts and validates requirements. Phase B focuses on preliminary design and establishing design-dependent requirements and interfaces, while Phase C finalizes the detailed design and prepares for manufacturing. During Phase D, the system is assembled, integrated, and rigorously tested to ensure operational readiness. In Phase E, the system transitions to operations and sustainment, where performance is maintained and necessary upgrades are made. Finally, Phase F addresses decommissioning, data archival, and disposal. For purposes of this paper, we were interested in phases A–D.

Table 3. NASA Phases

Phase	Purpose	Inputs	Description	Outputs
A	Concept and Technology Development	Mission needs, feasibility studies	Define mission architecture, identify technology gaps	Concept Study Report, preliminary requirements
B	Preliminary Design & Technology Completion	Concept studies, tech develop	Finalize architecture, complete risk analysis, technology	Preliminary Design Review (PDR), risk reduction results
C	Final Design and Fabrication	PDR results, matured requirements	Conduct detailed design, build and test components	Critical Design Review (CDR), manufactured components
D	Assembly, Integration, and Test (AIT) & Launch	CDR results, fabricated components	Integrate subsystems, conduct testing, prepare for launch	Fully integrated system, Launch Readiness Review (LRR)

The NASA Waterfall process was modeled in Innoslate based on NASA's Systems Engineering Handbook (SP-20166105). The model illustrated in Figure 2 adhered to phased development with sequential stages and formal review gates at each phase.

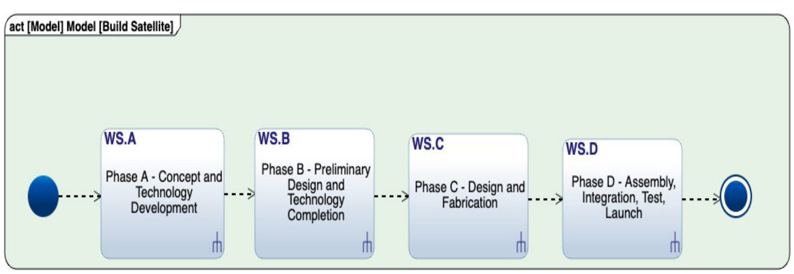

Figure 2. Model, Utilizing NASA Systems Engineering Handbook

Phase A: Concept and Technology Development

Phase A, illustrated in Figure 3, focuses on defining the mission concept, assessing feasibility, and identifying key technologies required for satellite development. The waterfall model, in general, is a sequential design process where progress flows steadily downwards through the phases of conception, initiation, analysis, design, construction, testing, production/implementation, and maintenance. However, at the close of Phase A, the customer will only have a series of documents without working capability. The goal of Phase A is to ensure that the project is technically, operationally, and financially viable before proceeding. However, this approach has not seemed to minimize overrun and schedule delays. The GAO has shown that their program cycle times are increasing by an average of three years from the planned date (GAO, 2024). We decomposed the system using Innoslate into small steps and then estimated using a triangular distribution for each step. For example, updating the Concept of Operations is calculated as a minimum of two weeks, a maximum of six weeks, and four weeks as most likely. The approach allows us to get cost and schedule estimates. The modeled system illustrated in Figure 3 completed in 1.16 years, which aligns with what GAO reports regarding the time SBIRS Phase A took, which is between 12–18 months (GAO, 2024).

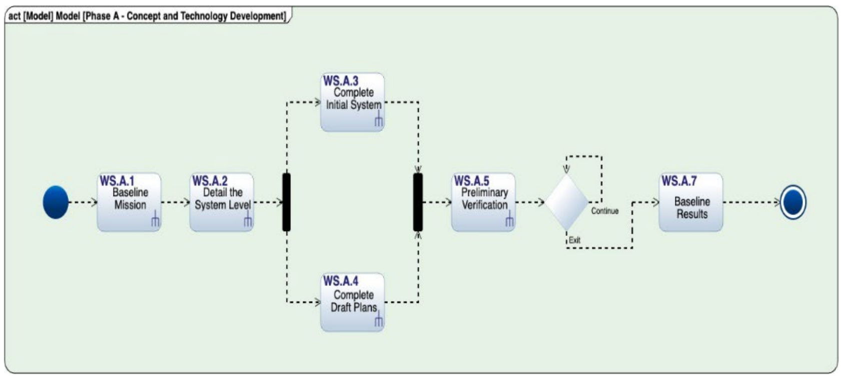

Figure 3. NASA Phase A: Concept and Technology Development

Phase B: Preliminary Design and Technology Completion

Phase 2, illustrated in Figure 4, the Preliminary Design and Technology Completion phase, is paramount to the success of space missions, serving as a critical bridge between the initial concept and final implementation. The mission design is rigorously refined during this phase, and key technologies are matured to minimize technical risks. Key activities include conducting a Preliminary Design Review (PDR) to evaluate the system design and maturing critical technologies like advanced propulsion systems or communication arrays. Further activities involve planning system integration and testing, refining cost and schedule estimates, managing risks, and engaging stakeholders. The goal is to ensure the project is on track for successful implementation, within budget, and on schedule, ultimately paving the way for a successful mission.

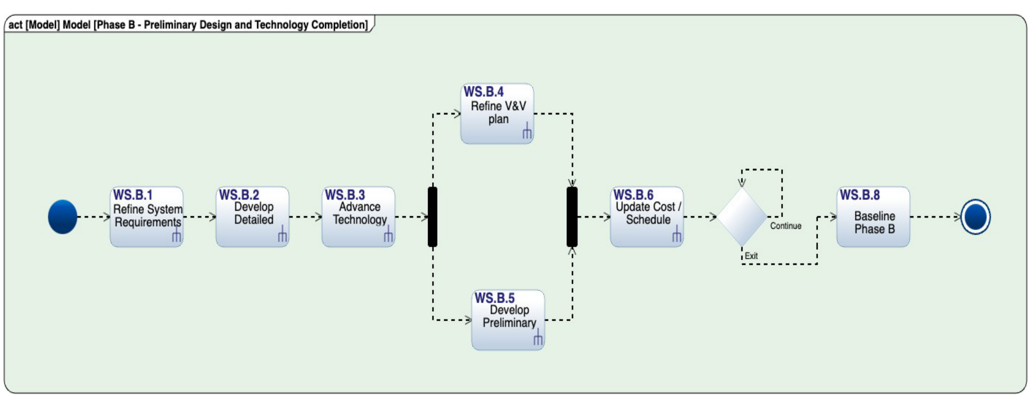

Figure 4. NASA Phase B

Phase C: Final Design and Fabrication

NASA's Phase C, illustrated in Figure 5, known as the Final Design and Fabrication phase, focuses on completing the detailed design of the system, fabricating and assembling components, and preparing for system integration and testing. Key activities include conducting a Critical Design Review (CDR) to ensure the design meets all mission requirements, finalizing detailed engineering drawings and specifications, and beginning the fabrication and assembly of system components. The project team also develops detailed plans for system integration and testing, continues to manage risks, and engages with stakeholders to keep them informed about the project's progress and any changes to the mission design or objectives.

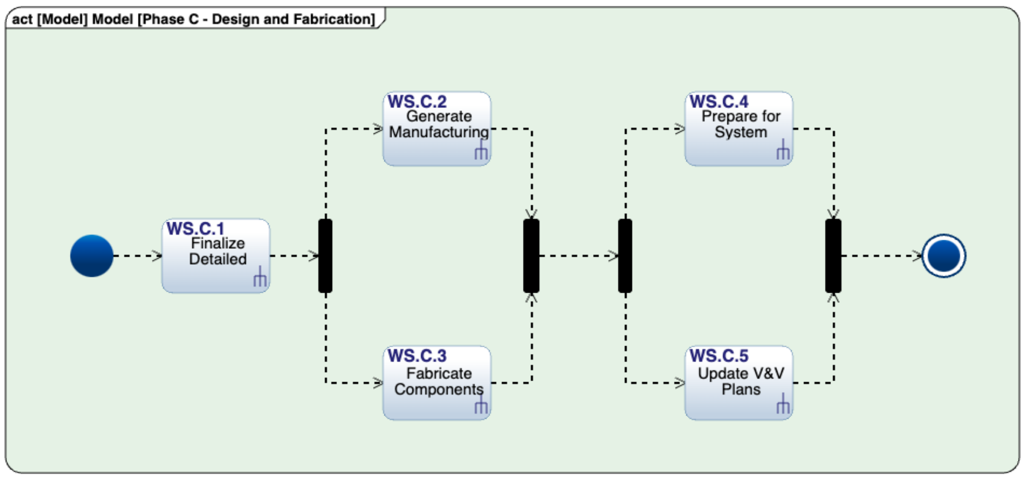

Figure 5. NASA Phase C

Phase D: Assembly, Integration, and Testing

Phase D, shown in Figure 6, known as the Assembly, Integration, and Testing (AIT) phase, focuses on assembling system components, integrating subsystems, and conducting comprehensive testing to ensure the system meets all mission requirements and is ready for deployment. Key activities include system assembly, integration, and extensive testing to verify performance, reliability, and safety. The project team conducts a Test Readiness Review (TRR) to confirm readiness for testing, prepares the system for operational deployment, and continues to manage risks. Ongoing stakeholder engagement ensures that all parties are informed about the project's progress and any changes associated with mission design or objectives.

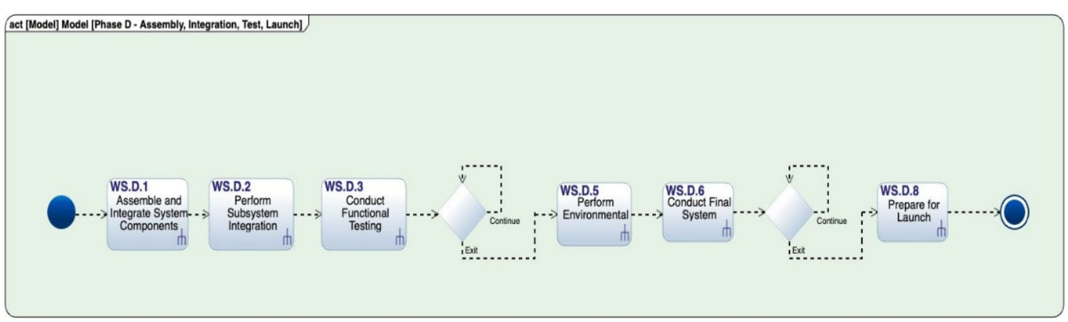

Figure 6. NASA Phase D

Analysis and Results

The Monte Carlo simulation in Innoslate provided key insights into the expected duration and labor cost for building a satellite, considering project timelines and resource expenditures variability. The analysis shown in Figure 7 revealed that the mean duration to build the satellite is 5.89 years, with a standard deviation of 1.53 months. This indicates that the average completion time is relatively stable. This stability is due to the assumption that all materials and resources were readily available. This would exhibit much greater variability if supply chain integration were factored in.

In terms of cost, Labor cost was estimated at $7,858,335.14, representing the primary expenditure tracked in the analysis. We assumed the Agile and Waterfall approaches would yield a similar BoM due to the same hardware and components used in both development methodologies. This assumption allowed for a focused comparison of schedule efficiency and labor expenditures between the two methodologies. The findings highlight the expected resource commitment for satellite development, with potential applications in refining project scheduling and cost allocation strategies for future space missions.

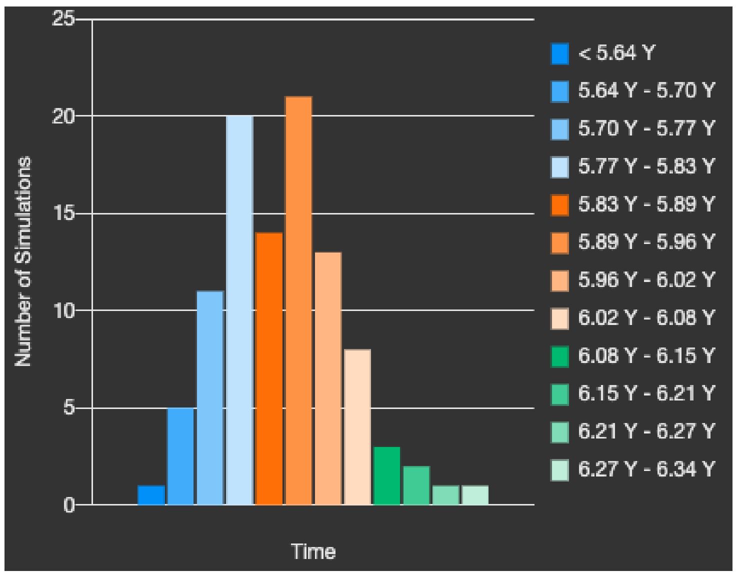

Figure 7. Monte-Carlo Analysis of Waterfall Development Process

Agile Approach

Agile is an iterative and incremental approach to engineering characterized by iterative and incremental development, short feedback loops, continuous integration and verification, and adaptability to change within complex, evolving environments. The traditional Waterfall approach has been the norm for aerospace, but a growing community in Space is transitioning to Agile (Ribeiro et al., 2024). Some of these trailblazers include SpaceX (Peterson & Mocko, 2024), Planet Labs (Donahue et al., 2024), Relativity (Araujo, 2019). For this paper, we took inspiration from organizations such as SpaceX (de Freitas Bart, 2024). We defined a hypothetical approach, the Continuous Assurance Plugin (CAP), that can support Agile Frameworks by adding specific guidance to support regulatory compliance, safety constraints, and integration complexity.

Continuous Assurance Plugin

The CAP illustrated below in Figure 8 begins by leveraging SAFe's core framework. We decomposed the satellite system into MVPs, Epics, Features, and Stories following core principles of decomposition, abstraction, encapsulation, well-defined interfaces, and independence. This resolved some well-documented challenges in Agile for Hardware: products are difficult to decompose into modules, and systems integration efforts are difficult to break down into small tasks (Drutchas & Eppinger, 2022).

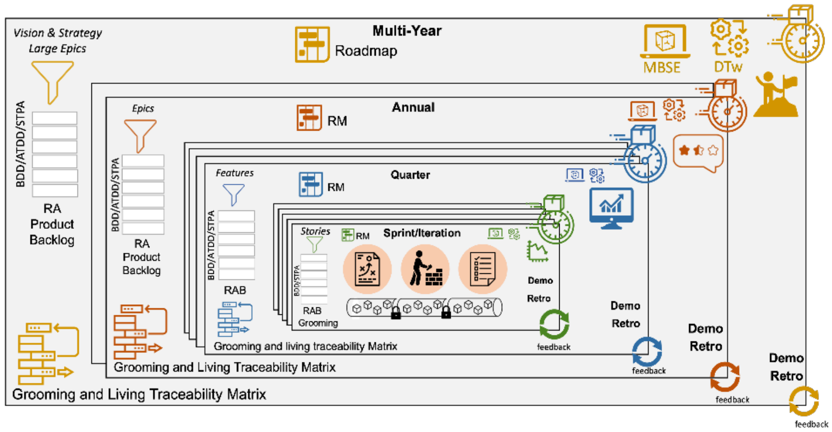

Figure 8. Building LS/SC/CP systems with CAS

An MVP is a concept popularized by Eric Ries. He defined MVP as "a product that allows a team to collect the maximum amount of validated learning about customers with the least effort" (Ries, 2009). We created MVPs associated with each of the satellite subsystems. According to SAFe, Epics are a significant solution initiative that requires an MVP. Due to the size of the fictional case study, our epics and MVPs have a 1 to 1 relationship. Epics decompose into more minor features, which, by definition, need to be less than 12 weeks. Features decompose into stories that need less than a sprint length, typically two weeks. Although our Agile approach forgoes Phase-gated Systems Engineering reviews, we must still meet regulatory compliance and safety assurance requirements through our CAP outlined in Table 4. Therefore, we are implementing a continuous assurance approach, contrasting with the traditional waterfall methodology, where assurance is tightly coupled to phase gates.

Table 4. CAP Features

Feature	Description	Benefit
Modular Architecture	Principles of decomposition with well-defined interfaces	Reduces dependencies across teams and impact of change.
MBSE	Model everything from requirements and design to verification and validation	System Transparency allows communication and reduces integration complexity
Digital Twin	Dynamic interactive model that mirrors the system's behavior and performance.	Real-time feedback on the impact of system updates. Allowing safe option exploration
Boundary Objects	Artifacts, terms, or concepts that serve as a point of reference	Facilitate communication and understanding between diverse groups.
Enabler Stories	Safety and regulatory tasks in product backlogs (e.g., "As a system, I must comply with MIL-STD-882E for fault tolerance.")	Ensuring that we are building regulatory compliance, safety, and security into the system.
BDD/STPA Integration	BDD defines system behavior through user stories and scenarios. STPA identifies potential hazards, ensuring safety constraints are met.	Write safety-focused scenarios that prevent hazards, including edge cases.
ATDD	Defining acceptance test criteria for regulatory and safety before development begins.	Ensures capabilities are not accepted until they comply with functional and safety requirements.

Risk-Adjusted Backlog	Prioritized backlog that incorporates risk analysis.	Provides transparency into risk exposure to enable prioritization
Living Traceability Matrix	Every requirement is traced to its corresponding design implementation, and test artifacts,	Provides transparency to support regulatory and safety compliance.
Compliance Test Automation	Automated Safety and Compliance Tests	Compliance validation is integrated into the development process
CI/CD Pipeline	CI/CD pipelines that incorporate HIL and SIL to validate cybersecurity (DO-326A, NIST 800-53) and reliability (ISO 26262)	Integrating SIL and HIL into the CI/CD pipeline, provides continuous/comprehensive validation of the entire system.
Chaos Engineering	CI/CD pipeline that regularly injects failures into the system before they manifest in production,	Enhances the resilience and reliability of systems.
Digital Compliance Checklist	Checklist integrates compliance activities into the Agile workflow.	real-time monitoring, validation, and documentation.
Iterative Reviews	A systematic approach to continuously meet safety and regulatory requirements	Identifies potential issues early, reducing the risk to safety and reliability of the system
Expand the Definition of Done	Define "Done" to include safety and compliance checks.	ensure that these critical aspects are addressed consistently and thoroughly.

We address safety and regulatory compliance challenges with our CAP that integrates continuous safety and regulatory compliance throughout the MVP development cycle. This approach decouples safety validation from traditional milestone reviews and embeds incremental safety checks, automated compliance verification, and regulatory traceability within Agile workflows.

Table 5. Caption

MVP	Safety / Compliance Actions	Validations
Startup/ Initialization	Incorporate Safety & Compliance into Risk Adjusted Backlog, define incremental safety validation workflow, set up regulatory checklists in Agile tools	System Safety: MIL-STD-882E (DoD, 2012), NASA NPR 8715.3 (NASA, 2020), Cybersecurity: NIST 800-53 (National Institute of Standards and Technology, 2020), ITAR compliance tracking (U.S. Department of State, 2021)
1 Basic Structure & Power System	Perform Continuous structural risk assessments (MBSE for load/stress), Automate material compliance tracking (e.g., REACH)	System Safety: IEC 61508 (Brown, 2000), ISO 26262 (International Organization for Standardization, 2018), Environmental & Health: REACH (European Chemicals Agency, 2022), OSHA (Occupational Safety and Health Administration, 2022), ANSI (American National Standards Institute, 2021) Aerospace: NASA-STD-8719.14 (Wilcutt, 2021)
2 Command & Data Handling (C&DH)	Implement early cyber compliance checks (DO-326A, NIST 800-53), Automate software static analysis	Software & Cybersecurity: DO-178C (Radio Technical Commission for Aeronautics, 2011), DO-326A (Radio Technical Commission for Aeronautics, 2014), NIST 800-53 (National Institute of Standards and Technology, 2020), FedRAMP (GSA, 2021)

3 Attitude Determination & Control	Integrate real-time fault tolerance testing into Agile test pipelines, Validate software/hardware failure modes in digital twin	System Safety: MIL-STD 882E (DoD, 2012), IEC 61508 (Brown, 2000) Cybersecurity: DO 326A (Radio Technical Commission for Aeronautics, 2014), ITAR (U.S. Department of State, 2021)
4 Propulsion System	•Perform continuous hazardous material tracking, Automate ITAR compliance for propulsion components	System Safety: MIL-STD-882E (DoD, 2012), Environmental & Health: EPA (U.S. Environmental Protection Agency, 2022), OSHA (Occupational Safety and Health Administration, 2022), Aerospace: FAA Part 450 (Federal Aviation Administration, 2021)
5 Communication System	Embed EMI/EMC compliance verification within Agile sprints, Automate the regulatory spectrum compliance (FCC, ITU)	Electromagnetic Compliance: MIL-STD-461 (DoD, 2015), FCC (Federal Communications Commission, 2021) regulations, Cybersecurity: NIST 800-53 (National Institute of Standards and Technology, 2020), ITAR (U.S. Department of State, 2021)
6 Thermal System	Integrate thermal risk modeling into MBSE simulations, Automate compliance with NASA-STD-8719.14	System Safety: ISO 26262 (International Organization for Standardization, 2018), IEC 61508 (Brown, 2000), Aerospace: NASA-STD-8719.14 (Wilcutt, 2021)
7 Payload	Ensure payload-specific safety testing in sprint test cases, Continuous FAA payload integration compliance tracking	System Safety: MIL-STD-882E (DoD, 2012), NASA NPR 8715.3 (NASA, 2020), Aerospace FAA Part 450 (Federal Aviation Administration, 2021), ITAR (U.S. Department of State, 2021)
8 Full System Integration	Implement incremental safety audits per increment, Continuous traceability of safety requirements via MBSE	System Safety: MIL-STD-882E (DoD, 2012), IEC 61508 (Brown, 2000), Cybersecurity: DO-178C (Radio Technical Commission for Aeronautics, 2011), DO-326A (Radio Technical Commission for Aeronautics, 2014), NIST 800-53 (National Institute of Standards and Technology, 2020)
9 Launch Ready	Final safety validations automated in DevSecOps pipeline, Incremental FAA Part 450 launch compliance verified continuously	Aerospace & Space: FAA Part 450 (Federal Aviation Administration, 2021), NASA-STD-8719.14 (Wilcutt, 2021), Environmental & Health: OSHA (Occupational Safety and Health Administration, 2022), EPA (U.S. Environmental Protection Agency, 2022), ANSI (American National Standards Institute, 2021)

Model Setup

We began with the SpaceX approach to decomposing the satellite into a modular set of capabilities (de Freitas Bart, 2024). Once we decomposed the system, we outlined a series of MVPs and next viable products (NVPs) to deliver the system. MVP and NVP refer to a concept in product development grounded in the principles of the Lean Startup methodology, which emphasizes rapid iteration, customer feedback, and adaptive planning (Stevenson et al., 2024). We leverage Planet Labs' approach to rapidly create and integrate a prototype and then evolve it with software updates to deliver satellites with relatively short design cycles. Before delivery for launch, the focus is on developing and validating an MVP (Donahue et al., 2024). The top-level model is shown in Figure 9.

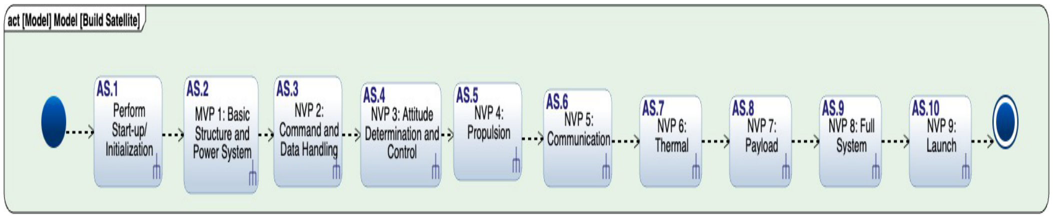

Figure 9. Agile Satellite Approach

Start-up and Initialization

Modeled in Figure 10, our Agile approach's Startup and Initialization timebox focuses on establishing the foundational digital environment, complete with a digital thread that spans the entire development process. This digital-first strategy is gaining traction, as illustrated by Istari's $19 million contract to digitally certify Lockheed Martin's XPlane (Istari Digital, 2024), and the digital system building approaches used in Formula 1 (Mayani et al., 2018). Key inputs include mission and system requirements, regulatory and safety constraints, performance parameters, development tools, and stakeholder involvement. The process begins with analyzing mission objectives and refining system requirements into actionable backlog items. Key performance and compliance factors are reviewed, and initial SysML and 3D modeling help define system structure and behavior. A roadmap outlines incremental MVPs for phased development. Business rhythms are established to ensure synchronization, an Agile performance measurement baseline is defined, and development teams are structured. A product backlog is created, incorporating ATDD acceptance criteria for each feature. Development and test environments, including Continuous Integration/Continuous Delivery (CI/CD) pipelines and automated testing frameworks, are established. Critically, during this increment, we integrate safety and compliance directly into our workflow by incorporating safety and compliance into the risk adjusted backlog, defining an incremental safety validation workflow, and setting up regulatory checklists within our Agile tools. We ensure we meet MIL-STD-882E, NASA NPR 8715.3, NIST 800-53, and ITAR compliance tracking. Outputs of this increment include a risk-adjusted backlog, incorporating quantitative risk analysis (Parente, 2018), an Agile performance measurement baseline covering budget, scope, and schedule (Alleman et al., 2014), a roadmap defining MVPs (Trieflinger et al., 2021), draft management and technical plans, and a finalized organizational structure. The Monte Carlo analysis for this portion of the project had a Mean of 4.05 months with a standard deviation of 11.38 days.

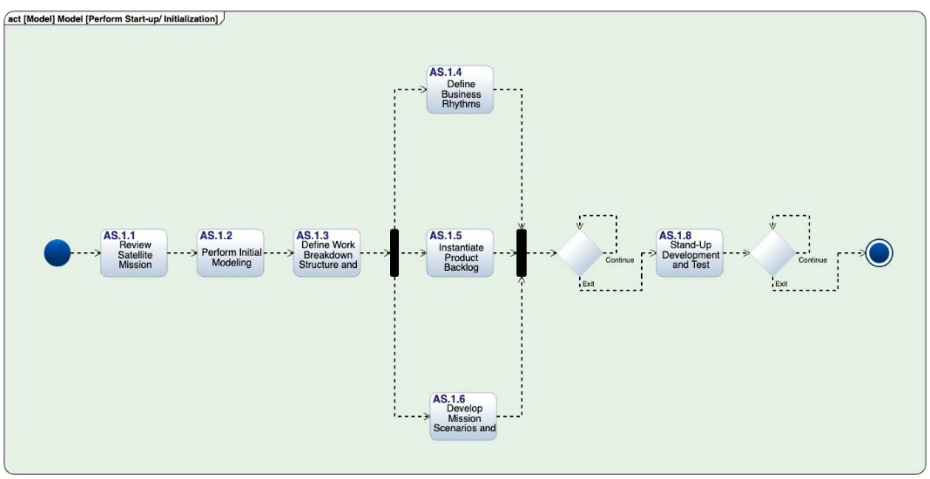

Figure 10. Start-up and Initialization

MVP 1 Basic Structure and Power System

MVP 1, as shown in Figure 11, establishes the foundational framework and power system required for the satellite: basic structure and power. This increment begins with backlog grooming and Program Increment (PI) planning, ensuring that acceptance criteria are well-defined. The roadmap, design specifications, and Interface Control Documents (ICDs) guide the development. Concurrently, teams gather materials, including the primary and secondary structures, solar arrays, batteries, and a PDU. The assembly process involves constructing the satellite's frame, installing solar panels and batteries, and integrating the PDU to regulate power distribution. In parallel with the assembly and testing, we perform continuous structural risk assessments using Model-Based Systems Engineering (MBSE) for load and stress analysis and automate material compliance tracking (e.g., REACH). These actions ensure adherence to critical safety and regulatory standards, including System Safety (IEC 61508, ISO 26262), Environmental & Health (REACH, OSHA, ANSI), and Aerospace (NASA-STD-8719.14). Testing focuses on validating structural integrity, power generation, and energy storage, ensuring all components function as expected before progressing to the next MVP.

Completion of MVP 1 results in a digitally validated structural and power system (Mirabella et al., 2024), with test reports confirming performance and risk-adjusted backlog updates informing the next development iteration. The demonstration showcases the assembled structure, operational solar arrays, and digitally demonstrated functional power distribution. The Monte-Carlo Analysis for this increment showed a Mean of 2.3 months with a standard deviation of 8 days. This would take much longer if we had not assumed we had procured materials.

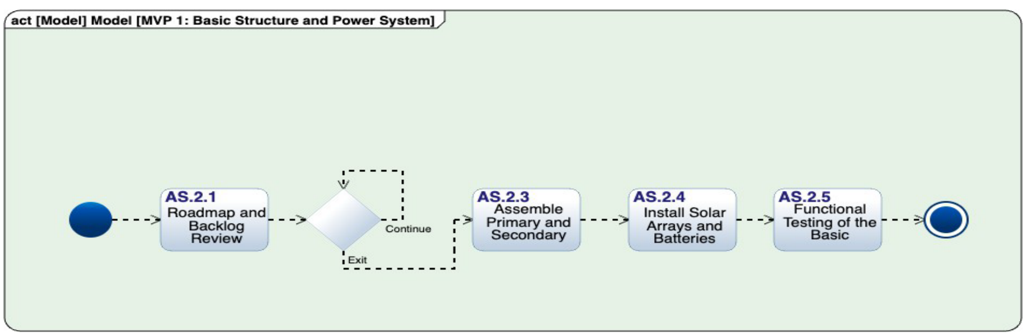

Figure 11. Structure and Basic Power

NVP 2 Command and Data Handling

C&DH, modeled in Figure 12, focuses on integrating the satellite's central processing and data management system, ensuring it can receive, process, and execute commands while handling telemetry and onboard data storage. This increment of development includes critical safety and compliance actions: implementing early cyber compliance checks (DO-326A, NIST 800-53) and automating software static analysis. The development starts with backlog grooming, PI planning, and refining acceptance criteria. The key components include the Onboard Computer (OBC), Data Storage Unit, Telemetry Interface, and redundant processing modules, all integrated and tested within our NASA-verified digital environment (Hill et al., 2024). The process involves assembling and connecting the OBC, configuring data storage, linking telemetry interfaces, and deploying the initial software stack to validate system functionality. Testing ensures command execution, data processing, and real-time system health monitoring, confirming that the C&DH system meets mission requirements before progressing to the next MVP. This work is conducted to meet the following standards: DO-178C, DO-326A, NIST 800-53, and FedRAMP.

The successful completion of NVP 2 results in an integrated and validated C&DH

system, providing a functional command execution and data handling framework. This system is foundational for controlling all subsequent subsystems, including Attitude Determination and Control (ADC), Propulsion, and Communication, ensuring the satellite can effectively manage operations and respond to mission commands. The output includes a risk-adjusted backlog, an operational OBC, verified telemetry reporting, and test reports confirming system reliability by following an iterative Agile approach similar to Liubimov's approach for CubeSat (Liubimov et al., 2023). Monte Carlo Analysis for this increment had a mean of 2.22 months with a standard deviation of 8 days.

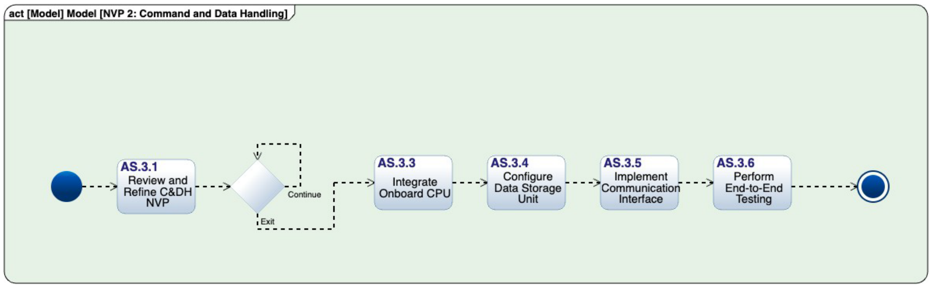

Figure 12. Command and Data Handling

NVP 3 Attitude Determination and Control

As illustrated in Figure 13, the ADCS enables the satellite to determine and adjust its orientation in Space. This increment begins with backlog grooming and PI planning. Key steps include integrating and configuring ADCS sensors, implementing attitude determination algorithms, and testing system responsiveness under Hardware-in-the-Loop (HIL) and Software-in-the-Loop (SIL) simulations. Testing ensures the system accurately determines orientation, executes attitude corrections, and maintains stability under simulated mission conditions.

In parallel with the ADCS integration and testing, we integrate real-time fault tolerance testing into Agile test pipelines and validate software/hardware failure modes in the digital twin. These actions ensure adherence to critical safety and regulatory standards, including System Safety (MIL-STD882E, IEC 61508) and Cybersecurity (DO-326A, ITAR).

Successful completion of NVP 3 results in a fully operational ADCS, with validated attitude accuracy, control responsiveness, and integration with the OBC. Key outputs include calibration reports, Reaction Control System (RCS) performance logs, end-to-end integration test reports, and updated ICDs. The RCS is a system of thrusters used to control the attitude and position of the satellite. These validations ensure the ADCS can support precision pointing for payload operations, stable communication alignment, and controlled maneuvers in future MVPs. MVP 3 sets the foundation for integrating propulsion, communications, and mission-specific payload operations by establishing a stable and autonomous orientation control system. The Monte Carlo analysis shows a Mean of 2.81 months with a standard deviation of 9 days.

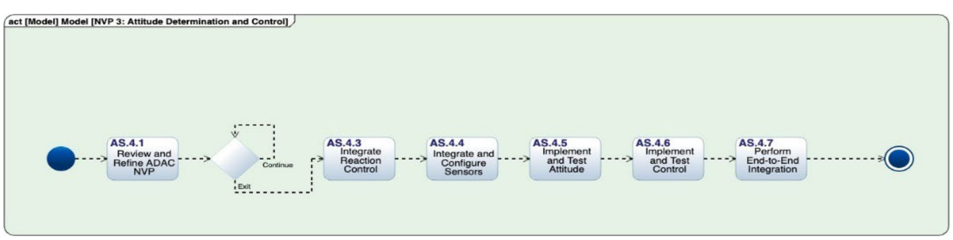

Figure 13. Attitude Determination and Control

NVP 4 Propulsion System

The process begins with backlog grooming and PI planning, ensuring alignment with previous NVPs such as ADCS and C&DH. The integration phase includes installing the propulsion unit, fuel tanks, valves, and sensors, and implementing thruster control algorithms to regulate fuel flow and thrust activation. Testing employs HIL and SIL simulations, assessing system responsiveness under simulated orbital conditions to validate fuel system functionality, thruster performance, and maneuver execution before final integration. (HIL simulations test the hardware and software together, while SIL simulations focus on testing software components.) Monte Carlo analysis for this MVP indicated a mean completion time of 3.28 months with a standard deviation of 11 days. This work is conducted to meet the following standards: System Safety: MIL-STD-882E; Environmental & Health: EPA, OSHA; and Aerospace: FAA Part 450.

The successful completion of NVP 4 ensures validated thruster performance, fuel flow control, and essential maneuvering capability, enabling the satellite to conduct orbital corrections and maintain stability. Key outputs confirm propulsion functionality within expected mission parameters, including integration and test reports, updated ICDs, and end-to-end system validation results. This increment lays the foundation for higher-level operations, such as payload positioning, communication adjustments, and station-keeping, while resolving anomalies and refining system parameters for future NVPs.

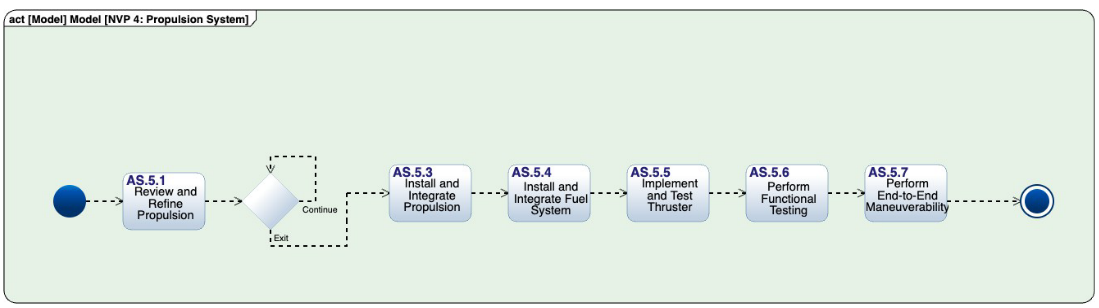

Figure 14. Propulsion

NVP 5 Communication System

The communication subsystem, illustrated in Figure 15, focuses on integrating and validating the satellite's ability to transmit and receive data reliably, a critical function for maintaining mission control and data integrity. This increment includes vital safety and regulatory actions: embedding EMI/EMC compliance verification within Agile sprints and automating regulatory spectrum compliance (FCC, ITU). This increment involves installing and testing transmitters, receivers, amplifiers, and high/low-gain antennas, ensuring seamless integration with the C&DH system. The system's communication control algorithms are deployed and validated through HIL and SIL setups, simulating real-world orbital conditions. (HIL simulations test the hardware and software together, while SIL simulations focus on testing software components.) Functional testing ensures data transmission rates, telemetry downlink, and ground station communication operate within expected parameters before full system integration. RF performance metrics are vital to ensure the signal strength and quality are within acceptable ranges for reliable communication. Monte Carlo analysis for this MVP indicated a mean completion time of 2.8 months with a standard deviation of 9 days. This work is conducted to meet the following standards: Electromagnetic Compliance: MIL-STD-461, FCC regulations; Cybersecurity: NIST 800-53, ITAR.

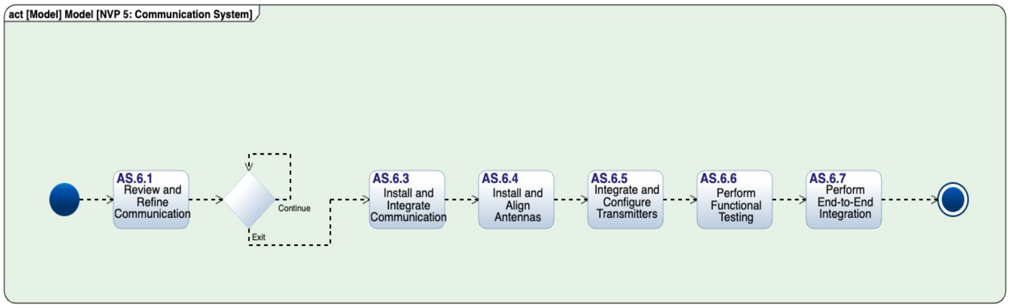

Figure 15. Communication

The successful completion of MVP 5 results in a validated communication system, enabling secure and efficient data exchange between the satellite and the ground station. Output includes integration test reports, RF performance metrics, updated ICDs, and resolved anomaly logs. This MVP ensures that telemetry, remote command execution, and payload data transmission function as required, laying the groundwork for full operational deployment. With a robust and tested communication link, the satellite is prepared for advanced mission operations, including real-time system monitoring and data collection, supporting the final integration and launch readiness phases.

NVP 6 Thermal

The Thermal Control System, modeled in Figure 16, ensures that the satellite can maintain stable operating temperatures in extreme orbital conditions, a critical function for preserving the integrity and performance of all onboard systems. This MVP includes vital safety and regulatory actions: integrating thermal risk modeling into MBSE simulations and automating compliance with NASA-STD8719.14. This subsystem integrates radiators, heaters, MLI, and temperature sensors, ensuring thermal regulation across all subsystems. The process begins with PI planning and backlog refinement, followed by the installation of thermal hardware and validation through thermal vacuum (TVAC) chamber testing and simulations. (TVAC testing simulates Space’s vacuum and extreme temperature conditions to ensure the thermal system can perform as expected.) The thermal control algorithms are implemented and tested under simulated operational scenarios to verify heat dissipation, insulation efficiency, and active temperature regulation. Functional and end-to-end integration tests confirm that radiators manage excess heat, heaters prevent cold-related failures, and MLI stabilizes subsystem temperatures, ensuring compliance with mission requirements. MLI is vital to minimize heat transfer through radiation, the primary form of heat transfer in Space. Monte Carlo analysis for this MVP indicated a mean completion time of 2.7 months with a standard deviation of 9 days. This work is conducted to meet the following standards: System Safety: ISO 26262, IEC 61508; Aerospace: NASA-STD-8719.14.

The successful completion of NVP 6 results in a validated thermal system, with test reports confirming temperature stability, heater responsiveness, and subsystem integration with the power and structural systems. Key output includes updated ICDs, integration test reports, and an adjusted backlog reflecting lessons learned. This MVP establishes a reliable thermal management framework, protecting critical satellite components and enabling sustained operation in Space. A robust and tested thermal system prepares the satellite for mission operations and long-duration performance in extreme environments.

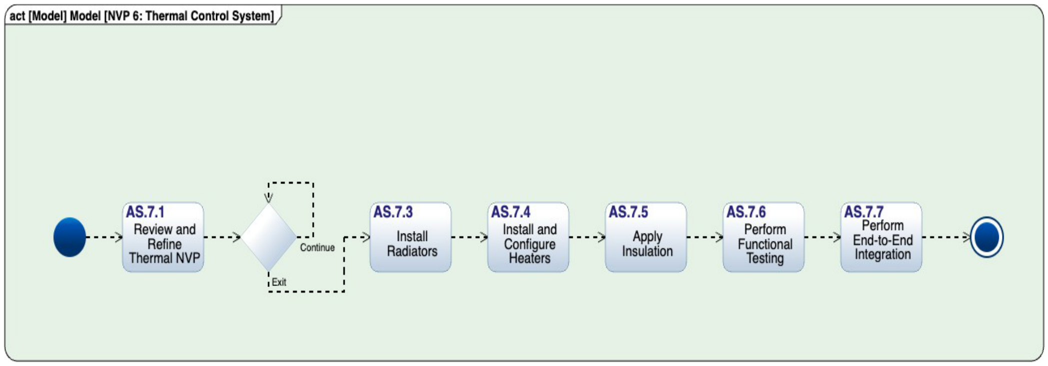

Figure 16. Thermal

NVP 7 Payload System

The Payload System, illustrated in Figure 17, focuses on integrating and validating the scientific instruments and data processing capabilities essential for the satellite's mission. This increment includes critical safety and regulatory compliance activities: ensuring payload-specific safety testing in sprint test cases and continuous FAA payload integration compliance tracking. This increment ensures seamless integration with the C&DH, Power, and Communication Systems, enabling efficient data collection, processing, and transmission. The process begins with planning for the PI, refining backlog priorities, and defining key milestones. The scientific instruments, power and data harnesses, and payload control software are installed and tested using HIL setups, functional test benches, and simulated operational scenarios. (HIL setups allow for testing hardware and software components in a simulated environment, ensuring they function together as expected.) Functional testing validates instrument accuracy, data acquisition, and real-time processing, ensuring stable payload operations before full system integration. The Monte Carlo analysis for this MVP indicated a mean completion time of 2.83 months with a standard deviation of 9 days. This work is conducted to meet the following standards: System Safety: MIL-STD-882E, NASA NPR 8715.3; Aerospace: FAA Part 450, ITAR.

The successful completion of NVP 7 results in a validated payload system with proven data collection, processing, and communication capabilities. Key output includes integration test reports, updated ICDs, and functional verification results, confirming power efficiency, OBC integration, and ground station connectivity. This NVP ensures the satellite is fully equipped for its mission by establishing a robust payload management and data transmission framework. With all payload components successfully tested and integrated, the satellite is prepared for final system validation and launch preparation in the next phase.

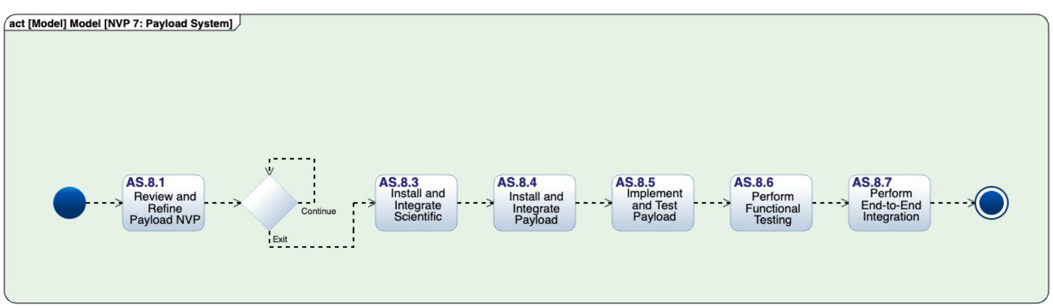

Figure 17. Payload

NVP 8 Full System Integration

The Full System Integration step, illustrated in Figure 18, ensures that all previously developed subsystems—including structure, power, C&DH, ADCS, propulsion, communication, thermal, and payload—are successfully assembled into a fully functional satellite, a pivotal achievement for mission success. This NVP includes critical safety and regulatory actions, such as implementing incremental safety audits per increment and continuous traceability of safety requirements via MBSE and digital twin. This increment begins with PI planning, refining integration steps, and validating that all ICDs, mission objectives, and testing procedures are in place. The integration process involves assembling mechanical, electrical, and data systems, ensuring seamless subsystem interaction. The payload control software is deployed and tested to verify command execution, telemetry monitoring, and data processing, while power and data harnesses are connected to ensure full operational capability.

The final integration test reports updated ICDs, and mission validation reports comprehensively assess system performance. These ICDs are vital for documenting and controlling the interfaces between the many subsystems of the satellite. Comprehensive functional and environmental testing is conducted to validate the satellite's performance under real-world conditions. TVAC tests simulate space conditions, ensuring the thermal control system functions as expected. Vibration and acoustic tests ensure structural integrity for launch, verifying that the satellite can withstand the stresses of liftoff. HIL and SIL setups are used for mission simulations, verifying end-to-end mission execution from launch to operational scenarios. (HIL tests combine hardware and software components, while SIL tests focus on software components.) A ground station emulator validates the satellite's ability to receive and execute ground commands, perform orbital maneuvers, and process payload data. Monte Carlo analysis for this MVP indicated a mean completion time of 3.1 months with a standard deviation of 8 days. This work is conducted to meet the following standards: System Safety: MIL-STD-882E, IEC 61508; Cybersecurity: DO-178C, DO326A, NIST 800-53.

With full-system functionality verified, this MVP confirms that the satellite is mission-ready and compliant with all regulatory requirements. The successful integration and testing of all components ensure the satellite can withstand launch stresses, operate reliably in orbit, and achieve mission objectives. This milestone prepares the satellite for final launch readiness assessments, marking the transition from development to deployment.

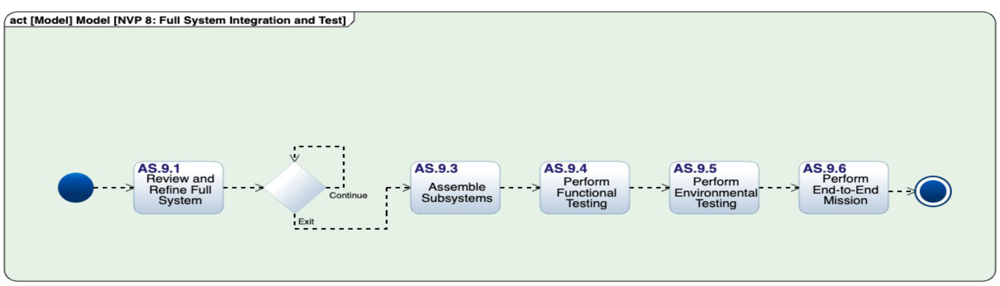

Figure 18. Full System Integration

NVP 9 Launch

The final MVP, shown in Figure 19, Launch Readiness ensures the satellite is fully prepared for launch, validating mechanical, electrical, and software integration with the launch vehicle and ground control systems, a crucial step for mission success. This NVP includes critical safety and regulatory actions: final safety validations are automated in the DevSecOps pipeline, and incremental FAA Part 450 launch compliance is verified continuously. This increment involves final pre-launch inspections, system validation, and compliance certification, ensuring the satellite can withstand launch conditions and establish a stable connection with ground control. The Launch Readiness Checklist, mission software, and telemetry systems are tested in a simulated launch control environment, verifying that the satellite can receive and execute commands post-deployment. (Simulating a launch control environment allows for verification of all procedures and software in a controlled setting.) The ground control interface is validated, ensuring seamless data transmission between the satellite and ground stations. Monte Carlo analysis for this NVP indicated a mean completion time of 2.8 months with a standard deviation of 9 days. This work is conducted to meet the following standards: Aerospace & Space: FAA Part 450, NASA-STD-8719.14; Environmental & Health: OSHA [126], EPA, ANSI.

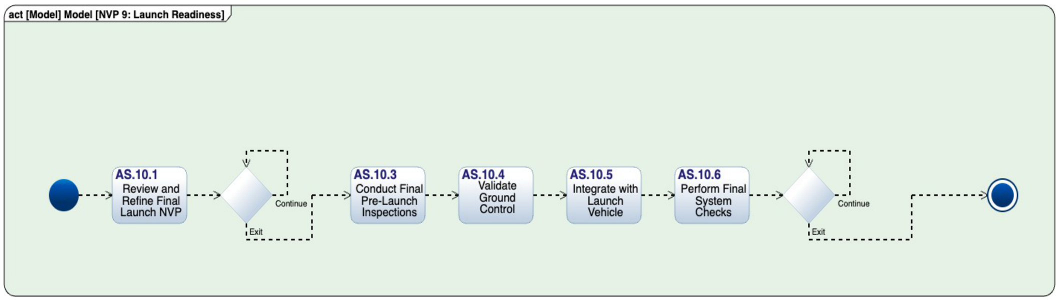

Figure 19. Launch

With successful final system checks, integration with the launch vehicle, and regulatory approval, this MVP confirms that the satellite is flight-ready and has no unresolved technical issues. Key outputs include final inspection reports, launch readiness certification, and validated telemetry systems. These telemetry systems are essential for monitoring the satellite's health after launch. This milestone marks the transition from development to operational deployment, ensuring the satellite is cleared for launch and prepared for its mission in orbit.

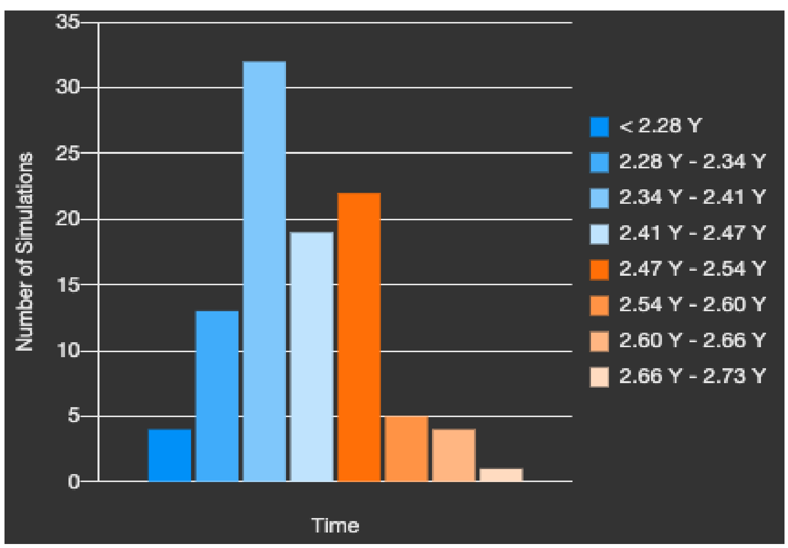

Figure 20. Monte-Carlo Analysis of Agile Development Cycle

Analysis and Results

The Monte Carlo simulation illustrated in Figure 20 for the Agile satellite development approach yielded a mean duration of 2.4 years with a standard deviation of 1 month. In terms of labor cost, we calculated $2,636,244.12. This result indicates a highly predictable development timeline, with Agile allowing for faster delivery compared to the Waterfall approach's mean duration of 5.89 years. The relatively low standard deviation further reinforces that Agile's incremental development cycles, iterative feedback loops, and continuous integration practices help maintain schedule stability, even in complex system builds.

Importantly, this analysis assumed full availability of materials and resources, meaning that delays related to procurement, supply chain disruptions, or resource shortages were not factored into the simulation. This assumption contributed to the high predictability of Agile's results, minimizing variability in the projected timeline. In real-world conditions, Agile's adaptability to changing requirements and resource fluctuations may provide an advantage over Waterfall, which tends to experience more schedule slips when unexpected constraints arise. The findings demonstrate that, under optimal conditions, Agile can deliver a satellite in less than half the time of a traditional approach while maintaining low schedule uncertainty, making it a viable methodology for accelerating space system development.

Discussion

This study compares Agile and Waterfall methodologies for satellite system development, evaluating their impact on timeline efficiency, risk mitigation, and regulatory compliance. The Monte Carlo analysis demonstrated that Agile significantly reduces development time, with a mean duration of 2.4 years compared to Waterfall's 5.89 years, while maintaining a lower standard deviation. These findings suggest that Agile's iterative cycles, continuous integration, and incremental validation contribute to a more predictable and efficient development process. Our results align with the results Ciric found in their paper regarding Agile Project Management (APM; Ciric et al., 2019).

Agile's Impact on Development Efficiency

With its iterative approach, Agile development significantly shortens development timelines by fostering early and frequent testing, thereby minimizing late-stage rework—a clear advantage over the Waterfall model's delayed validation. We implemented a CAP to bolster agility in safety critical and regulated domains, seamlessly integrating people, process, and technology. This framework prioritizes the inclusion of regulatory compliance and safety expertise within development teams, early engagement of auditors for automated test development, and continuous collaboration with subject matter experts during reviews. Process enhancements include embedding compliance and safety user stories into the risk-adjusted product backlog, which is constantly managed to address emerging risks proactively, conducting hazard analysis via STPA, and employing continuous validation checklists (Vieira et al., 2020; Zahedi et al., 2023). Technology is leveraged through advanced verification and validation using MBSE, digital twin simulations, robust automated testing, and integrated toolsets. We emphasize quantifiable metrics, such as reduced compliance defects and improved safety rates, and cultivate a culture of shared responsibility and continuous improvement. By integrating a risk adjusted product backlog, we ensure that risk management is a dynamic and integral part of the development process, allowing teams to respond swiftly to potential issues and maintain project agility while upholding stringent safety and compliance standards.

Challenges in Applying Agile to Safety-Critical Systems

Despite its advantages, Agile's implementation in a safety critical domain such as regulatory compliance, safety assurance, integration complexity, traceability and documentation, and organizational communication barriers.

Regulatory Compliance

Space systems must comply with stringent industry standards, including MIL-STD-461, NASASTD-8719.14, FAA Part 450, NIST 800-53, and ITAR regulations. Traditional Waterfall models inherently align with these compliance requirements through predefined verification stages. Conversely, Agile's iterative approach requires decoupling regulatory compliance checks from stage gates and moving to right-size documentation (Rodrigues et al., 2022), performing incremental compliance checks with checklists (Zaydi et al., 2024). In addition, we can model compliance using MBSE, simulating the impact using a digital twin (Bouhali et al., 2024). For instance, digital twin simulations can assess compliance impact by virtually testing system responses to various regulatory scenarios. Compliance with these regulations is crucial for ensuring the space systems.

Safety Assurance

Failures in safety-critical systems necessitate rigorous methodologies that ensure consistent safety evaluations across design and operational stages. The integration of a CAP that employs Behavior Driven Development (BDD) and Acceptance Test Driven Development (ATDD) can complement the Systems-Theoretic Process Analysis (STPA) framework to enhance safety verification. STPA is particularly effective in identifying potential failure modes, as it views safety violations as a result of unsafe interactions among components rather than merely from component failures (Kim et al., 2021). In addition to STPA, implementing MBSE systematically organizes safety system designs within agile frameworks. MBSE enhances the iterative development approach by documenting safety requirements, facilitating clear communication among stakeholders, and integrating safety checks into the user story definition of done (Ahlbrecht et al., 2022). We utilize the risk-adjusted product backlog to prioritize safety concerns continuously. In conclusion, the CAP that integrates BDD, ATDD, and STPA, enhanced by MBSE, and managed in a risk-adjusted backlog presents a robust approach for managing safety in complex systems.

Integration Complexity

Our CAP supports the challenge of integration complexity by supporting Agile with MBSE and digital twins. This synergistic approach fosters early integration and validation, which are pivotal in managing the inherent complexities associated with these systems. MBSE provides a structured and formalized method for capturing CPS's requirements, architecture, and design, thus establishing a well-documented framework that supports iterative development. The integration of MBSE and digital twins to support Agile was demonstrated by Vodyaho with the Smart City case study, which managed transport and flows in St. Petersburg (Russia; Vodyaho et al., 2022). Digital twins complement MBSE by creating real-time virtual representations of physical systems, allowing continuous integration and validation throughout development. They enable hardware-software co-simulation, predictive analytics, and real-world scenario testing without waiting for full system deployment. Integrating Agile, MBSE, and digital twins reduces delivery times and lowers risk exposure (Honcak & Wooley, 2024).

Traceability and Documentation

MBSE within our CAP enhances traceability and documentation processes. A common perception is that Agile teams often neglect documentation, presenting a barrier to effective traceability. However, integrating Agile methodologies with MBSE can address these challenges while ensuring the documentation is appropriately scaled and valuable. MBSE leverages models to facilitate various systems engineering activities, including requirements capture, system functionalities identification, and verification tasks, significantly improving traceability (updating requirements as changes occur) compared to traditional document-based methods (Boggero et al., 2021; Huss et al., 2023). For Agile teams, embracing these methods allows for a more adaptable documentation process that aligns with rapid development cycles while maintaining compliance with traceability requirements.

Organizational Culture Barriers

The fictional case study did not demonstrate unique considerations regarding overcoming organizational and cultural barriers. This contrast between industry mindsets creates inherent challenges when introducing agile methodologies. Safety-critical industries prioritize risk minimization and predictability, often adopting a “fail-safe” rather than “fail-fast” mentality. In contrast, Agile methodologies emphasize cross-functional, self-organizing teams. However, traditional structures in safety-critical sectors typically separate engineering, safety, regulatory compliance, and testing into separate silos. Furthermore, the heterogeneous teams familiar with cyber-physical systems tend to increase resistance to change. Heterogeneity, defined in this context as the diversity of team backgrounds and perspectives, significantly impacts communication, collaboration, and overall teamwork dynamics, as noted by Grotto and Andreassi (2022). These implications highlight the challenges of integrating agile practices into environments where rigid, siloed structures have historically prevailed. Socio-technical systems (STS) theory may effectively resolve the difficulties of incorporating agile methodologies into safety-critical industries. STS theory emphasizes the interplay between social and technical factors in organizational systems, recognizing that both aspects must be considered for optimal performance. Therefore, by utilizing STS theory, safety-critical industries can better integrate agile methodologies.”

Conclusion

This study demonstrates that Agile can significantly reduce satellite development time while maintaining predictable scheduling and adherence to regulatory requirements. However, its application in safety-critical space systems requires specific adaptations, including incremental safety audits, continuous compliance tracking, and advanced risk modeling. While Agile’s benefits are evident, its limitations in full-system integration and long-term mission assurance highlight the potential value of a hybrid development model. Future research should investigate Agile’s impact on mission reliability, cost, and scalability in real-world space system deployments.

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PANEL 17. BALANCING QUALITY AND QUANTITY: INNOVATIONS AND SPEED IN DEFENSE ACQUISITION

Thursday, May 8, 2025	
0825 – 0940 PT 1025 – 1140 CT 1125 – 1240 ET	**Chair: Brigadier General Tamara Campbell, USMC, Commander, Marine Corps Systems Command** ***Mixed Risk Course of Action*** Harrison Schramm, Senior Lecturer, Naval Postgraduate School ***Utilization of Middle Tier for Acquisition: Speeding Operational Capabilities to the War Fighter*** Phil Antón, Chief Scientist, Acquisition Innovation Research Center ***Innovation in Acquisition: Case Study of Marine Corps Manpower Information Technology Systems Modernization (MITSM) Portfolio*** Noelle Shott, Program Executive Office for Manpower, Logistics, and Business Solutions (PEO MLB)

Brigadier General Tamara Campbell, USMC—is a native of Boston, MA. She graduated from the United States Naval Academy in May 1997 with a Bachelor of Science degree in Oceanography.

She attended The Basic School, Quantico, VA in June 1997 and upon completion proceeded to Marine Corps Communications and Electronics School, 29 Palms, CA for MOS training as an Air Defense Control Officer. Upon completion, 2ndLt Campbell was assigned to MACS-1, Camp Pendleton, CA earning her qualifications as an Air Intercept Controller. In 2001, Captain Campbell was selected to attend Naval Postgraduate School (NPS) where she earned a dual Master of Science degree in Program Management and Financial Management.

Upon graduation from NPS, Captain Campbell was assigned to Marine Corps Systems Command. From April 2003 to July 2006, she served in several key billets before being assigned as an Integrated Air and Missile Defense Capabilities Officer within the Combat Development Directorate, Marine Corps Combat Development Command in 2006. In September 2007, she was assigned as the Command and Control Plans Officer within the G-3, Force Fires Section at III MEF, Okinawa, Japan. She was then selected for lateral re-designation as an Acquisition Professional and in 2009 transferred to MTACS-18 to serve as the S-6, Maintenance Officer and Senior Air Coordinator within the Tactical Air Command Center.

From August 2010 to July 2013, she served as the Deputy Program Manager for Air Traffic Control (ATC) Systems at PMA213, NAVAIR. In July 2013, she returned to Marine Corps Systems Command and served within PM-MAGTF Command, Control and Communications as the Product Manager for Integration, Interoperability and Situational Awareness, a Command Equivalent tour. LtCol Campbell was then selected for Top Level School and attended The Eisenhower School at National Defense University. In 2017, she earned a M.S. in National Security and Resource Strategy with a concentration in Strategic Acquisition.

From July 2017 to July 2018, she served as the Chief of Staff for the Deputy Assistant Secretary of the Navy, for Expeditionary Programs and Logistics Management. She returned to NAVAIR in July 2018 and served as the Strategic IPT Lead for PMA-272, Advanced Tactical Aircraft Protection Systems.

On 19 Aug 2020, Colonel Campbell assumed command as Program Manager of PMA-272. On 3 June she was promoted to Brigadier General.

Mixed Risk Course of Action

Harrison Schramm—is a Senior Lecturer for the Department of Defense Management at the Naval Postgraduate School in Monterey, CA. [Harrison.schramm@nps.edu]

Abstract

Commanders are looking for courses of action. However, translating this desire to an actionable system requires nuanced approach to both mathematics and government-industry relations. This talk will be in three parts; first describing the specific problem that INDOPACOM needs to address as an executive (read: unclassified, non-nerdy) level. The second part will be about how NPS and our Industry Partners leveraged A collaborative research and development agreement (CRADA) in order to bring the capabilities of both the university (i.e. NPS) and industry to bear to create a solution, as well as likely transition pathways into acquisition. The third part will focus on the technical aspects of the solution, and will be around a patent-pending innovation generated by faculty at NPS.

Introduction

Finding the "shortest distance" between two points is a common problem both in military and historical applications. "Shortest Distance" typically is taken to mean linear distance (i.e., lines you draw on a map) or functions that are linear and additive, such as cost and time. This is of course not the only operationally relevant way to measure distance. Another approach has been to measure distance via risk, which is multiplicative, not additive. Our novel contribution is to combine these two methods, with the unexpected outcome of creating a system for developing a small number of logistically- and risk- balanced courses of action from a very large universe of possibilities.

This work was supported by US INDOPACOM.

Generally, optimization problems are typically solved by creating graphs where vertices represent elements from a set of numbers, and edges connect pairs of elements that sum to a desired value, usually by analyzing additive structures within a set. In mathematics, "graph theory used in additive math" refers to the application of graph theoretic concepts and techniques to solve problems in additive number theory, particularly within the field of "additive combinatorics," where the focus is on studying the structure of sets of integers under addition, often leveraging the visual representation and analysis capabilities of graphs to identify patterns and prove theorems about sums of integers. The most commonly used technique for finding the shortest path is the principle behind Dijkstra's algorithm:

$$\mathrm{D} = \min\left(\mathrm{d}(\mathrm{v}), \left(d[\mathrm{u}] + \mathrm{w}(\mathrm{v}, \mathrm{u})\right)\right),$$

where $\mathrm{d}([\mathrm{v}]$ is the current calculated shortest distance from a source node to node "v", and $\left(d[\mathrm{u}] + \mathrm{w}(\mathrm{v}, \mathrm{u})\right)$ calculates the potential new shortest distance $\mathrm{d}(\mathrm{v})$ which allows one to find the shortest path between one vertex and all other vertices in a weighted graph, provided the edge weights are non-negative; essentially, it states that at each step, one should select the unvisited vertex with the smallest distance from the starting point to build the shortest path. Edge weights are typically assigned a numerical value, a weight, to represent a metric such as distance, cost, or time between the connected vertices. Edges are lines or connections linking two "vertices," representing the relationship between different points within the graph structure, which define how different nodes are connected within the network.

Typically, an optimized solution is an additive combinatory solution utilizing weighted edges. Weighted edges are an additive combinatory means, where the total weight of a path or subgraph is calculated by adding up the weights of all the individual edges included in that path or subgraph; meaning, the weights are combined through addition, and therefore "additive."

Risk is typically a unitless parameter representing a probability or likelihood of an event occurring and a potential consequence. Solutions to probabilities of events occurring simultaneously require multiplication to find the combined probability; essentially, multiplying the individual probabilities of each event to get the probability of all events occurring in sequence. Weighted edges found using multiplicative methods may not be trivially nor linearly combined with weighted edges found with additive combinatorial methods. Therefore, a system and method are needed to determine the shortest path using a mix of risk and linear costs.

The problem of determining the shortest path while maintaining acceptable survivability risk using unitless and multiplicative parameters in weighted graphs is solved by incorporating a convex and risk distance parameter to provide the shortest path based on acceptable risk.

Figure 1 is a block diagram of our automated mixed course of action (COA) generation system. As shown in Figure 1, an automated mixed COA system may include one or more risk data input sources, map sources, a risk mix manager, a risk assessment engine, and a COA communications output. Risk data input sources may include but should not be limited to user sensors, feedback, social media, marketing analysis, user behavior data, government data, and databases. The risk mix manager may identify, assess, and provide options for reduced risks that could impact a COA. The risk assessment engine may identify and assess potential risks that could negatively impact the user. The primary purpose is to determine the probability and impact of the identified risks and provide strategies to minimize or avoid the risk. The risk assessment engine may estimate the potential impact of the risk, monitor and report on the risk, and types of risk analysis using qualitative risk and/or quantitative risk analysis.

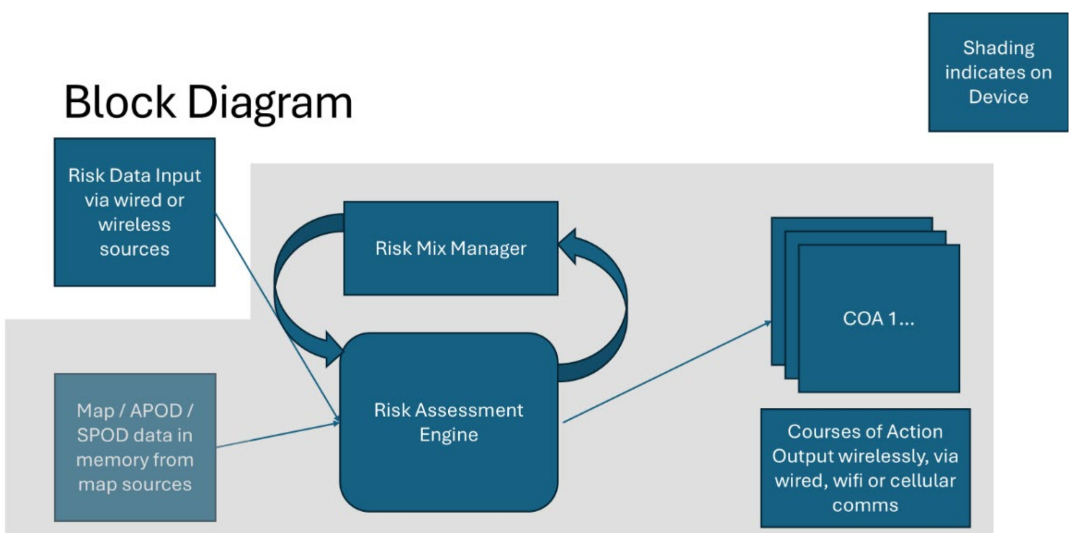

Figure 1: Block Diagram of Our Automated Mixed Course of Action (COA) Generation System

Figure 2 is a functional example showing a system generating a course of action based on mixed risk. This app, implemented in R/markdown is a demonstration of *risk-adjusted shortest paths*. We have a somewhat messy 6-node network. The two boxes on the right hand side of the "Demo" page show two measures on the same network; the top is the distance in *additive units*: you might think of this as being miles, but it could also be money or time. The lower plot is risk, measured in probability of survival, that is, 1 is certain survival, and 0 is certain death. The *risk-scored distance* is shown in the left plot.

This is determined by computing

$$\lambda LD + (1 - \lambda)\kappa(-ln(RD)),$$

where LD is the linear distance, RD is the Risk Distance, and λ is a convexity parameter,

$0 \leq \lambda \leq 1$. The **shortest path** is computed and displayed (somewhat primitively) at the bottom of the input box.

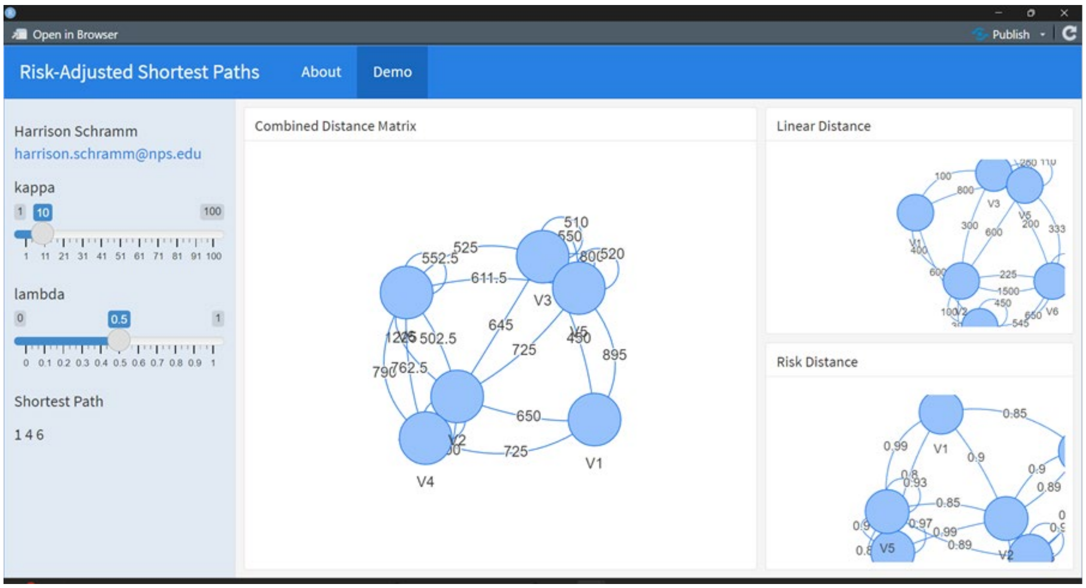

Figure 2: Risk-Adjusted Shortest Paths

A note about *κ*

Probabilities are unitless as are their functions. In order to add "risk" to "distance," we need to introduce a parameter, κ that provides units. In addition to making the math work, it also has an important operational interpretation, in the "how many miles would you go out of your way to reduce risk?" In this example, we have benchmarked 10 miles per 1% of risk; so a route that has a 90% probability of survival inherits a 100 mile penalty.

Quantifying this risk in a way that is palatable to decision-makers is a key task for adoption. Our sense is that once κ is set, it will remain so for the duration of the exercise/scenario.

A note about *λ*

This parameter creates a *convex combination* of risk and distance; you might think of this as the proportion of froth and coffee in a latte, that is, a frothy latte would have a high value of λ. The key idea for this parameter—and the entire analytic approach for that matter—is to vary λ to create different solutions to the shortest path routing problem based on the relative importance of time and risk. In the current formulation, low values of λ emphasize speed while high values of λ emphasize low risk. Each solution provided by this approach is analytically defensible. Each solution produced by varying λ is a unique Course of Action, or COA. Trivially, it is possible that a network will have only one COA for all values of λ. It is unclear the upper limit of COAs that could be produced as a function of network complexity. That's a math problem, not an operational problem.

Figure 3 shows minimal hardware implementation, consisting of a Raspberry Pi 5 computer, SixFab Cellular Modem, and Coral TPU. A $20 bill is included for size comparison.

Figure 3: Minimal Hardware Implementation

Beyond creating this algorithm, we have placed a functional version on a minimal hardware stack, consisting of a Raspberry Pi 5 with a quad core, 2.4 GHz processor, coupled with a SixFab cellular modem for on/off board communication and a Google Coral TPU for enhanced AI inference (note, the TPU is not necessary for the solution of the basic problem). This hardware implementation demonstrates the computational efficiency of the method, and the ability to be run on a hardware "stack" with a total price of less than $500. Such a system is readily and easily deployable at the tactical edge.

Future research: Future work on this project will involve implementation on a smaller technical stack, specifically the Raspberry Pi Zero 2W, and replacing the cellular modem with a LoRA radio.

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Utilization of Middle Tier for Acquisition: Speeding Operational Capabilities to the War Fighter

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Abstract

The Department of Defense's (DoD's) Middle Tier of Acquisition (MTA) authority was established by Congress to streamline rapid prototyping and rapid fielding of operational capabilities. The House Armed Services Committee (H.R. 118-125) asked how much MTA programs have produced operational capabilities versus conducting research and development (R&D) for prototypes. This paper provides the results of our research using the DoD's Defense Acquisition Visibility Environment (DAVE), Federal Procurement Data System (FPDS) and the Defense Logistics Agency (DLA) Business Directory for company Commercial and Government Entity (CAGE) codes or the company name in online database searches to provide answers to their questions.

Introduction

This paper summarizes analysis performed for the Under Secretary of Defense for Acquisition and Sustainment (USD[A&S]) to inform a report to the U.S. House Committee on Armed Services that measures and quantifies the use of Middle Tier Acquisition (MTA) authorities across the Department of Defense (DoD). The analysis was requested in House Report 118-125 (pp. 254–255), accompanying H.R. 2670—the House version of the National Defense Authorization Act (NDAA) for Fiscal Year 2024. The directive requested information on the production value of MTAs to "inform Congress on what is being fielded at a speed of relevance through both authorities at the Department." Congress noted that its most critical interests are

- *The production [basis] demonstrating what is actually being purchased; and*
- *The technology-focused enterprises to ensure the data [are not] skewed by contracts that are used for food or landscaping, for example.*

For MTAs, Congress specified that the DoD's report include

> *(1) data on the production … MTA contracts across the Department by service and by product-type;*
>
> *(2) what products and services the Department is procuring using … MTAs. We will also show which of those MTAs are using OTAs [Other Transaction Authorities];*
>
> *(3) composition of the entities the Department is [contracting] with using…MTAs, including size (revenue and employees), type (filing status), geography, and industry;*
>
> *(4) data on the trends in defense MTA obligations by service and buyer for the past 5 years;*
>
> *(5) data on the competition for production … MTA contracts for each fiscal year beginning with fiscal year 2018; and*
>
> *(6) data on trends in … MTA production contracts transitions to programs of record.*

Background on MTAs

Congress created the MTA authority in the fiscal year (FY) 2016 NDAA, Section 804. This statute directed the USD(A&S)—in consultation with the Comptroller of the DoD and the Vice Chairman of the Joint Chiefs of Staff—to provide guidance for a "middle tier" of acquisition programs to be completed in 2–5 years, including authority for rapid prototyping and rapid fielding. Rapid prototyping is for "use of innovative technologies to rapidly develop fieldable prototypes to demonstrate new capabilities and meet emerging military needs." Rapid fielding provides for "the use of proven technologies to field production quantities of new or upgraded systems with minimal development required." (See the 2016 NDAA, Public Law 114–92—Nov. 25, 2015, Section 804, codified in the Statutory Notes and Related Subsidiaries provided under Chapter 221 Front Matter of Title 10, U.S. Code, Release Point 118-41, as amended.)

Data Sources and Analytical Approach

Three primary data sources were used to answer Congress' questions:

(1) **MTA budget data** from records within the DoD's Defense Acquisition Visibility Environment (DAVE). The data were extracted on March 29, 2024, providing past actual appropriations and proposed FY 2024 appropriations from the President's Budget (PB) request to Congress. Note that FY 2024 data were requested instead of actual appropriations. Most of the FY 2018–2023 budget data reflects prior actuals reported in future PB requests. These are in then-year (TY; unadjusted for inflation) dollars for each FY. These data informed

   a. RDT&E; Procurement; O&M, MILPERS, and MILCON

   b. MTA budgets by military service or component

   c. Transitions to Programs of Record

(2) **MTA contract data** from the Federal Procurement Data System (FPDS; fpds.gov) using contract numbers from DAVE for MTAs. The FPDS contract data are very comprehensive, and the MTA data from DAVE indicated which contracts are for MTA programs, allowing Defense Pricing, Contracting and Acquisition Policy (DPCAP) to pull those contract data from FPDS. Combined, these data inform

   a. Products and services procured (through Product and Services Codes or PSCs)

b. Contractors (e.g., state, industry, type [filing status])

c. Competition nature of each contract

(3) **Company data** from the Defense Logistics Agency (DLA) Business Directory. Company data was obtained using either the Commercial and Government Entity (CAGE) codes or the company name for the company data required for the report. Several sources we searched to try and find information about a company's number of employees, revenue, and type were used based on availability of the data in each source. The North American Industry Classification System (NAICS) was used from the contract or these online sources if not available in the DAVE data. The information search was completed between June and July of 2024.

a. SAM.gov was used for company type/filing status (private, subsidiary, etc.) and profit structure if the company could be found in that database.

b. Mergent Online™ which provides information on international and domestic companies including Dun & Bradstreet's private company database was used to find the number of employees and revenue and provided a company's type/filing status (private, subsidiary, etc.) and profit structure if the company was not found in SAM.gov.

c. ZoomInfo was used in cases where these other two databases did not have any information.

d. General use of Google searches was our last resort to find information missing in these three databases.

As rapid prototyping generally focuses on the Research, Development, Test and Evaluation (RDT&E) of prototypes with little to no leave-behind operational capabilities, our analysis took the simplifying assumption that rapid prototyping MTA programs are RDT&E with no production and fielding of operational capabilities. In contrast, rapid fielding MTA programs focus on production and delivery of capabilities, so this analysis assumes that rapid fielding MTA programs as a whole are (either by count or by dollar value) production even though there may be elements of RDT&E in those programs.

When using budget data, this analysis treated dollars in the RDT&E appropriation category as not producing and fielding capabilities. In contrast, this analysis treats Procurement dollars as all contributing to production and fielding of capabilities. In some cases, when rapid fielding MTA program budgets also included Operations and Maintenance (O&M), Military Personnel (MILPERS), and Military Construction (MILCON) appropriations, the analysis also included these as production and fielding.

Results

MTA Counts by Type: Prototyping or Fielding

From FY 2018–2024, the DoD had 228 MTA programs across six components (see Table 1).

Each MTA is designated as either a rapid prototyping or a rapid fielding effort (but not both). The breakdown of those MTA between rapid prototyping and rapid fielding is provided in Table 2. Overall, 39% (almost 2 out of 5) of DoD MTAs from FY 2018 onward are for rapid fielding (i.e., our measure for count of production MTA programs) rather than prototyping (i.e., RDT&E by program counts). Sixty percent of rapid fielding MTAs are in U.S. Special Operations Command (USSOCOM), with another 26% in the Department of the Air Force.

In terms of contract counts, these MTAs issued an increasing number of contracts from FY 2018 to 2021, after which the number of contracts per FY began to decrease (see Table 1).

Table 1. Number of DoD MTA Programs and Contracts (FY 2018–2024)
(DoD DAVE: MTA programs and contracts in PB 2018–2024)

		# of MTA Contracts by FY						
Component	**# of MTA Programs**	**FY 2018**	**FY 2019**	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**
Air Force	65	26	43	60	60	60	39	20
Army	39	6	16	29	36	50	50	44
Navy	35	3	25	32	45	45	50	39
DCSA	1	0	2	2	2	0	0	0
Space Force	15	4	4	6	7	13	14	14
USSOCOM	73	8	19	20	29	93	75	67
TOTALS	***228***	***47***	***109***	***149***	***179***	***261***	***228***	***184***

Table 2. Number of MTA Programs by Rapid Prototyping or Rapid Fielding (FY 2018–2024)
(DoD DAVE: MTA programs in PB 2018–2024)

Component	**Rapid Prototyping**	**Rapid Fielding**	**Rapid Prototyping**	**Rapid Fielding**
Air Force	42	23	65%	35 %
Army	31	8	79%	21 %
Navy	30	5	86%	14 %
DCSA	1	0	100%	0%
Space Force	15	0	100%	0%
USSOCOM	20	53	27%	73 %
TOTALS	***139***	***89***	***61%***	***39 %***

MTAs That Utilize Other Transactions (OTs)

The overall percentage of MTA programs using OTs or some other contracting approach (non-OTA) contracts from DAVE is provided as a chart in Figure 1. The breakdown by percentage of MTA programs by component that are identified as OT agreements and non-OTA contracts from DAVE is listed in Table 3. Almost half (by count) of MTAs utilize OTs for contracting.

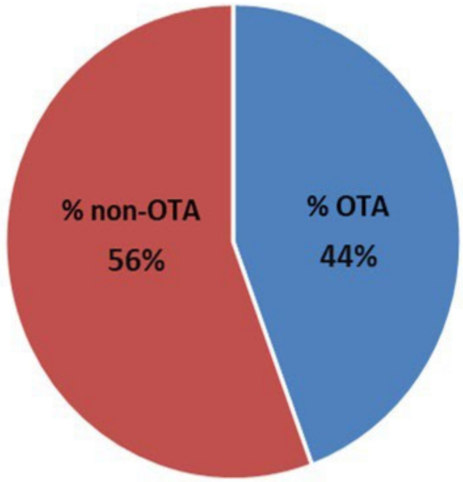

Figure 1. Percentage of DoD MTA Programs Using OTA Agreements
(MTA Activities for PB 2018–2024 [extracted from DoD DAVE]. Based on MTA data where contract type is specified.)

Table 3. MTA Use of OTs or Non-OTA Contracting by Component
(MTA Activities for PB 2018–2024 [extracted from DoD DAVE])

Component	OTs	Non-OTA	% OTs	% Non-OTA
Air Force	11	59	16%	84%
Army	40	17	70%	30%
Navy	15	15	50%	50%
DCSA	1	0	100%	0%
Space Force	12	8	60%	40%
USSOCOM	*n/a*	*n/a*	*n/a*	*n/a*
TOTALS	***79***	***99***	***44%***	***56%***

Note: Total OTs versus non-OTA contracts where the contract type is specified in DAVE. USSOCOM data were not yet available at the time of the data extraction from DAVE for this analysis.

Service and Product Type of MTAs

Product and Service Codes (PSCs)[1] were used to answer Congress' first question on "MTA contracts across the Department by service and by product-type."

MTA service and product-type information was extracted from DAVE and FPDS, then correlated according to the contract number, CAGE code and program identifier. Table 4 provides the breakdown of product service codes by OT agreements where service codes were found. Table 5 provides the breakdown of product service codes by non-OTA contracts where service codes were found.

OTA contracting actions by then-year (TY) dollars (Table 4) are dominated by R&D for Defense (categories AC or AD; over 61%) and a mix of military systems and components (33%).

[1] Product and Service Code Manual | Acquisition.GOV

Non-OTA contracting actions by TY dollars (Table 5) are dominated by production of fixed-wing aircraft, engines, and components (40% by spend), plus another 11% for other military products. Just under 40% were for defense R&D services and the balance in other R&D and services.

MTA Contractor Demographics

Geography. Table 4 shows the number of MTA contracts by state or country of the contractor (entities). In a simple count of contract award numbers, California, Virginia, and Maryland had the higher number of contracts. Note, however, that these are numbers of contracts, not dollars, so they do not necessarily reflect the total size of the MTA activities per state. This demographic analysis used MTA CAGE Code information from the DoD's DAVE system together with a search of DLA's CAGE Search capability when the code was included with the contract information and was found by DLA's website search (see the Appendix of Buettner et al. [2024] for the full list of DLA results). When the CAGE code did not identify a company, and DAVE included a company name for the supplier, DLA was also searched by the company name. In at least one case, this identified an error in the DAVE database that was corrected in Buettner et al. (2024), Table 12.

Table 4. Number of MTA Contracts or Funding by U.S. State or Country

(President's Budget Request from DoD's DAVE data system for FY2024 correlated with FPDS contract information and DLA CAGE Code search)

State	# Contracts	State	# Contracts	State or Country	# Contracts
AL	4	KS	1	OH	5
AR	1	LA	3	OK	2
AZ	2	MA	9	PA	4
CA	27	MD	14	SC	2
CO	7	MI	5	TX	6
DC	1	MN	1	UT	3
FL	9	MO	3	VA	21
GA	5	MS	1	WA	3
HI	1	NH	5	WI	1
IA	1	NJ	4	France	1
IL	2	NV	2	Norway	1
IN	4	NY	4		

Note: This analysis only includes entities (corporate division or government) for which we have CAGE codes from DAVE. These are contract numbers, not dollars, so they do not reflect the size of the MTA actions per state. The appendix information only lists the companies and their CAGE identified business location.

Numbers of Employees. Figure 2 uses data on the number of corporate employees for the 158 different business entities with MTA contracts. Our analysis used corporate numbers of employees as site specific employee numbers were not always available or there were conflicting results from the online databases searched.

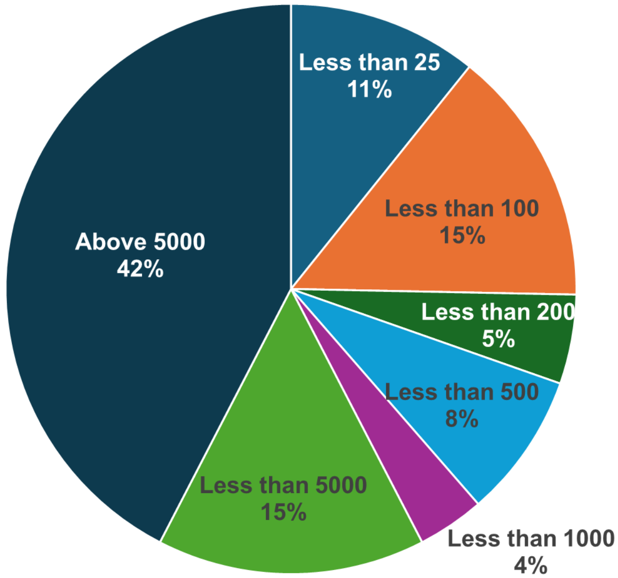

Figure 2. Number of Employees at MTA Contracted Companies (FY 2018–2024)
(Merchant Online™ and ZoomInfo searches of the entity names)

Note: This analysis only includes entities (corporate division or government) for which we have CAGE codes from DAVE. If a company has multiple divisions identified by a unique CAGE code (two examples are Boeing and Lockheed Martin), each division of the parent company is counted separately but uses the parent company's values. MTA contracts given to the Combat Capabilities Development Command (CCDC) Armaments Center and the Department of the Army U.S. Army Electronics Command Night Vision Laboratory are not included in this analysis.

Revenue. Figure 3 uses corporate revenue data available in online databases for the 158 different business entities with MTA contracts. Our analysis used corporate revenue data as site specific data were not always available or there were conflicting results from the online databases searched.

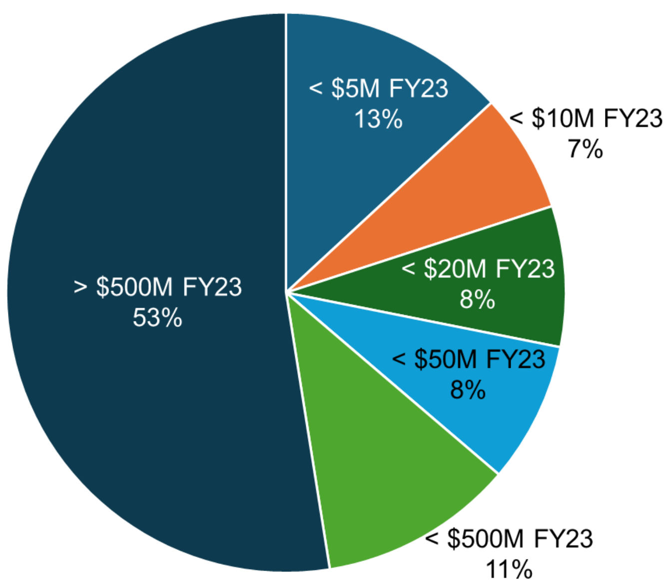

Figure 3. FY23 Revenue of MTA Contracted Companies (FY 2018–2024)
(Merchant Online™ and ZoomInfo searches of the entity names)

Note: This analysis only includes entities (corporate division or government) for which we have CAGE codes from DAVE. If a company has multiple divisions identified by a unique CAGE code (two examples are Boeing and Lockheed Martin), each division of the parent company is counted separately but uses the parent company's revenue values. MTA contracts given to the Combat Capabilities Development Command (CCDC) Armaments Center and the Department of the Army U.S. Army Electronics Command Night Vision Laboratory are not included in this analysis.

Filing Status. Figure 4 uses corporate revenue data available in online databases for the 160 different entities with MTA contracts. Our analysis used corporate revenue data as site specific data were not always available or there were conflicting results from the online databases searched.

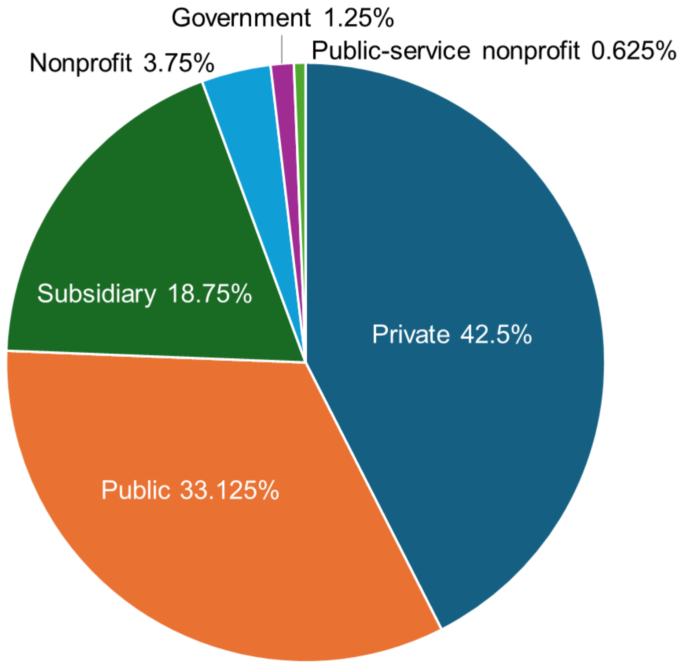

Figure 4. Filing Status of MTA Contracted Companies (FY 2018–2024)
(SAM.gov, Merchant Online™ and ZoomInfo searches of the entity names)

Note: This analysis only includes entities (corporate division or government) for which we have CAGE codes from DAVE. If a company has multiple divisions identified by a unique CAGE code (two examples are Boeing and Lockheed Martin), each division of the parent company is counted separately but uses the parent company's revenue values.

Entity Specific Industry. Table 5, providing the NAICS codes and their descriptions, was derived (for the most part) from DAVE; however, when the NAICS was not available, the Merchant Online™ and ZoomInfo databases or Google searches were used to identify the parent company and their service offerings. The NAICS codes were then categorized as *Manufacturing*, *Technical Services*, *Purchasing* (for example, wholesale distribution of a product), *Research and Development* and *Other* (which represents the National Security NAICS code). The categories are provided below the table in Figure 5.

Table 5. Industry Types from NAICS Code

(NAICS codes derived [for the most part] from DAVE; when the NAICS was not available, basic database or Google searches were used to identify the parent company and their service offerings.)

(NAICS) Description	#	%
(541330) Engineering Services	16	10.00%
(334511) Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing	11	6.88%
(334220) Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing	10	6.25%
(336413) Other Aircraft Parts and Auxiliary Equipment Manufacturing	10	6.25%
(336411) Aircraft Manufacturing	8	5.00%
(541511) Custom Computer Programming Services	8	5.00%
(541712) Research and Development in the Physical, Engineering, and Life Sciences (except Biotechnology)	7	4.38%
(541715) Research and Development in the Physical, Engineering, and Life Sciences (except Nanotechnology and Biotechnology)	7	4.38%
(541611) Administrative Management and General Management Consulting Services	5	3.13%
(541990) All Other Professional, Scientific, and Technical Services	5	3.13%
(334111) Electronic Computer Manufacturing	4	2.50%
(336414) Guided Missile and Space Vehicle Manufacturing	4	2.50%
(541512) Computer Systems Design Services	4	2.50%
(811219) Other Electronic and Precision Equipment Repair and Maintenance	4	2.50%
(332994) Small Arms Manufacturing	3	1.88%
(336992) Military Armored Vehicle, Tank, and Tank Component Manufacturing	3	1.88%
(518210) Computing Infrastructure Providers, Data Processing, Web Hosting, and Related Services	3	1.88%
(541710) Research and Development in the Physical, Engineering, and Life Sciences	3	1.88%
(GOVT) Defense and Research	2	1.25%
(332311) Prefabricated Metal Building and Component Manufacturing	2	1.25%
(334290) Other Communications Equipment Manufacturing	2	1.25%
(334413) Semiconductor and Related Device Manufacturing	2	1.25%
(334519) Other Measuring and Controlling Device Manufacturing	2	1.25%
(336611) Ship Building and Repairing	2	1.25%
(511210) Software Publishers	2	1.25%
(611420) Computer Training	2	1.25%
(315228) Men's and Boys' Cut and Sew Other Outerwear Manufacturing	1	0.63%
(315990) Apparel Accessories and Other Apparel Manufacturing	1	0.63%
(332992) Small Arms Ammunition Manufacturing	1	0.63%
(333120) Construction Machinery Manufacturing	1	0.63%
(334210) Telephone Apparatus Manufacturing	1	0.63%
(334412) Bare Printed Circuit Board Manufacturing	1	0.63%

(NAICS) Description	#	%
(334515) Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals	1	0.63%
(334516) Analytical Laboratory Instrument Manufacturing	1	0.63%
(335999) All Other Miscellaneous Electrical Equipment and Component Manufacturing	1	0.63%
(336211) Motor Vehicle Body Manufacturing	1	0.63%
(336412) Aircraft Engine and Engine Parts Manufacturing	1	0.63%
(336992) Defense and Vehicle Manufacturing	1	0.63%
(423450) Medical, Dental, and Hospital Equipment and Supplies Merchant Wholesalers	1	0.63%
(423720) Plumbing and Heating Equipment and Supplies (Hydronics) Merchant Wholesalers	1	0.63%
(423910) Sporting and Recreational Goods and Supplies Merchant Wholesalers	1	0.63%
(423990) Other Miscellaneous Durable Goods Merchant Wholesalers	1	0.63%
(441227) Motorcycle, ATV, and All Other Motor Vehicle Dealers	1	0.63%
(443120) Computer and Software Stores	1	0.63%
(483111) Deep Sea Freight Transportation	1	0.63%
(517110) Wired Telecommunications Carriers	1	0.63%
(531330) Military and Aerospace Equipment and Military Weapons (MAE&MW)	1	0.63%
(541519) Other Computer Related Services	1	0.63%
(541620) Environmental Consulting Services	1	0.63%
(541720) Research and Development in the Social Sciences and Humanities	1	0.63%
(561611) Investigation Services	1	0.63%
(561920) Convention and Trade Show Organizers	1	0.63%
(611512) Flight Training	1	0.63%
(611699) All Other Miscellaneous Schools and Instruction	1	0.63%
(928110) National Security	1	0.63%

Note: This analysis only includes entities (corporate division or government) for which we have CAGE codes from DAVE. If a company has multiple divisions identified by a unique CAGE code (two such examples are Boeing and Lockheed Martin), each division of the parent company is counted separately but uses the division’s NAICS for the contract if available from DAVE.

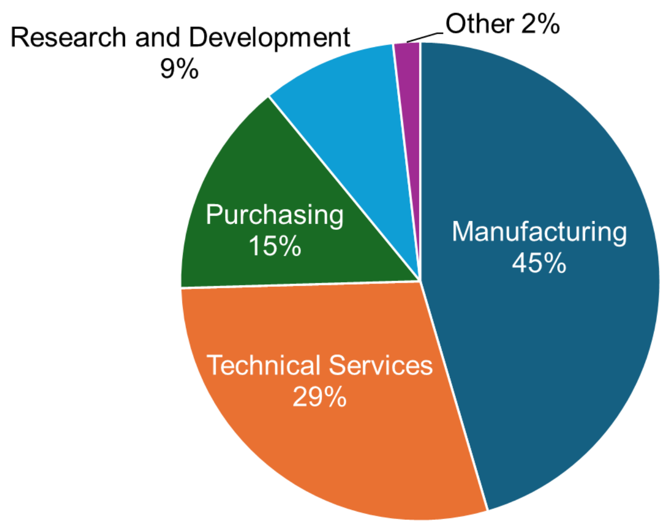

Figure 5. Industry Types of MTA Contracted Companies (FY 2018–2024)

Trends in MTA Spending by Military Service and Component

Budget appropriations were used as a surrogate for contract obligations because it allowed the separation of those obligations not only by military service or component but also by appropriation category, allowing a quantified measure of the dollars and relative percentages of total spending on procurement and related operational categories (O&M and MILCON) compared to prototyping (RDT&E).

Table 6 provides the overall dollar distribution of MTA across appropriations categories using MTA PB data from DAVE. Figure 6 plots these data and shows the trends.

Over time, the fraction of Procurement appropriations rather than RDT&E (prototyping) has been increasing. When combined with O&M and MILCON, the percentages have been running in the high teens to the upper twenties. It is too early to tell if this trend is beginning to flatten or will continue to increase.

The trends by military service or component are provided in Figure 7–**Error! Reference source not found.**. The service trends are discussed after each graph.

Table 6. MTA President Budgets by Appropriation Categories (FY 2018–2024)
(President's Budget [PB] Request from DoD's DAVE data system)

Appropriations (TY $, M)	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Subtotal Acquisition	**$1,467**	**$3,991**	**$7,837**	**$10,077**	**$12,949**	**$15,380**	**$12,186**
Total RDT&E	$1,421	$3,275	$6,695	$7,281	$9,542	$12,611	$9,596
Total Procurement	$46	$716	$1,142	$2,796	$3,063	$2,769	$2,591
Total MILCON	-	-	-	-	$344	-	-
Subtotal O&S	**$100**	**$117**	**$127**	**$127**	**$568**	**$567**	**$497**
Total O&M	$100	$117	$127	$127	$334	$333	$263
Total MILPERS	-	-	-	-	$234	$234	$234
TOTAL	**$1,567**	**$4,108**	**$7,964**	**$10,204**	**$13,517**	**$15,947**	**$12,683**
% of Total for Procurement	**3%**	**17%**	**14%**	**27%**	**23%**	**17%**	**20%**
% of Total for Procurement, MILCON, and O&M	**9%**	**20%**	**16%**	**29%**	**28%**	**19%**	**23%**

Note: FY 2024 are requested dollars instead of actual appropriations. Most of the FY 2018–2023 are actuals reported in future PB requests. These are in TY dollars (unadjusted for inflation). OT agreements are actual obligations; there is an overlap in OTs and MTAs. We did not test for statistical significance of the trends in FY 2021–2024.

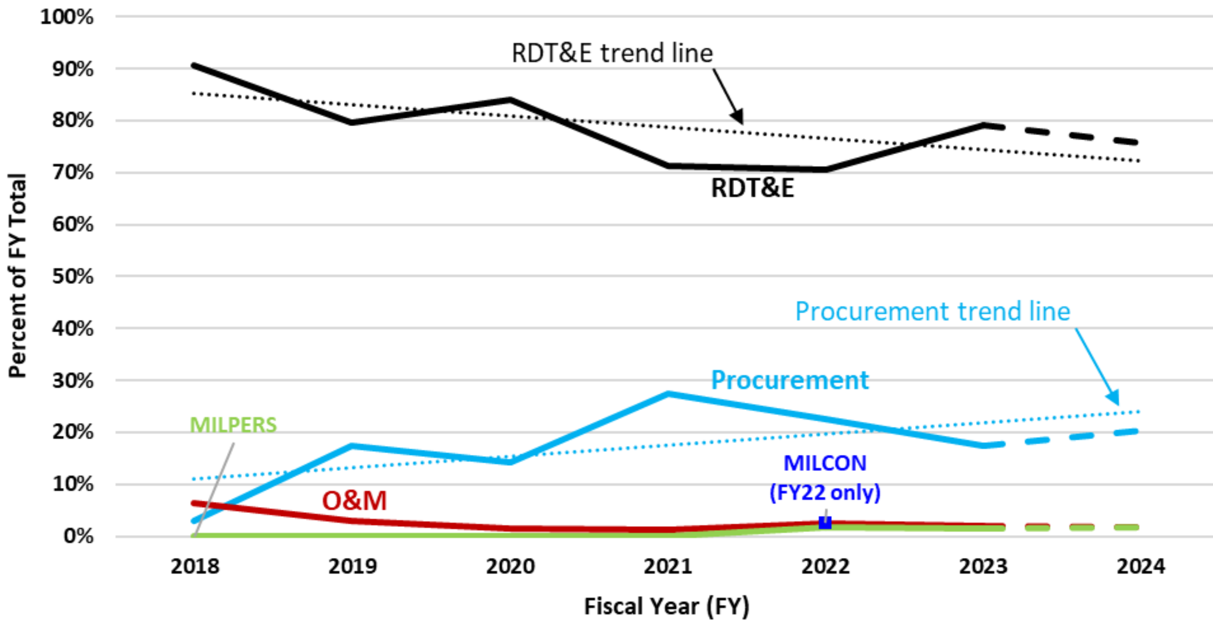

Figure 6. Appropriation Category Percentage of Total MTA Funding (FY 2018–2024)
(President's Budget [PB] Request from DoD's DAVE data system)

Note: FY 2024 values are requested (not actual) appropriations. Most FY 2018–2023 values are actuals as reported in subsequent PBs. The R^2 (amount of variation explained by the trend line) is 42% for RDT&E trend line and 37% for the Procurement trend line.

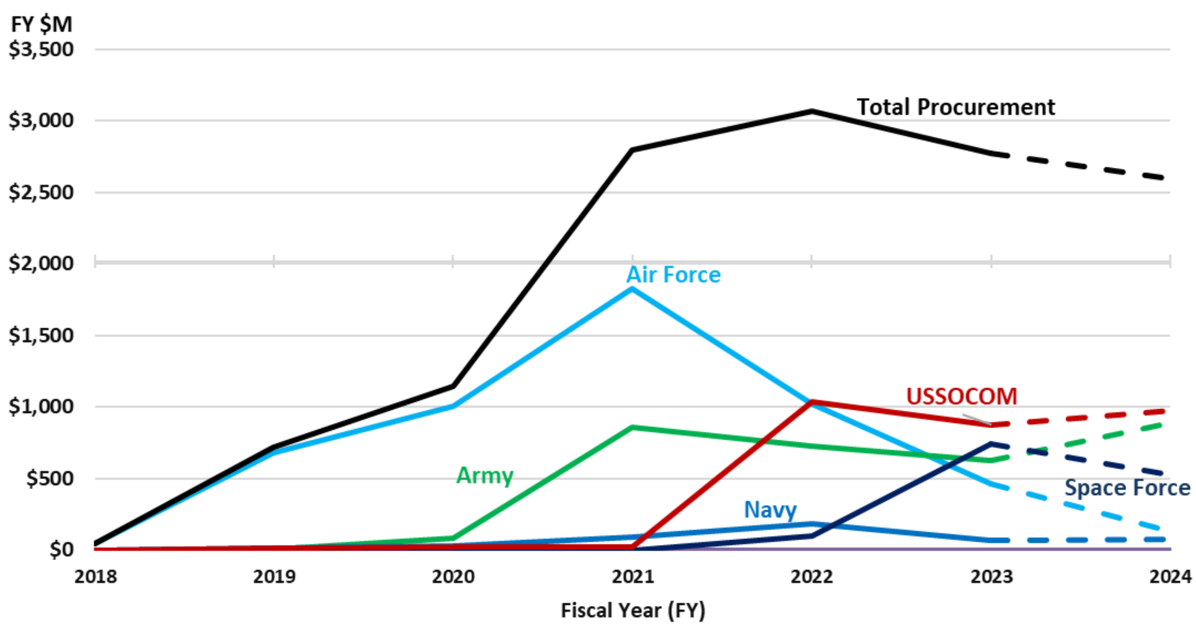

Figure 7. MTA Procurement Appropriations by Component (FY 2018–2024; TY $,M)
(President's Budget [PB] Request from DoD's DAVE data system)

NOTE: FY 2024 values are requested (not actual) appropriations. Most FY 2018–2023 values are actuals as reported in subsequent PBs.

Figure 7shows that the Air Force had the highest use of MTAs Procurement appropriations. It steadily increased from FY 2018 through FY 2021 but has decreased significantly since the FY 2021 peak. The Army increased in FY 2021 and has remained at about the same level since then. USSOCOM increased their use in FY 2022 and has remained at about that level since then. Relatively speaking, the Navy has a very modest use of MTA Procurement appropriations over the entire period with a peak in FY 2022.

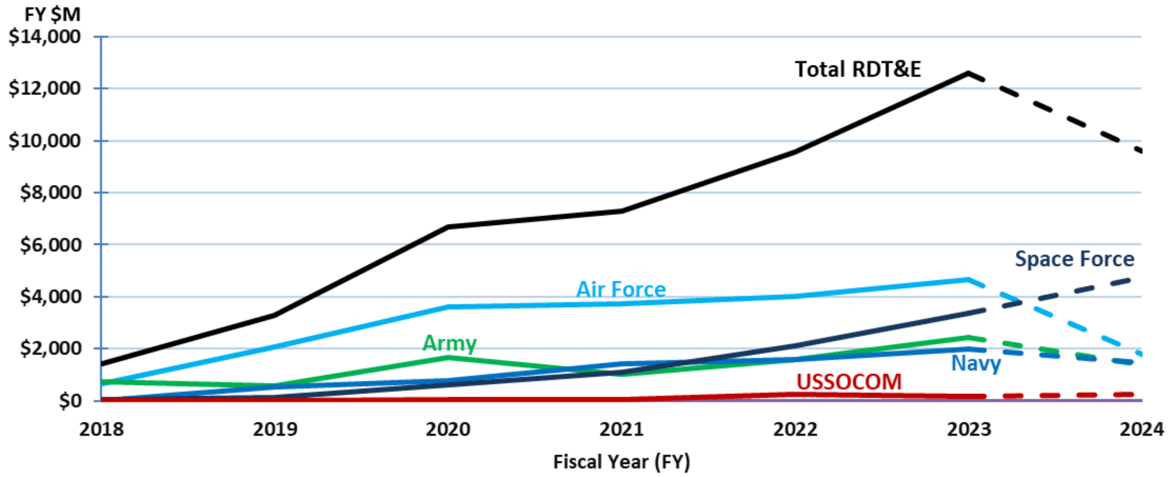

Figure 8. MTA RDT&E Appropriations by Component (FY 2018–2024; TY $,M)
(President's Budget [PB] Request from DoD's DAVE data system)

Note: FY 2024 values are requested (not actual) appropriations. Most FY 2018–2023 values are actuals as reported in subsequent PBs.

Figure 8 shows an initial increasing trend by all the services, with the Air Force having the most significant use of MTAs for RDT&E. However, in FY 2023, the Air Force spent less than the Space Force, which had a gradual increase over FY 2018–2024.

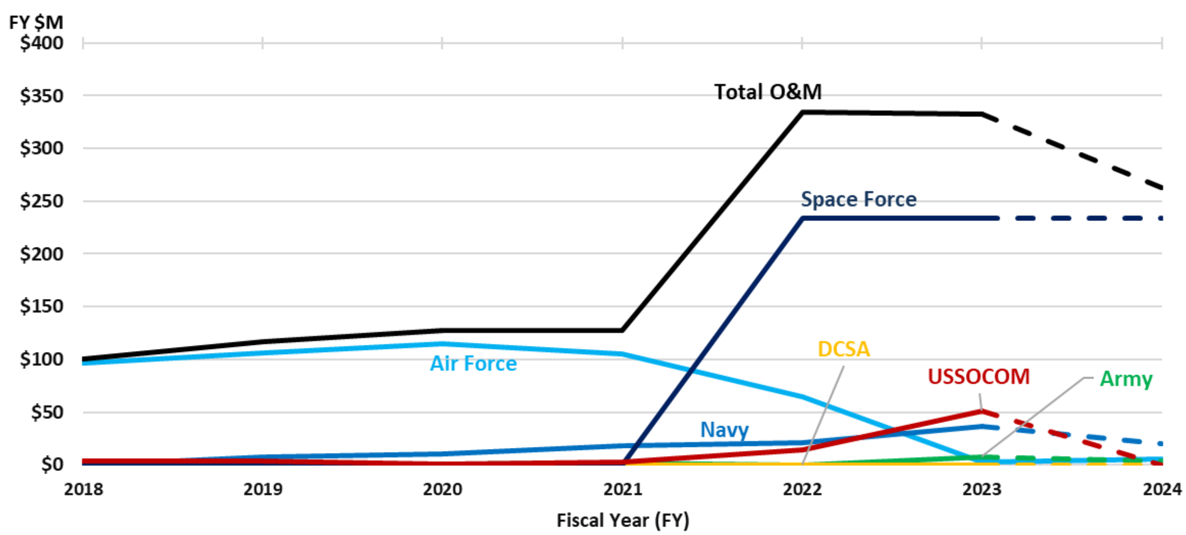

Figure 9. MTA O&M Appropriations by Component (FY 2018–2024; TY $,M)
(President's Budget [PB] Request from DoD's DAVE data system)

NOTE: FY 2024 values are requested (not actual) appropriations. Most FY 2018–2023 values are actuals as reported in subsequent PBs.

Figure 9 shows a steady use of MTAs for O&M by the Air Force, but starting in FY 2020, there has been a steady decreasing trend to a very low proposed level in FY 2024. The Space Force, on the other hand, has outpaced all the other services combined in the use of MTAs for O&M starting in FY 2022.

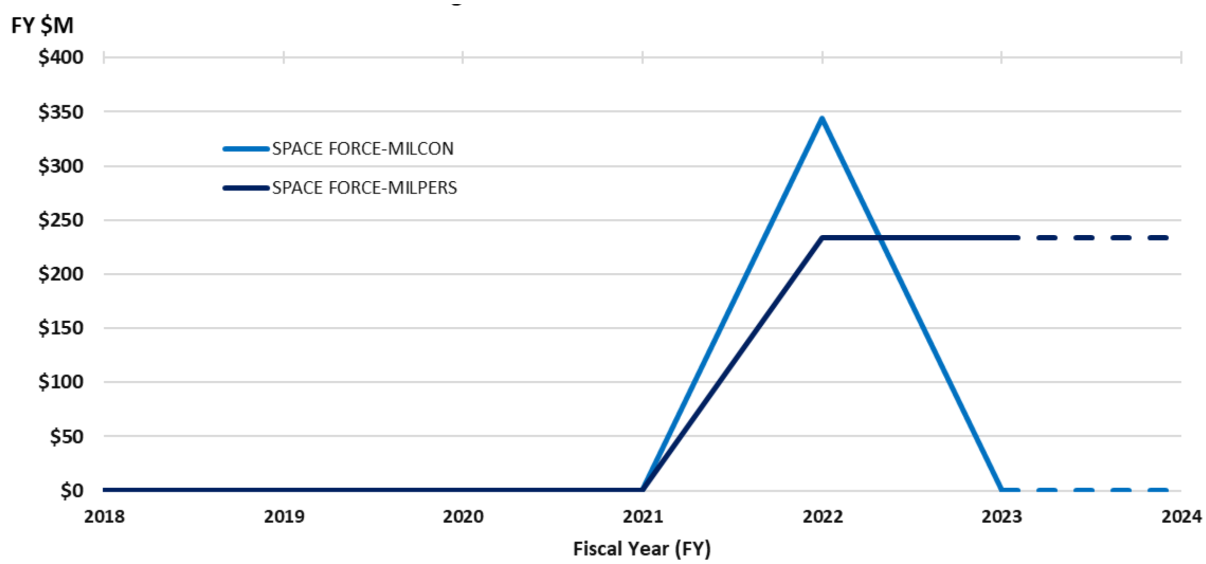

Figure 10. MTA MILCON & MILPERS Appropriations by Component (FY 2018–2024; TY $,M)
(President's Budget [PB] Request from DoD's DAVE data system)

Note: FY 2024 values are requested (not actual) appropriations. Most FY 2018–2023 values are actuals as reported in subsequent PBs.

Figure 10 shows the use of MTAs for MILCON and MILPERS by the Space Force, the only service doing so. The MILCON use was only for a single year, FY 2022. Also, starting in FY 2022, they have consistently been using MTA MILPERS appropriations at the same rate.

Transitions to Programs of Record

Figure 11shows the overall transition or restructured percentage of MTA Activities to programs of record. Table 7 provides the transition status by service. Overall, about three-fifths (59%) of MTAs from FY 2018–2024 remain active, while about a third (31%) have transitioned to programs of records or are about to be transitioned.

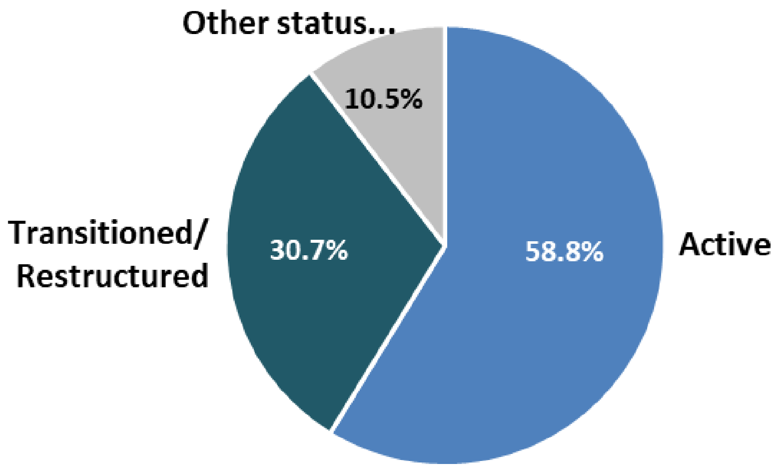

Figure 11. Transition Status of MTA Programs
(PB Request from DoD's DAVE data system)

Table 7. Transition Status of MTA Programs by Military Service or Component

Component	Active	Transitioned/ Restructured	Terminated	Residual Capability	Pre-Decisional	FOC/FD
Air Force	37%	45%	12%	2%	2%	3%
Army	79%	21%	0%	0%	0%	0%
Navy	71%	17%	6%	0%	3%	3%
DCSA	0%	100%	0%	0%	0%	0%
Space Force	67%	20%	0%	0%	13%	0%
USSOCOM	60%	32%	7%	1%	0%	0%
TOTALS	*58.8%*	*30.7%*	*6.6%*	*0.9%*	*1.8%*	*1.3%*

(President's Budget [PB] Request from DoD's DAVE data system)
Note: The TOTALS line displays the total for the column in fractions of a percent to ensure the chart in Figure 11 sums to 100%.

Discussion

The DoD's Middle Tier of Acquisition (MTA) authority was established by Congress to streamline rapid prototyping and rapid fielding of operational capabilities. The House Armed Services Committee (H.R. 118-125) asked how much MTA programs have produced operational capabilities versus conducting research and development (R&D) for prototypes. Across all MTA programs from FY 2018–2024, about two out of five (by count) are rapid fielding programs (i.e., producing and fielding products) rather than rapid prototyping (i.e., conducting R&D). The fraction of MTA appropriations going to procurement rather than R&D (prototyping) has been increasing. When combined with O&M and MILCON, the percentages have been running from 16%–29%. It is too early to tell if this trend is beginning to flatten or will continue to increase. About three-fifths (59%) of MTAs from FY 2018–2024 remain active, while about a third (31%) have transitioned or are about to be transitioned to programs of records.

In terms of companies funded by MTAs, we found that just over a third (39%) of these contracts that had recorded CAGE codes went to small businesses. In close alignment with the fractions for small businesses, just over a third (36%) had revenue less than $50 million (FY 2023), over half (53%) of the contractors had revenue exceeding $500 million (FY 2023), and another 11% had revenue exceeding $50 million (FY 2023). Most of the companies receiving these contracts filed as a private corporation (~43%), approximately 33% were publicly traded companies, with about 19% being identified as a subsidiary of another company, and 5% of the remaining companies were nonprofits, and two were government entities (about 1%). Less than half (45%) of the companies identified as manufacturing of a product, less than a third (29%) provided technical services, 15% of the companies sold a product, while R&D made up 9%, and one NAICS was simply "National Security" for 2% of the entities.

Conclusions

The DoD has generally experienced growth in the use of MTAs and the use of MTAs for fielding capabilities for our warfighters. MTA use for procurement of capabilities is an upward trend across all of FY 2018–2024. Procurement peaked in FY 2022 but may be flattening or decreasing; future years of data are needed to determine if this is a statistically significant trend. MTA use for RDT&E by FY funding steadily increased through FY 2023. As percentages, the overall trend in the percentages of RDT&E and Procurement across the total funding shows RDT&E declining, while Procurement initially increased but has recently plateaued.

The DoD continues the data collection and reporting requirements described in this paper to update policy and guidance on the use of MTAs and their use of OT agreements, where less than 50% of MTAs use OTs. Further analysis would be needed to obtain data from additional sources to assess contractor size (revenue and employees), and additional data correlations would be needed to assess contractor filing status.

Acronyms and Abbreviations

AIRC	Acquisition Innovation Research Center
CAGE	Commercial and Government Entity
DAVE	Defense Acquisition Visibility Environment
DoD	Department of Defense
DLA	Defense Logistics Agency
DPCAP	Defense Pricing, Contracting, and Acquisition Policy
FD	Final Deployment
FOC	Full Operational Capability
FPDS	Federal Procurement Data System
FY	Fiscal Year
MTA	Middle Tier of Acquisition
NAICS	North American Industry Classification System
NDAA	National Defense Authorization Act
O&M	Operation and Maintenance
OT	Other Transaction
OTA	Other Transaction Authority
PB	President's Budget
PSC	Product and Service Code
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
SERC	Systems Engineering Research Center

TY	Then-Year (dollars unadjusted for inflation)
UARC	University-Affiliated Research Center
USD	Under Secretary of Defense
USD(A&S)	Under Secretary of Defense for Acquisition and Sustainment
USSOCOM	U.S. Special Operations Command

Acknowledgements

We would like to thank Katherine (Katie) Coyne for her sponsorship and support of our analytical effort.

The views, findings, and conclusions in this document are solely those of the authors and do not necessarily reflect the views or positions of the U.S. Government (including the DoD or any other government personnel) or the Stevens Institute of Technology.

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Innovation in Acquisition: Case Study of Marine Corps Manpower Information Technology Systems Modernization (MITSM) Portfolio

Noelle Shott—is the Marine Corps Manpower Information Technology Systems Modernization (MITSM) Product Manager with the Department of the Navy's (DON) Program Executive Office for Manpower, Logistics and Business Solutions (PEO MLB). Shott is responsible for modernizing the Headquarters Marine Corps Manpower & Reserve Affairs (HQMC M&RA) Information Technology (IT) systems to optimize talent management. In this role, she brings her philosophy of lean startup, user-centered design, and agile methodology to rapidly spin up prototypes that demonstrate real value to customers that enable a long-term digital transformation strategy that solves their pain points. [Noelle.shott@usmc.mil]

Abstract

The Program Executive Office for Manpower, Logistics and Business Solutions' (PEO MLB) Marine Corps Manpower Information Technology Systems Modernization (MITSM) portfolio uses an innovative acquisition approach incorporating agile, user-centered design, existing enterprise services, and Other Transaction Authorities (OTA) to develop complex technology prototypes that mature to become programs of record to support warfighters at the speed of relevance. MITSM's complex prototypes achieve Minimum Viable Product (MVP) and transition to Minimum Viable Capability Release (MVCR) within 2 years. MITSM's innovative approach, titled the Prototype to Program (P2P) Process, involves accelerating requirements development, reducing procurement time, allocating resources based on learning, increasing customer satisfaction, and paralleling Information Technology (IT) transformation planning. Using the Software Acquisition Pathway, MITSM's P2P Process incorporates design thinking and agile user-centered design and uses the flexibility of OTA prototype agreements and existing enterprise services to accelerate the delivery of software prototypes to achieve large-scale enterprise results.

Keywords: Innovation, User-Centered Design, Agile, Other Transaction Authority, Software Acquisition

Introduction

The Program Executive Office for Manpower, Logistics and Business Solutions' (PEO MLB) Marine Corps Manpower Information Technology Systems Modernization (MITSM) Portfolio was established by the assistant secretary of the Navy for research, development, and acquisition (ASN[RD&A]) in February 2023 to operationalize Talent Management 2030—the Commandant of the Marine Corps' (CMC) vision to modernize the Marine Corps' manpower Information Technology (IT) systems. Talent Management 2030 enables a transparent, commander-focused collaborative system and aligns the individual abilities, skills, and aspirations of our Marines to our warfighting needs by digitally modernizing our Human Resource Development Process (HRDP) systems and IT environments. To meet the timeline of Talent Management 2030, MITSM had to bridge the "valley of death" by implementing industry-acknowledged best practices in IT acquisition to ensure that successful results would be demonstrated within the first 2 years of standing up the MITSM Portfolio. MITSM accomplished this by using faster acquisition processes like the Software Acquisition Pathway (SWP) and Other Transaction Agreements (OTA). The MITSM Prototype to Program (P2P) Process combines these acquisition processes with innovative development methods that take ideas to programs in a short amount of time.

Historically, software programs that follow the Defense Business System (DBS) Business Capability Acquisition Cycle (BCAC) process fail to deliver capability to warfighters at the speed of relevance. The BCAC process is not aligned to modern software development methodologies because it requires lengthy requirements analysis and documentation up front.

Additionally, the BCAC process includes burdensome administrative bureaucracy due to the multiple phases and decision points required before new capabilities can be developed and deployed.

Figure 1 shows that the DBS pathway requires a program to complete three phases, Capability Need, Solution Analysis, and Functional Requirements and Acquisition Planning, before a contract is awarded to initiate program execution. In comparison, Figure 1 also illustrates the streamlined SWP with just two phases, a Planning Phase and an Execution Phase, removing the DBS pathway's multiple phases and barriers leading to program execution. The MITSM P2P Process uses SWP, replacing the initial three DBS pathway phases with Design Thinking Workshops that incorporate warfighter feedback to rapidly identify their pain points and prioritize their use cases to produce OTA Prototype Agreements.

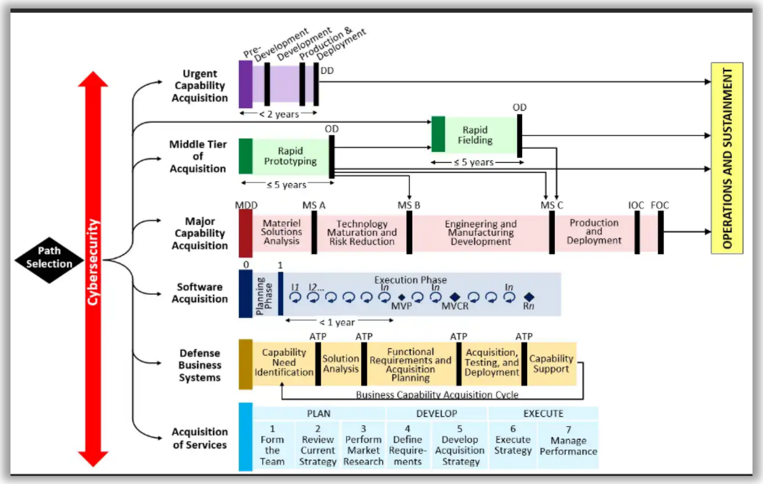

Figure 1. Adaptive Acquisition Framework

At MITSM, SWP provides a more agile and efficient approach to acquiring software systems. MITSM's P2P Process (Figure 2) mimics SWP's Planning and Execution phases to emphasize flexibility, allowing for faster and more iterative delivery of software products. Using the SWP Planning Phase to prototype is a tool for bridging the "valley of death." The "valley of death" is a common occurrence in new system acquisitions because historically it can take 3 years from requirements generation to contract award and the program receiving their first official budget in the Program Objective Memorandum (POM). For the first 3 years, the program can be in a state of documentation paralysis with no forward movement or demonstrable success. The MITSM P2P Process eliminates the "valley of death" by showing immediate business value.

Figure 2. TFRS 2.0 MITSM's Prototype to Program (P2P) Proce

Phase 1: Define is when we detail the project scope, including goals, requirements, and success criteria. During this phase, we conduct the up-front Design Thinking Workshops and complete the OTA Request for Proposal (RFP) Process, which takes approximately 9 months. At the Authority to Proceed Decision (ATP) Point 1, MITSM chooses if it wants to proceed to the SWP Planning Phase by awarding an OTA to complete a prototype.

From MITSM's inception, CMC and Headquarters Marine Corps Manpower & Reserve Affairs (HQMC M&RA) leadership directed MITSM to use time to market (i.e., field capability to Marines to support the commandant's vision for talent management through digital modernization of the Human Resource Development Process [HRDP] systems and IT environments) as our principal measure of effectiveness (MOE) in developing IT requirements and delivering new applications and IT capabilities. To this end, we concluded that applying User-Centered Design (UCD) principles across our efforts would be critical to our success. MITSM determined that to achieve the time to market MOE, we must accelerate the front end of the acquisition process. Initiating prototyping efforts using UCD efforts like Design Thinking Workshops allowed us to accelerate requirements gathering to reach the OTA prototype agreement award faster.

Phase 2: Develop reflects the 12–15 months required to build a complex prototype. A simple prototype only proves that a Commercial Off-The-Shelf (COTS) product works in the contractor's environment. The MITSM P2P Process requires complex prototypes to ensure it mitigates the high-risk areas of data migration and system interfaces in a Department of Defense (DoD) environment. This occurs in the SWP Planning Phase to reduce the schedule risk of delivering Minimum Viable Capability Release (MVCR) within 12 months of entering the SWP Execution Phase. ATP Decision Point 2 requires the prototype to:

1) Successfully meet its success criteria, which demonstrates the Minimum Viable Product (MVP) provides business value.
2) Reach Risk Management Framework Step 4 (Interim Authority to Test [IATT]).
3) Demonstrate enterprise viability and scalability during a User Acceptance Test (UAT) event.

Phase 3: Deliver transitions the prototype from an OTA agreement to an Other Transaction Production (OTP) agreement in about 4 months. The prototype becomes a program and enters the SWP Execution Phase. At this point, the program completes the Risk Management Framework (RMF) process, receives an ATO, and deploys the MVCR.

The MITSM P2P Process is also aligned to the new *Directing Modern Software Acquisition to Maximize Lethality* memorandum issued by Secretary of Defense Pete Hegseth on March 6, 2025. The memo directs "all DoD Components to adopt the Software Acquisition Pathway (SWP) as the preferred pathway for all software development components of business and weapon system programs in the Department."

HQMC M&RA stated about the MITSM P2P Process:

> [It] makes small investments to validate capability before scaling to production. Time has shown that big-bang delivery of enterprise resource planning software often leads to cost and schedule overruns and, at worst, failed delivery of capability. MITSM's mantra of no big-bang deliveries helps ensure that the Marine Corps maximizes the impact of information technology expenditures across its Future Years Defense Plan. This approach involves choosing narrowly scoped business processes and then making a small capital investment to develop and deliver a prototype capability that can be validated and tested. This capability is then scaled for enterprise use and incrementally

> expanded to continue delivering value and eventually incorporate the entire business process. Once complete, the legacy system is sunset, and the portfolio moves on to the next modernization effort. Making small investments, competing prototypes, and ensuring rigorous testing and validation push industry to produce consistent quality results on time and within budget. This process also ensures that the Marine Corps executes incremental development and delivery, helping to avoid the pitfalls of the big-bang approach, which often leads to IT modernization failures due to changing requirements and scope creep. This iterative, feedback driven approach ensures systems can meet evolving needs while minimizing the risk of obsolescence before deployment. (Peterson, 2024)

The purpose of this paper is to discuss how MITSM implemented the MITSM P2P Process described by HQMC M&RA in the above paragraph and demonstrate how these changes in acquisition approach and engagement with the defense industry appreciably accelerate capability delivery and better meet user needs and objectives over traditional practices. This paper will explore this hypothesis by answering the following research questions:

1) Do opportunities exist for collaboration between defense, industry, and academia that will create an environment to rapidly develop, test, and transition ideas and solutions into practical applications?
2) Innovation by nature starts small, and current innovation efforts are happening in pockets across the DoD on a small scale. How can we build on this momentum to achieve more large-scale results? Is it possible to scale these efforts up across the DoD? Or is there another way to promulgate innovation while preserving the efficiency and creativity of small teams?
3) How do we collaborate with our industry partners, small and large, throughout the processes of development, testing, production, and sustainment to generate innovative technology and solutions? What does this collaboration look like from different roles in the acquisition community, such as contracting officers, program managers, senior leaders, engineers, and others?
4) How can changes to the RFP process (e.g., length restrictions, demonstration requirements, contract structure) ensure that awarded contracts are mission-oriented and outcome-driven to drive competition and innovation opportunities, maximize utility of the product or system to the end user, and mitigate risk to the DoD?

Background

The Marine Corps' HRDP is a cornerstone of force readiness, but outdated systems, fragmented data, and inefficient workflows have long hindered its ability to effectively manage personnel. Rigid legacy infrastructure, manual processes, and disconnected databases have led to delays in decision-making, inefficiencies in manpower allocation, and limitations in talent management. To maintain operational effectiveness, the Marine Corps must transition to a modern, integrated, and data-driven HRDP ecosystem capable of supporting the evolving needs of the force. This is aligned with Force Design 2030, which calls for modernization efforts to ensure the Marine Corps remains effective in contemporary and future warfare scenarios

Recognizing these challenges, MITSM and HQMC M&RA have partnered to modernize HRDP through a comprehensive digital transformation initiative. This effort focuses on consolidating disparate legacy systems, automating personnel workflows, and enabling data-driven decision-making. The solution is not just about upgrading technology but fundamentally restructuring how HRDP data is processed and utilized to create a more agile, efficient, and responsive manpower management framework.

This paper examines MITSM's first two efforts that used the MITSM P2P Process to transform the HRDP. The first effort is the Total Force Retention System (TFRS) 2.0, which uses an OTA agreement. The second is Models Modernization's first initiative, USMC Staffing Goal (SGM), which uses existing enterprise services within the DoD Chief Digital and Artificial Intelligence Office (CDAO) Advana Platform.

TFRS 2.0

TFRS 2.0 transforms today's manual paper-based Reenlistment Extension Lateral Move (RELM) submission by providing the capability to automate, expedite, and digitize the reenlistment process. As part of the OTA prototype agreement, the following success criteria were established to demonstrate success of the prototype:

- Reducing the time of RELM submission to final execution
- Decreasing errors in reenlistment processing
- Fully digitizing the process, eliminating manual paper routing
- Minimizing data sources that career planners must manually access outside the system to perform their job

> "TFRS 2.0 took advantage of Software as a Service (SaaS) systems and cloud-native tooling to streamline delivery and reduce customization. Leveraging the Salesforce enterprise license model allows us to build as many modules as we need. Salesforce and our other COTS tools (Okta, DocuSign) are SaaS managed. This means the government does not have to manage the infrastructure and platform layer and can focus on configurations based on our specific workflow needs. It also means that by using SaaS products, the government does not have to invest significant manpower, compute, and resources to maintain the systems, as required with fully customized solutions. Lastly, all our COTS tools maintain provisional authorities to operate (ATO) at the Defense Information Systems Agency (DISA) level, meaning the ATO process is significantly compressed compared with developing a full ATO from scratch" (H. Hunt,[1] personal communication, March 2, 2025).

This paper will explain how the MITSM P2P Process was used to award the TFRS 2.0 OTA complex prototype in 9 months, achieve MVP in 15 months, and transition to an OTP Agreement to complete delivery of MVCR in 4 months.

Models Modernization SGM

The Models Modernization SGM application allows analysts at HQMC M&RA to manage and run algorithmic models to determine which billets should plan to have Marines issued orders to them in the coming new assignment season and which monitors should be responsible for filling those billets from within their monitored populations.

The legacy Models Modernization SGM application was built in Fortran. The transformed version of the Models Modernization SGM is a

> "modern, cloud-based application that is a centralized and scalable solution for manpower modeling. Instead of relying on siloed databases, manual processes,

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[1] **Hannah Hunt** serves as a distinguished technical fellow at MetroStar Systems in the Defense Business Unit, where she supports technical delivery across MetroStar's defense customers. Hunt previously served as the chief product and innovation officer at the Army Software Factory and as chief of staff for the U.S. Air Force's Software Factory Kessel Run. At the Army Software Factory, Hunt led the development and delivery of a cohesive suite of products "by soldiers, for soldiers" and evangelized agile acquisitions and Development, Security and Operations (DevSecOps) in the Army.

> and laborious iterations of process, the modernized Models Modernization SGM integrates data sources across the HRDP environment, streamlining access to data for M&RA analysts. This transition eliminates inefficiencies caused by redundant data entry, manual record-keeping, and disconnected manpower functions, ensuring that leaders have accurate, real-time insights into manpower requirements, planning, and forecasting" (J. Castillo,[2] personal communication, March 2, 2025).

This paper will explain how the MITSM P2P Process accelerated speed to market, enabling the Models Modernization SGM application to reach MVP within 6 months by leveraging existing enterprise services provided by the CDAO Advana platform. The C3 AI software application was already accredited for the CDAO Advana platform with the data sources needed for the application and access to contract vehicles to quickly add task orders needed to configure the models using the C3 AI Platform.

As part of the MITSM P2P Process, establishing a defined innovation success criteria is critical for prototype MVPs. "The minimum viable solution is the smallest solution release that successfully achieves its desired outcome" (Patton & Economy, 2014, p. 34). Both TFRS 2.0 and the Models Modernization SGM demonstrated they achieved their respective innovation success criteria business value outcome. By modernizing antiquated manual processes, the TFRS 2.0 RELM package processing time is completed 2–3 months faster, creating a 75% efficiency, and now provides a better customer experience to the reenlisting Marine. For Models Modernization SGM, M&RA analysts state the timeline required to develop, review, and publish the Models Modernization SGM takes days now compared to the previous months, creating an 85% efficiency.

Discussion

The MITSM P2P process involves the following key features:

Accelerating Requirements Development

The MITSM P2P Process reduces the time and cost of procurement by focusing on software's rapid delivery and continuous improvement.

> "The integrated SWP functionality encourages smaller, more manageable contracts, which provide the ability to adjust throughout the development process. For MITSM, adopting SWP concepts into the P2P Process significantly enhanced the speed and effectiveness of modernizing and optimizing applications, better enabling them to meet evolving mission requirements while keeping pace with technological advancements" (H. Hunt, personal communication, March 2, 2025).

The following phases outline the MITSM P2P Process used at initiation of a prototype to accelerate requirements development to rapidly execute OTA prototype agreements.

Phase 1: Define. A Design Thinking Workshop is a facilitation process for answering crucial questions with customers in a stepwise and iterative fashion. MITSM uses design thinking principles and techniques from Sprint, LUMA Institute, *Think Wrong*, and Naval X's Center for Adaptive Warfare (CAW). Following Jake Knapp's *Sprint*, the workshop typically lasts 5 days and includes a range of activities, including problem definition, conceptual design,

[2] **Jake Castillo** is a senior director of strategic solutions for C3 AI, where he is responsible for business development and total lifecycle client support, with a focus on digital transformation for the DoD. He leverages experiences from 20 years of Marine Corps service combined with a deep understanding of industry-leading digital transformation methodologies to solve modernization challenges across the DoD.

prototype development, and user testing. To meet the unique needs of Lean Start-Up Model, MITSM has tailored the schedule to 2–3 days.

Time	Day 1 Agenda: Empathy and Current Process	Time	Day 2 Agenda: Future State
15m	**Welcome & Opening Remarks**	15m	Welcome Back, Recap Day 1,
25m	Introductions and Icebreakers	60m	**Exercise #6:** Industry Demonstration- Provide Audience with potential ideas for tomorrow's To-Be Process Mapping.
60m	**Exercise #1:** Modernization Inputs Framework to Agree on Problem Statement, North Star, and Goals	60m	**Exercise #7:** How Might We Statements
15m	Break	15m	Break
45m	**Exercise #2:** Stakeholder Mapping / Empathy Mapping / Dot Voting to determine persona point of view for Journey Mapping	60m	**Exercise #8:** To- Be Process- If you were King or Queen for the Day- how should it work!
15m	Break	15m	Break
60m	**Exercise #3:** Create As-Is Journey Map	30m	**Exercise #9:** Success Criteria- Identify on the ToBe Chart where business value will be gained from the improvement in the process
60m	**LUNCH**	60	**LUNCH**
30m	**Exercise #4:** Pain Points- To identify if opportunities for improvement in the To-Be Process	60	**Exercise #10:** Product Backlog- Write the Epic Ability Statements based on ToBe Process
30m	**Exercise #5:** Problem Tree Analysis	15	Break
15m	Break	60	**Exercise #11:** PICK Chart- to identify near-term and long-term actions and innovations.
15m	Daily Wrap Up, Facilitated Open Discussion	15	Workshop Wrap-Up and Next Steps

Figure 3. Sample Design Thinking Workshop Agenda

Figure 3 is a sample of a Design Thinking Workshop agenda MITSM used to develop the artifacts used for the TFRS 2.0 OTA RFP. Definitions of the workshop exercises are provided in Enclosure 1.

Design Thinking Workshop Day 2 is when the user community representatives from HQMC M&RA and Career Planner Subject Matter Experts developed the TFRS As-Is (Enclosure 2) and TFRS 2.0 To-Be (Enclosure 3) Process Charts. The steps in the To-Be Process have corresponding How Might We (HMW) Statements. Phrasing of HMW Statements provide for "opportunities and challenges, rather than getting bogged down by problems or, almost worse, jumping to solutions to soon" (Knapp, 2016, p. 74). Both artifacts are provided in the OTA RFP so that industry can understand the current user pain points and the To-Be Process with their corresponding HMW Statements which represents the use case to be developed as the MVP and the start of the Agile Sprint Product Backlog.

As Jeff Patton (2014) says in *User Story Mapping*, "One of the tough realities about software development is that there's always more to build than we have time and money for. So the goal should never be to build it all. The goal is to minimize the amount we build" (p. 9). The To-Be Process is the agreed-to MVP.

Phase 2: Develop. MITSM P2P Process follows a UCD agile methodology approach. Incorporating UCD into the software delivery process

> "ensures that the needs and preferences of end users are central to the development process. UCD focuses on iterative testing and feedback from users, leading to the creation of systems that are more intuitive and effective. For MITSM, this approach helps ensure that the software not only meets functional requirements, but is also user-friendly, enhancing user adoption and operational efficiency. By engaging with end users throughout the development process, the Marine Corps can avoid costly missteps, reduce training requirements, and

improve overall user satisfaction" (H. Hunt, personal communication, March 2, 2025).

For TFRS 2.0, the HQMC M&RA Product Owner defined our priorities of work though the UCD agile process. Based on user involvement, Metrostar, the prime contractor for TFRS 2.0, configured the features and functions that had the greatest value and contribution to the Marine Corps' manpower mission first. The Marine subject matter experts (SME) that participated in the agile sprint development were empowered to recommend trade-off decisions between capabilities and time to the Product Owner, so we were able to keep the prototype on track and meet the optimized versions of capability and schedule concurrently.

For Models Modernization SGM, C3 AI was responsible for all aspects of digital transformation, modernization, and artificial intelligence (AI)/machine learning (ML), while MITSM facilitated stakeholder engagement, requirement definition, and system alignment with DoD infrastructure. This collaboration allowed for real-time testing and iterative improvements, ensuring the new HRDP platform met M&RA requirements. Leveraging 6-month agile sprints, the team cyclically defined a scope of work, iteratively designed, configured, and deployed user-centric workflows. Once each sprint is complete, the team analyzes the results, identifies what remains to be completed, and restarts the cycle. This collaborative effort requires a great deal of time from HQMC M&RA SMEs during each sprint but results in a product that is highly tuned and tailored to meet the specific demands of the user. MITSM and C3 AI accelerated deployment timelines, improved data-driven personnel management, and laid the groundwork for broader digital transformation within the Marine Corps.

"We're making sure we build the right thing right, as opposed to building the wrong thing right. By putting our end users, mission owners and product owners at the center of our agile teams, we optimized our ability to make sure we built the correct application or capability that best met the end users' desires and fulfilled mission value objectives."
– Colonel Robert Bailey[3]

Reducing Procurement Time

"Non-traditional contract mechanisms, such as OTAs, play a crucial role in enabling the Marine Corps to work with a broader range of industry partners. OTAs provide flexibility that is often lacking in traditional contracts, making it easier to collaborate with innovative firms, including startups, small businesses, and non-traditional defense contractors not commonly contracted within the DoD. These agreements facilitate quicker procurement processes, direct collaboration with vendors, and allow for more tailored solutions, reducing bureaucracy and the associated delays often seen in standard contracting procedures. For Marine Corps manpower systems, OTAs enable experimentation with emerging technologies and processes and the incorporation of novel solutions that would otherwise be constrained by rigid contractual frameworks. Based on the successful completion of the TFRS 2.0 initial prototype OTA, we were able to move forward with a production OTA that expands upon the work in the prototype and focuses

[3] **Col. Robert Bailey** served as the portfolio director for PEO MLB's MITSM, where he oversaw the development and implementation of new IT systems and processes related to manpower management within the Marine Corps. Previously, Col. Bailey served as the deputy program executive officer and director of the Command Strategy and Business at PEO Digital and Enterprise Services and was commanding officer of Marine Corps Tactical Systems Support Activity.

on the entire ‘hire-to-retire’ lifecycle for Marines” (H. Hunt, personal communication, March 2, 2025).

MITSM uses the Information Warfare Research Project (IWRP) Consortium for OTAs. The benefit of using an established consortium is to take advantage of a pool of vetted non-traditional companies, which streamlines execution and RFP evaluation, simplifying documentation. Figure 4 illustrates the OTA RFP timeline TFRS 2.0 followed from industry day to contract award. This timeline is aggressive and requires commitment from the government evaluation team. It was critical that the government evaluation team included representatives from the HQMC M&RA Product Owner to ensure buy-in from the very beginning. In addition, the OTA RFP process provides an ability to conduct market research through the white paper and industry demonstrations.

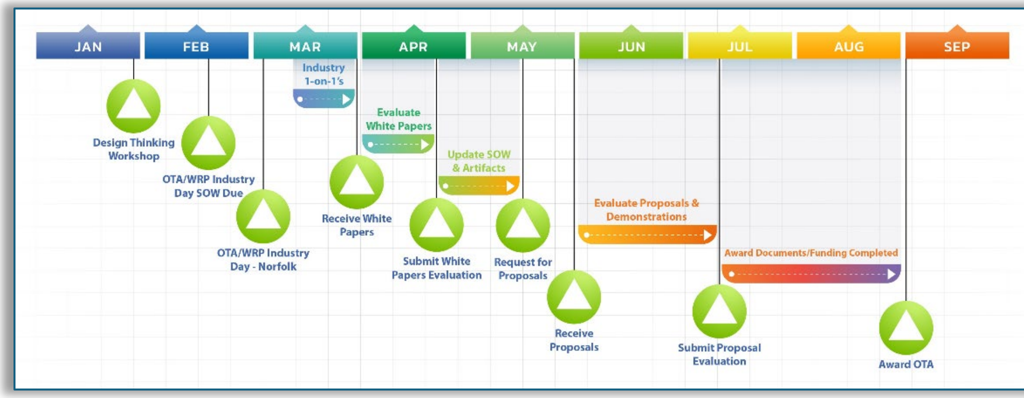


Figure 4. OTA RFP Schedule

Industry engagement throughout the TFRS 2.0 OTA RFP process was essential for the government evaluation team to learn and understand the latest technological advancements and innovative solutions and how to leverage them to improve Marine Corps manpower systems. Collaboration with industry leaders during the one-on-one meetings and white paper evaluations enabled MITSM to tap into a wider range of expertise to update the RFP package, ultimately leading to better, more cost-effective outcomes.

> “Regular engagement with industry also allows for the incorporation of best practices in software development and delivery, ensuring that the solutions implemented are scalable, sustainable, and adaptable to changing requirements. Through ongoing dialogue with industry partners, the Marine Corps can stay ahead of the curve in integrating cutting-edge technologies into its manpower systems” (H. Hunt, personal communication, March 2, 2025).

To accelerate implementation in Models Modernization SGM, MITSM used existing enterprise services provided by the CDAO Advana platform to access C3 AI technology, which enabled rapid prototyping, iterative development, and direct engagement with end users. CDAO’s existing contract vehicles allowed the HRDP modernization effort to move forward without the delays typical of traditional acquisition processes. This ensured capabilities could be developed, tested, and refined in stride with HQMC M&RA requirements.

Both the TFRS 2.0 OTA with Metrostar and the Models Modernization SGM with C3 AI use milestone deliveries with a Firm Fixed Price (FFP) modular contracting approach. By establishing the MVP/MVCR use cases up front in the OTA/OTP award and enterprise service task order, the Statements of Work (SOW) establish clear milestone deliveries via the agile sprint cadence. This helps ensure the government understands the total cost required to achieve the business value being delivered with the MVP/MVCR. This modular contracting using FFP controls cost overruns because using agile, we understand the industry partner's sprint velocity and have the flexibility to shift priorities to achieve our outcomes.

Allocating Resources Based on Learning

Based on IT industry's best practices, the MITSM P2P Process follows a Lean Startup model by learning fast regardless of whether the prototype MVP meets the innovation success criteria. "Lean thinking defines value as providing benefit to the customer; anything else is waste" (Ries, 2011, p. 56). The result of these prototypes allows MITSM and HQMC M&RA to quickly explore innovative technology options and learn whether the MVP solution has enterprise viability, scalability, demonstrated business value, and if it will achieve user acceptance before making long-term investment decisions.

Figure 5 summarizes the TFRS 2.0 business value metrics used to determine if the prototype would transition to MITSM P2P Process Phase 3 and enter the SWP execution phase to become a program. During Day 2 of the Design Thinking Workshop, users defined measurable success criteria for the To-Be Process Use Case. The MITSM Program determined the baseline metric values by developing a retention process improvement survey to measure the As-Is Process (Enclosure 2). The survey (Enclosure 4) was built using the Department of the Navy (DoN) Voice of the Customer Tool, and the survey link was advertised on social media and Marine Online. The survey responses from over 1,500 Marines resulted in the baseline metric column. Finally, "the value hypothesis tests whether a product or service really delivers value to customers once they are using it" (Ries, 2011, p. 70). Using the value hypothesis that the prototype will deliver something better than they have today in the baseline metric, during the TFRS 2.0 MVP prototype UAT, Marine testers were given the survey again and asked to evaluate if the MVP once deployed would deliver the business value defined in the success criteria. "Through this UCD process, we were able to define business value and articulate return on investment in relatable terms" (Col. R. Bailey, personal communication, March 2, 2025).

Success criteria	TFRS Baseline Metric (Surveyed based on experience)	TFRS 2.0 Metrics (Surveyed at User Acceptance Test)
Reduce process time of Reenlistment Extension Lateral Move (RELM) submission to final execution	On average, Career Planners (CPs) and Marines say RELM packages take 2-3 months to complete.	99% of Marines responded: TFRS 2.0 will reduce RELM Process Time.
Decrease errors in reenlistment process	25% of CPs say they often encounter performance issues in TFRS.	93% of Marines responded: TFRS 2.0 will decrease errors in reenlistment process.
Fully digital process that eliminates manual paper routing	93% of CPs don't have a fully digital process to submit RELM packages.	98% of Marines responded: TFRS 2.0 will eliminate manual paper routing of the reenlistment package.
Increase productivity by minimizing external system data sources used by the Career Planner to prepare the reenlistment package	On average, CP spends 1 hour to prepare each reenlistment package.	97% of Marines responded: TFRS 2.0 will eliminate the need to access external data sources.
Ease of use (i.e., System Usability Score)	SUS score was not tested for TFRS 1.0.	SUS score = 70%
Increase in customer satisfaction from sprint demos to final UAT	64% of CPs say TFRS allows them to easily perform and complete tasks.	100% of Marines responded with a Customer Value Metric of Relative Perception: Able to achieve more with TFRS 2.0.

Figure 5. Business Value Metrics

Increasing Customer Satisfaction

The MITSM P2P Process employs a UCD and agile methodology involving warfighters in the acquisition process. Ahead of each development sprint, warfighter feedback is gathered and incorporated into the software configuration plans. This reduces agile recidivism metrics and increases customer satisfaction in each sprint. Additionally, implementing UCD supports integrating Organizational Change Management (OCM) throughout the system development process ensures much-needed support in the introduction of a new capability to successfully gain initial user acceptance and buy-in.

“While this process is time and labor-intensive for SMEs, it maximizes user input throughout the development lifecycle, aligns with modern software development best practices, and ensures that critical design decisions are made by the end user, enhancing software viability and usability upon delivery” (Peterson, 2024).

Figure 6 below shows an example of the customer satisfaction metric collected at each agile sprint. This metric is qualitative feedback that captures the Marine end users experience while testing the breadth of the newly developed TFRS 2.0 functionality during each agile sprint. All participant roles are captured so the development team can determine if there are any results with significant variations that could be associated with the user’s role. These findings assist the MITSM team and HQMC M&RA Product Owner in making data-driven decisions about product enhancements and identifying areas of the application that warrant a training focus, where enhancements are reserved for follow-on releases. The MITSM team can also review user sentiment due to the team’s continuous user involvement throughout the development of the MVP and MVCR.

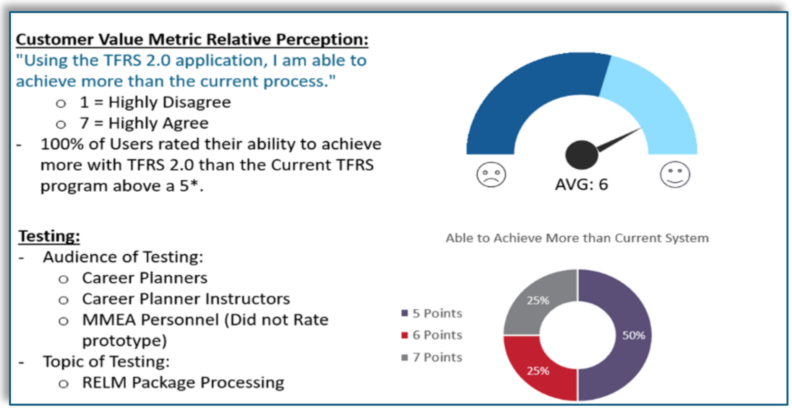


Figure 6. User Engagement Metric

Paralleling IT Transformation Planning

In conjunction with learning from the prototyping efforts, MITSM performed transformation planning to inform future state architecture. When analysis and prototyping take place concurrently, the team can make real time adjustments based on findings, which encourages innovation and adaptability. The high-level outcome of transformation planning is that MITSM has a clear and documented approach to application prioritization, rationalization, and modernization. The IT Transformation Plan was accomplished with support from our SMEs at Massachusetts Institute of Technology Research and Engineering (MITRE) and industry insights from Metrostar and C3 AI.

First, Metrostar conducted UCD-driven business process analyses to identify pain points across the HRDP value chain to inform the future state environment. Second, Metrostar and government stakeholders

> “assessed 16 legacy systems, data flows, and interfaces and developed an application rationalization framework to help define the future state architecture. Rationalization helps prioritize investments in systems that align with strategic goals, while phasing out or consolidating outdated or ineffective solutions. This process is crucial for maximizing the value of the Marine Corps' software portfolio. Leveraging a governance framework that defines clear metrics to measure business, user, and mission value allows MITSM to make data-driven investment and divestment decisions across their portfolio of products. It provides an opportunity to invest in more emerging technologies and deprecate legacy systems by tracking progress across key metrics every quarter” (H. Hunt, personal communication, March 2, 2025).

For Models Modernization SGM, C3 AI assessed over 40 models used across HQMC M&RA to power the HRDP. C3 AI held several SME workshops to understand the models. A scoring rubric was developed to assess models across various dimensions and themes that represented criticality to the business, technology readiness, and urgency to modernize. The assessment lays out modernization priorities by considering final aggregated-model scores qualitative factors, and funding/budget constraints, and provides a recommendation for how and when these models should be prioritized.

Research Questions

To capture the viewpoints of the commercial firms who supported these MITSM efforts, the author posed four research questions to key contractor personnel. The questions and the responses from industry representatives who directly supported the MITSM efforts are discussed below.

1) Do opportunities exist for collaboration between defense, industry, and academia that will create an environment to rapidly develop, test, and transition ideas and solutions into practical applications?

> “From an industry perspective, the traditional defense acquisition process presents significant challenges to rapid technological advancement. Rigid procurement structures, prolonged development timelines, and limited engagement with non-traditional vendors create barriers that prevent cutting-edge commercial solutions from reaching operational environments in a timely manner. Fostering a collaborative ecosystem between defense, industry, and academia is essential for addressing this challenge.
>
> A core element of this collaborative approach is the use of OTA agreements and existing enterprise services, which enable faster prototyping, iterative development, and continuous engagement with warfighters. Unlike traditional defense contracts, OTAs provide a streamlined path for non-traditional vendors, startups, and research institutions to contribute to mission-critical projects without being hindered by excessive bureaucracy. MITSM leveraged OTAs to rapidly develop and test manpower applications for the HRDP. Industry’s view is clear: reducing procurement friction through OTAs creates an environment where commercial solutions can be quickly adapted and deployed for defense applications.
>
> Looking ahead, expanding these collaborative frameworks will be essential for ensuring that defense organizations can keep pace with technological advancements and maintain strategic superiority in an increasingly digital battlefield” (J. Castillo, personal communication, March 2, 2025).

2) **Innovation by nature starts small, and current innovation efforts are happening in pockets across the DoD on a small scale. How can we build on this momentum to achieve more large-scale results? Is it possible to scale these efforts up across the DoD? Or is there another way to promulgate innovation while preserving the efficiency and creativity of small teams?**

"The defense sector faces growing challenges in adopting innovative digital solutions due to bureaucratic acquisition processes, siloed research efforts, and slow technology transitions. Traditional procurement models often fail to bridge the gap between cutting-edge industry solutions, academic research, and operational defense needs, limiting the ability to rapidly integrate new capabilities into mission-critical environments. From an industry perspective, a more agile and collaborative ecosystem is necessary — one that fosters real-time innovation, rapid prototyping, and seamless technology adoption.

One of the key mechanisms for fostering this collaboration is the use of OTA agreements, which provide a faster and more adaptive contracting vehicle for engaging non-traditional defense partners, startups, and research institutions. Unlike traditional defense acquisition methods, OTAs enable iterative testing, industry-academic partnerships, and direct user engagement throughout the development process. Together, MITSM, HQMC M&RA, Metrostar, and C3 AI demonstrate how OTA-driven partnerships can streamline the deployment of advanced digital solutions, ensuring that modern, data-driven technologies reach military end users more efficiently.

Additionally, joint research and development efforts must evolve beyond academic studies and prototype demonstrations to focus on real-world implementation at scale. Industry sees value in collaborative test environments that integrate academic research, commercial best practices, and defense operational needs into a single, unified development pipeline" (J. Castillo, personal communication, March 2, 2025).

3) **How do we collaborate with our industry partners, small and large, throughout the processes of development, testing, production, and sustainment to generate innovative technology and solutions? What does this collaboration look like from different roles in the acquisition community, such as contracting officers, program managers, senior leaders, engineers, and others?**

"Collaboration with industry partners, both small and large, is essential for accelerating the development, testing, production, and sustainment of innovative technology solutions that meet evolving defense needs. Effective collaboration requires an agile and adaptive approach that fosters continuous engagement between government stakeholders, commercial innovators, and operational users. This iterative development process ensures that new technologies are not only cutting-edge but also mission-ready and scalable for large-scale deployment.

During testing and evaluation, close coordination between program managers, engineers, users, and industry developers allows for real-world validation of capabilities, ensuring interoperability with existing defense infrastructure. Production efforts benefit from a well-defined transition strategy, where contracting officers and logistics teams collaborate with industry to streamline software development, integration, and deployment. Sustainment is equally critical, as long-term partnerships with industry enable continuous upgrades, cybersecurity enhancements, and feature enhancements to keep systems operationally effective" (J. Castillo, personal communication, March 2, 2025).

4) **How can changes to the RFP process (e.g., length restrictions, demonstration requirements, contract structure) ensure that awarded contracts are mission-oriented and outcome-driven to drive competition and innovation opportunities, maximize utility of the product or system to the end user, and mitigate risk to the DoD?**

The MITSM software acquisition pathway serves as a prime example of how the RFP process can be improved to be more mission-oriented, outcome-driven, and innovation-focused. Unlike the traditional BCAC, which often includes lengthy timelines, rigid documentation requirements, and bureaucratic hurdles, MITSM's P2P Process streamlines acquisition by focusing on rapid prototyping, iterative development, and early end user engagement. By reducing RFP length restrictions, incorporating clear demonstration requirements, and adopting more flexible contract structures, the acquisition process can better ensure that awarded contracts align with operational needs, foster competition, and accelerate technology deployment.

A key improvement in MITSM's P2P Process is the emphasis on modular contracting and phased capability rollouts, allowing vendors to prove feasibility through real-world testing before full-scale implementation. This minimizes the risk of failed procurements and ensures that solutions deliver measurable value to the DoD.

For example:

- For TFRS 2.0, the OTA agreement includes agile contracting mechanisms using monthly milestone deliveries following the sprint schedules. In addition, the MITSM OTA approach encourages participation from non-traditional defense vendors and commercial technology leaders, broadening the competitive landscape and injecting cutting-edge innovations into defense systems.
- For the Models Modernization SGM, MITSM task orders require inspection of the delivery of the product at the midpoint and end of each six-month phase. This allows stakeholders to ensure that all deliverables satisfy requirements while enabling maximum flexibility to incorporate the latest innovations by industry.

The RFP process should be modified to mirror these improvements by prioritizing outcomes over rigid compliance measures, fostering collaborative development environments, and adopting a continuous feedback loop between government stakeholders and industry partners. By learning from the MITSM P2P Process, the DoD can reduce acquisition bottlenecks, maximize the utility of emerging technologies, and drive mission success through a more adaptive and efficient procurement process.

Conclusion

This paper illustrates how MITSM's P2P Process successfully implements industry best practices to rapidly transition technology by ensuring organizations promulgate user-centered design, agile software development, and innovative acquisition processes such as OTA agreements and existing enterprise services.

> "With our users at the center of our development efforts, we generated advocacy from junior enlisted Marines all the way up to senior officers. Our users fought for and advocated for the resources we needed as a software development team to help them be successful in their missions. Similarly, within the Marine Corps the senior enlisted ranks are extremely influential. We gained their trust throughout the agile development process and in return, they advocated for new capabilities both

from a resource prioritization perspective and by lending much-needed support in the OCM continuum of introducing new capability and successfully gaining initial acceptance and buy-in" (Col. R. Bailey, personal communication, March 2, 2025).

The modernization of HRDP represents a critical step forward in the Marine Corps' broader digital transformation efforts. By eliminating outdated processes, improving data integration, and enhancing decision-making through modern digital tools, this initiative sets the foundation for a more agile and effective HRDP ecosystem. The collaboration between MITSM and the user community represented by HQMC M&RA, along with the support of our industry partners, demonstrates the power of innovative partnerships and rapid digital modernization in ensuring that the Marine Corps remains ready and adaptive in a rapidly evolving operational landscape in support of Force Design 2030.

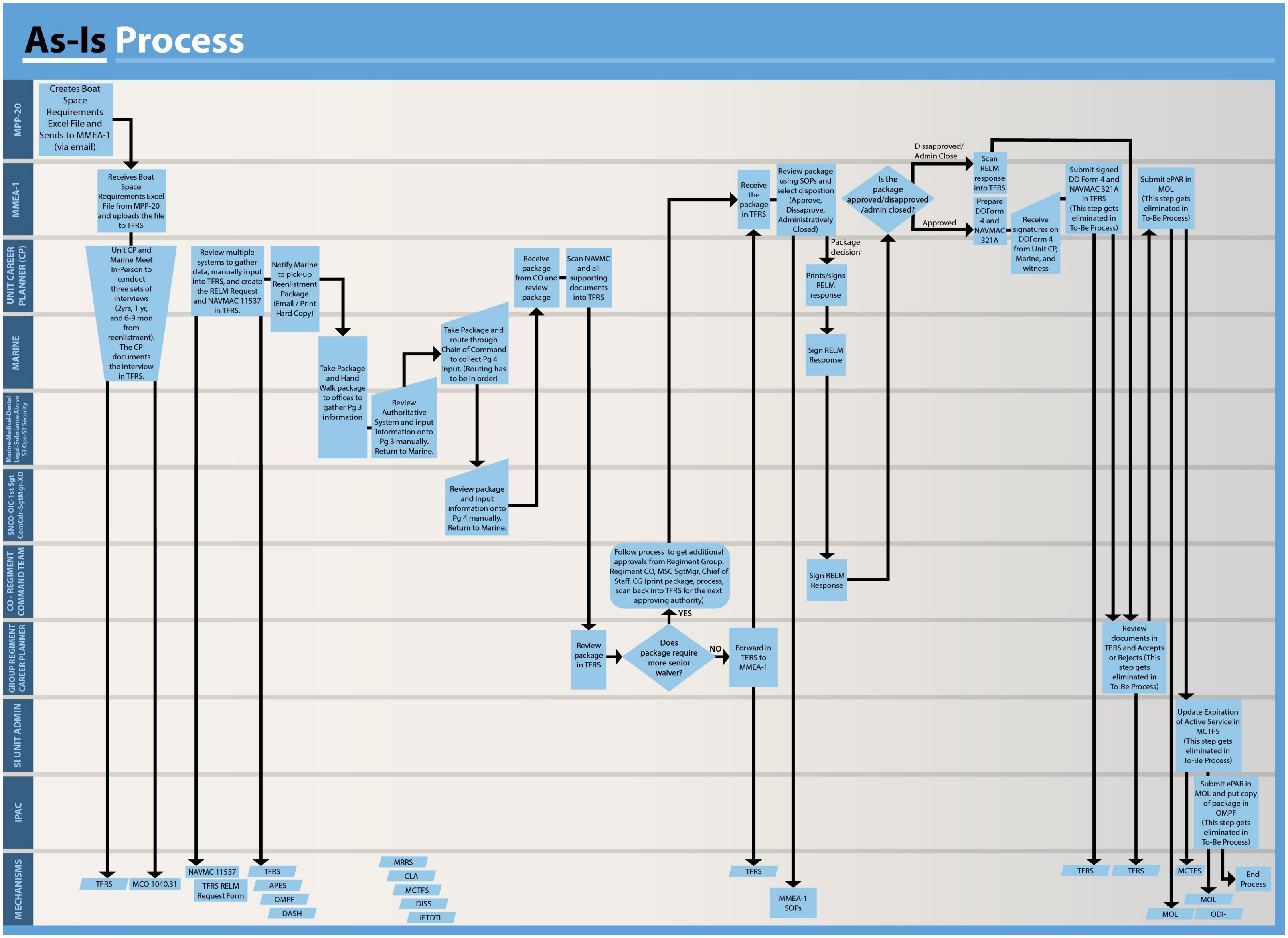
Disclaimer: *The views represented in this case study are those of the author and do not reflect the official policy positions of the Navy, the Marine Corps, the Department of Defense, or the federal government. The commercial firms and products discussed herein were procured in accordance with applicable government procurement regulations, through authorized government personnel; references to those firms and products should not be construed as an implied or explicit endorsement. The contributions of the author and any cited contributors to this case study were provided in a personal capacity without compensation of any kind.*

Enclosure 1. Design Thinking Workshop Exercise Descriptions

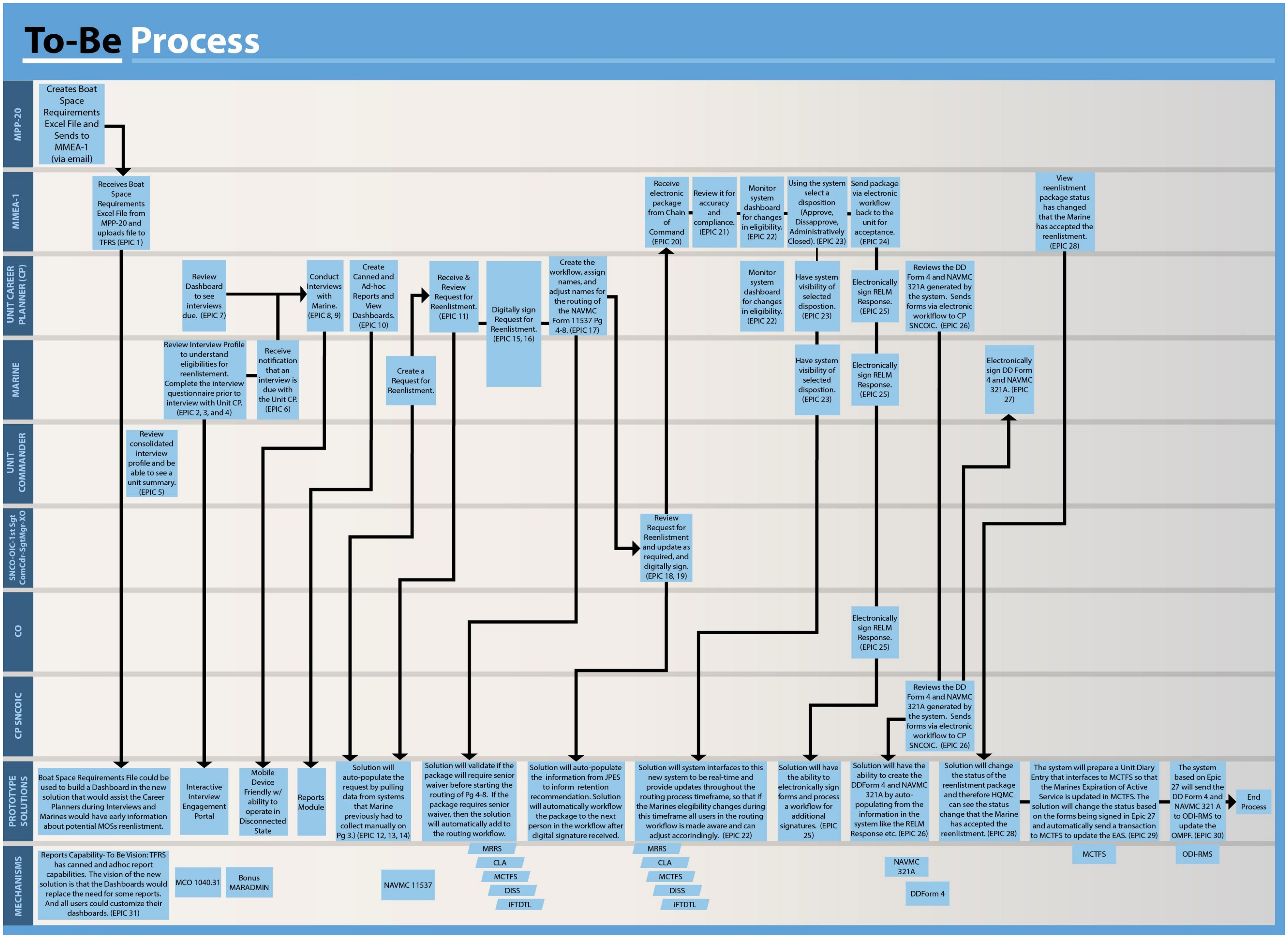
Exercise Name	Description/Purpose
Modernization Inputs Framework	Canvas Chart used to collect feedback on Problem Statement, Stakeholders, North Star, Goals, Barriers, etc. as inputs to modernization planning.
Stakeholder Mapping	Stakeholder Mapping is a method to quickly generate a list of people involved in a process or activity. This exercise can help lead into Empathy and Journey Mapping.
Empathy Mapping	An empathy map is a collaborative visualization used to articulate what we know about a particular type of user (Say, Think, Do, Feel).
Anchors and Rockets	This exercise gives everyone a blank canvas to think outside the box on the obstacles and opportunities to their challenges in order to innovate on solutions.
Affinity Clustering	Grouping similar stickies into common themes and labeling those clusters. This provides a method of drawing insights out of otherwise disparate information.
Gallery Walk	Can be used during different parts of the workshop: 1) To review work completed prior to the workshop to obtain buy-in and refinement from the attendees. 2) To review work completed during the workshop and then lead into Dot Voting to prioritize work in the follow-on exercises.
Journey Maps	As-Is journey maps and To-Be journey maps are used to visualize the process that a person goes through in order to accomplish a goal.
Pain Points	To brainstorm the pain points within the journey map and from the user's point of view what they would want to change to make their experience better.
Dot Voting	A quick poll of the workshop attendees to reveal preferences, opinions, and/or priorities.
Problem Tree Analysis	It provides a structured way for your team to reveal concerns, discern causes from symptoms, and potentially frame problem statements in a new and better way.
How Might We Statements	Encourages a more exploratory and innovative approach to problem-solving.

PICK Chart	Aids in categorizing ideas based on two critical dimensions: the ease (or difficulty) of implementation and the potential impact each idea holds. It is a way to identify near-term and long-term actions and innovations.
Over the Shoulder/ Day In The Life	SMEs using the current IT system provide a demonstration and explain out loud the steps they take, pointing out things they like and things they don't like.
Industry Demonstrations	Schedule industry partner demonstrations that will help the workshop attendees to brainstorm and ideate on what the future state could look like.

Enclosure 2. TFRS 2.0 As-Is Process



Enclosure 3. TFRS 2.0 To-Be Process



Enclosure 4. TFRS 2.0 Baseline Survey

TFRS 2.0 Reenlistment Baseline Survey

Persona 1

- I am a Unit Career Planner.
- I am a Career Planner SNCOIC.
- I am a MSC Career Planner.
- I am a HQMC Career Planner.

Q1. On average, how many Reenlistment, Extension, or Lateral Move (RELM) packages do you process in a fiscal year?

Q2. On average, how long does it take you to prepare a single NAVMC 11537 in support of RELM request?

- Less than 15 minutes
- 16 - 30 minutes
- 31 - 60 minutes
- 1 - 4 hours
- Other

Q3. On average, how long does it take from the time the Marine receives the package to when it is returned to the Career Planner for submission into TFRS?

- Less than 1 week
- 1 week - 2 weeks
- 2 weeks - 1 month
- Other

Q4. On average, how long does it take from the time the Group / Regiment Career Planner receives the package to the time they forward the package to Manpower Management Enlisted Assignments 1 (MMEA-1)?

- Less than 1 day
- 1 day - 2 days
- 3 days - 1 week
- Other

Q5. On average, how long does it take from submission to decision made by MMEA-1?

- Less than 1 week
- 1 week - 1 month
- 1 month - 2 months
- 2 months - 3 months
- Other

Q6. On average, how many pages do you have to print for each RELM package?

- None
- 6 - 10 pages
- 11 - 20 pages
- Other

Q7. How often do you have visibility of RELM requests during the routing process?

- Never (0% of the time)
- Rarely (1% - 25%)
- Sometimes (26% - 50%)
- Often (51% - 75%)
- Always (76% - 100%)

Q8. To complete a RELM package, how much time do you spend manually accessing data sources outside of TFRS?

- Less than 1 hour
- 1 - 3 hours
- 4 - 5 hours
- 6 - 10 hours
- Other

Q9. How much do you agree with the following statement?

- Strongly disagree
- Disagree
- Neither agree or disagree
- Agree
- Strongly agree

Persona 2

I am a Marine involved in the routing/recommendation process for Marine Corps' reenlistments.

Q1. How much time did it take for your (RELM) package to process from submission to decision made by Manpower Management Enlisted Assignments?

- 1 week - 1 month
- 1 month - 2 months
- 2 months - 3 months
- 3 months - 4 months
- Other

Q2. How much time on average do Reenlistment Extension Lateral Move (RELM) packages take to process within your command from start to submission?

- Less than 1 week
- 1 - 2 weeks
- 2 weeks - 1 month
- More than 1 month
- Other

Q3. On average, how many pages do you have to print off for each RELM package for Marines within your command?

- None
- 6 - 10 pages
- 11 - 15 pages
- 16 - 20 pages
- Other

Q4. On average, how many pages do you have to scan for each RELM package for Marines within your command?

- None
- 6 - 10 pages
- 11 - 15 pages
- 16 - 20 pages
- Other

Q5. How often do RELM packages on Marines within your command get lost and have to restart the routing process?

- Never (0% of the time)
- Rarely (1% - 10%)
- Sometimes (11% - 30%)
- Often (31% - 50%)
- Always (51% - 100%)

Q6. How much do you agree with the following statement? "I always have visibility of RELM request within my command during the routing process."

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Q7. On average, how much time on average do RELM packages take to process within your command from submission to decision made by Manpower Management Enlisted Assignments (MMEA-1)?

- 1 week - 1 month
- 1 month - 2 months
- 2 months - 3 months
- 3 months - 4 months
- Other

Persona 3

I am a Marine that has gone through the reenlistment process and/or is currently going through the reenlistment process.

Q1. What motivates you the most to reenlist when deciding to reenlist?

Drag and drop the options below with the highest option being the most important, and the lowest option being the least important to you.

______ Retention Bonuses
______ Duty Station of Choice
______ Special Duty Assignment
______ Lateral Move to another MOS
______ Sense of Duty

Q1a. Please explain if there are other motivators not already mentioned in the comment box.

Q2. How much time did it take for your Reenlistment, Extension, or Lateral Move (RELM) package to process from start to submission?

- Less than 1 week
- 1 - 2 weeks
- 2 weeks - 1 month
- More than 1 month
- Other

Q3. Did your RELM package get lost while processing and had to be restarted?

- Yes
- No

Q4. How much do you agree with the following statement? "I always have/had visibility of my RELM request during the routing process."

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

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SUMMIT PANEL 1. INNOVATING DEFENSE: A FIRESIDE CHAT

Thursday, May 8, 2025	
0950 – 1050 PT 1150 – 1250 CT 1250 – 1350 ET	**Doug Beck, Director, Defense Innovation Unit and Senior Advisor to the Secretary of Defense** **Ann Rondeau, VADM USN (ret.), President, Naval Postgraduate School**

Doug Beck—is the Director of the Defense Innovation Unit and Principal Staff Assistant to the Secretary of Defense. In this role, he oversees efforts to accelerate the Department's adoption of commercial technology throughout the military and serves as principal liaison for the Department to the tech sector and other nontraditional defense companies and investors, as well as to related efforts by interagency and international allies and partners. He also serves as senior advisor to the Secretary and Deputy Secretary on technology innovation, competition, and strategic impact. In his previous experience with DIU, he founded and led its joint reserve component from inception in 2015 to 2019.

Prior to joining DIU, Doug was a Vice President at Apple and a direct report to its CEO, Tim Cook. From 2009-2023, he co-led global business development and sales functions, led Apple's businesses across Northeast Asia and the Americas, and, most recently, led several of the company's purpose-driven businesses worldwide, including in health, education, and other institutions of public impact.

Doug also previously served as Senior Vice President and Chief Strategy Officer at Charles Schwab Corporation. Prior to Schwab, he was a partner at McKinsey & Company, co-leader of McKinsey's global strategy practice, and a leader of other industry and functional practices in the United States and Asia. In 2000, he was elected as a McKinsey partner.

Currently a Captain in the U.S. Navy Reserve, Doug served in Iraq and Afghanistan from 2006-2007 with a joint special operations task force. He has also served extensively throughout the Asia Pacific region during his nearly 26 years of service, including command of a large joint reserve unit supporting U.S. Indo-Pacific Command in Pearl Harbor, Hawaii. His personal and unit awards include the Defense Superior Service Medal (two awards), the Bronze Star Medal, the Combat Action Ribbon, and the Presidential Unit Citation. As a civilian, he has been awarded the Department of Defense Medal for Distinguished Public Service, the highest civilian award conferred by the Secretary of Defense.

Doug holds a bachelor's degree summa cum laude from Yale and an M.Phil in International Relations from Oxford, where he was a Rhodes Scholar.

Ann E. Rondeau, VADM USN (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, support and student service.

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.

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).

She is a proud member of the Arizona State University Flag Officer Advisory Council, the National Museum of the American Sailor Foundation Board of Directors, the Military Advisory Board (under the aegis of Center for Naval Analysis), the Dwight D. Eisenhower Memorial Commission, the Chicago Regional Growth Corporation Board, Choose DuPage Board of Directors, and the Council for Higher Education Accreditation. Additionally, Dr. Rondeau serves on the Executive Board of the U.S. Navy "Education for Seapower Study" —a clean-sheet review of naval learning.

SUMMIT PANEL 2. AI-DRIVEN ACQUISITION: NAVIGATING SOFTWARE, PLATFORMS, AND COMPLIANCE

Thursday, May 8, 2025	
1100 – 1215 PT 1300 – 1415 CT 1400 – 1515 ET	**Chair: Randy Pugh, Col USMC (ret), AI Task Force Lead / AI Portfolio Director, Vice Provost, Warfare Studies, Naval Postgraduate School** ***A New Path Forward: An Analysis of Current AI Software Acquisition Procedures*** Richard Beutel, Senior Fellow, George Mason University ***Acquire AI - AI Platform for Acquisition Management*** Pradeep Krishnanath, Senior Vice President, TechSur Solutions LLC ***Unpacking the Authority to Operate (ATO) Process: Implications for the DoD*** Captain Grant Wilson, Contracting Officer, United States Air Force

Randy Pugh, Col USMC (ret.) joined the Naval Postgraduate School in 2019, where he served as the Marine Corps Senior Service Representative and Military Associate Dean of Research. He became Deputy Director of the Naval Warfare Studies Institute in 2020 and took on the role of Acting Director in 2022. In August 2023, he becomes the first permanent director of NWSI. In this position, he helps connect NPS to the Fleet Marine Forces and Headquarters Marine Corps and Navy on research topics of the highest priority and helps ensure that NPS' educational offerings satisfy the Navy's knowledge and skills requirements.

Colonel Pugh has spent the majority of his career as a Signals Intelligence / Electronic Warfare Officer, serving in command and staff billets at 1st Radio Battalion, as the SIGINT/EW Project Lead at Marine Corps Systems Command, as the Operations and Executive Officer at 3d Radio Battalion, and as the Commanding Officer of 2d Radio Battalion. He has deployed with the 31st Marine Expeditionary Unit (Special Operations Capable), I MEF, II MEF, Special Operations Command Pacific and Special Operations Command Europe to locations including Iraq, Afghanistan, and the southern Philippines. He recently served as the Commanding Officer of Marine Corps Intelligence Schools.

Colonel Pugh has a Master's degree in National Security and Strategic Studies from the Naval War College, a Master in Military Studies from the Marine Corps Command and Staff College, a Master of Science degree in Computer Science (Software Engineering) from Naval Postgraduate School, and a Bachelor of Science degree from United States Naval Academy. His NPS Master's thesis explored the use of artificial intelligence as a means to accelerate system integration.

A New Path Forward: An Analysis of Current AI Software Acquisition Procedures

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Abstract

Maintaining a competitive edge in AI enabled software requires sustained investment in research, development, and workforce training. But it also requires an evaluation of the specific acquisition tradecraft applicable to the procurement and deployment of transformative software technology.

Currently, contracts used for DoD software development programs, including software containing embedded AI elements, are negotiated using a hodgepodge of existing contract vehicles, accelerated procurement frameworks and acquisition tradecraft approaches.

While completely reinventing the wheel may be a bridge too far, we believe it helpful to examine the current status quo pertaining to software acquisition procedures and to evaluate how they can (or should) be improved, modified or even discarded in favor of a different approach.

The Unique Characteristics of AI-Based Software Technologies

> Victory or defeat in the air or in space at the human scale is likely to be determined by which combatant has fielded the most advanced AI technology in the areas most crucial to achieving victory. —Frank Kendall, Secretary of the Air Force (Easley, 2025)

Software has rapidly emerged as a transformative force across various sectors, and its significance for modern warfare cannot be overstated.

As noted by Air Force Secretary Frank Kendall in his congressionally mandated *Air Force 2050* Report, "It is likely these areas of advanced military technology will be manifest through the increasingly widespread use of autonomy and automation, in all domains, but especially in space, in cyberspace, and in the air" (Easley, 2025).

For warfighters—the individuals who engage in military operations—AI-based software technologies promise to revolutionize the battlefield by enhancing decision-making, operational efficiency, and survivability. As the global security environment becomes increasingly complex, the integration of software platforms with AI technologies will play a pivotal role in ensuring military readiness and superiority.

A defining characteristic of software-based technologies, including those that contain or exploit Artificial Intelligence (AI) is that they never work perfectly. As sure as the sun rises in the east, software technologies, including AI based software acquisitions, are problematic, generate frustration, and often fail.

That most software applications are riddled with imperfections is not due to deception by software developers. Absent evidence or facts otherwise, software inadequacies are par for the course for an industry that embraces imperfection as a fact of life. Simply put, software systems are rarely deemed complete in the same sense a finished good like a car might be. Instead, software applications are more appropriately considered works in progress or evolutionary drafts that provide increasing increments of better functionality over time.

As the renowned author of *Software Engineering*, Ian Sommerville (2016) stated, the "distinction between [software] development and maintenance is increasingly irrelevant…it is more realistic to think of software engineering as an evolutionary process where software is continually changed over its lifetime."

Software is imperfect because the cost of perfect software would overwhelm its value and make it economically impossible to purchase. For virtually all software development projects, the industry follows Facebook's Sheryl Sandberg's advice, "Aiming for perfection causes frustration at best and paralysis at worst" (Sommerville, 2016). Yet, the largest single buyer of IT in the world, the Federal Government, will continue to spend approximately $100 billion this fiscal year on IT services and products. Despite the inefficiencies and flaws, software applications usually work well enough, evolve over time to become better, and typically offer a solid return on investment. Imperfections in software have long been accepted as a fact of life. Generally, the inevitable list of flaws slowly, but surely, is corrected over time.

The Government Market for All Types of Software

The government has approximately 2 million software and/or cloud users. For most large commercial IT companies, the government is their single largest consumer. The government has enormous scale. For example, the Veterans Administration, a single agency, currently pays about $600 million per year for just Microsoft products.

The GAO broad estimates are useful but imprecise. Detailed government spending on software and cloud services by brand has never been available. Because most software and cloud are *resold* through government contractors, the brands that are purchased are hidden in the minutia of hundreds of thousands of contracts, which are not available to the public.

Nonetheless, using an average of $17.5 billion per annum, and GAO percentage estimates, the chart below illuminates the approximate market share the U.S. government holds of the top five software or cloud companies (see Table 1 and Figure 1). (Table 1 is an extrapolation by the author from GAO analysis of agency data. The exact percentages are unreported in the literature.)

Table 1. U.S. Government Market Share of Top Five Software or Cloud Companies

Software Company	GAO Gov't Spend Data	Gov't Revenue	Total Corp Revenue 2023	Gov't Revenue
Microsoft	31%	$5,425,000,000.00	$236,000,000,000.00	2%
Adobe	10%	$1,750,000,000.00	$20,000,000,000.00	9%
SalesForce	9%	$1,552,500,000.00	$35,700,000,000.00	4%
Oracle	7%	$1,207,500,000.00	$52,000,000,000.00	2%
ServiceNow	5%	$913,500,000.00	$9,400,000,000.00	10%

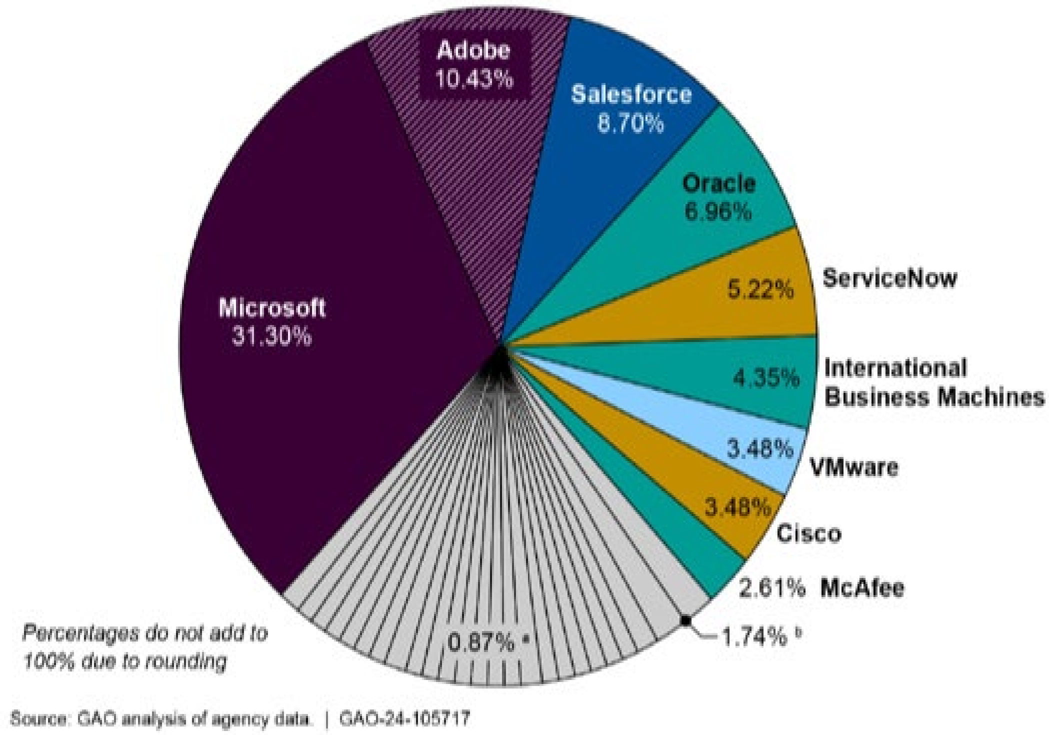

Figure 1. Software Vendors With the Highest Amounts Paid by Agencies for Fiscal Year 2021

In terms of acquisition policy, the government serves in two roles when it acquires pre-existing software-based AI or develops its own custom code. In one role, it procures goods and services to perform its essential functions and fulfill agency missions. During this process, as in the private sector, contracting officers are tasked with negotiating such terms as inspection, acceptance, risk of loss, title transfer, terminations, invoicing, and the like.

In its other role, the federal government "acts as the sovereign"—by driving public policies and imposing unique requirements to advance politically defined societal goals and to further those public policies (Section 809 Panel, n.d., Vol. 3).

These societal policies may indeed promote the public good, but in themselves carry costs that necessarily impose friction in the acquisition process by going well beyond the nature of the product or service being procured.

What are the relevant policy concerns that must be addressed when acquiring AI based software?

First, OMB should issue guidelines to define appropriate government use cases that are appropriate for software technologies that embody AI. For example, it may be a bad idea to give AI control over nuclear launch codes!

Working with tech companies, academia, and other stakeholders, OMB and the agencies can leverage the latest AI advancements and best practices to define appropriate boundaries for appropriate use cases for AI based software contracts. The characteristics of these use cases should reflect a review of such factors as security and ethical use, foster collaboration, provide proper training, and maintain continuous oversight and evaluation.

Second, acquisition tradecraft should adopt a robust evaluation framework to assess AI solutions based on scalability, security, compliance with federal regulations, and transparency.

Third, effective deployment considerations should address up front the best means to integrate AI systems with existing infrastructure, ensuring smooth integration and minimal disruption. New programs must ensure sufficient funding and proper budgeting for AI projects, recognizing their resource-intensive nature.

Fourth, laser-like focus should be applied to the implementation of robust cybersecurity measures. AI systems and sensitive government data must be protected through encryption, access controls, and regular security audits. One approach would be to centralize authority to oversee AI initiatives, ensuring coordination and consistency across federal agencies.

Finally, these contracts must design AI technologies to be fair, unbiased, and respectful of privacy.

Three Procurement Models Currently Predominate for Software Technologies

The current legal disposition of the government's software estate is a hybrid of older contracting models and newer contemporary contracting models stitched together in a complicated patchwork. The power over IT acquisition remains widely diffused. Each agency receives its own budget and makes its own IT acquisition decisions.

As a result, the government's purchase of IT is highly decentralized with little to no government-wide administration. From a technological trends perspective, although the government is not an earlier technology adopter, it has aggressively moved into cloud computing and AI-enabled technologies over the last decade and is now moving into AI embedded software as well.

The mixture of older and newer legal models means that the delivery, licensing, and applicable Terms and Conditions for AI software are as varied as the items purchased. Our research concluded that there are dominant models but no monolithic or one size fits all approach.

Other than the boilerplate terms and conditions that come from shared governmentwide contracts, like the GSA Multiple Award Schedules and NASA SEWP contract vehicles, government purchasers are largely left to their own devices when it comes to AI software acquisitions, including any warranties (or lack thereof).

When the government does review software contract terms, the focus is typically on eliminating potential illegalities in agreements rather than receiving the most useful terms.

Furthermore, because acquisition authorities are agency-based, and agencies only make large software acquisitions every three to five years, they are largely outgunned by the software providers who sell to consumers every day. There is a marked asymmetry of knowledge and expertise, in favor of software companies, despite the enormous spending power of the government. This asymmetry is particularly acute when it comes to AI software acquisitions. It is not unusual for the Contracting Officer responsible for the purchase of AI based software to be more focused on adherence to the procurement rules than on an understanding of the technologies being purchased (Section 809 Panel, n.d., Vol. 3).

At present, there are three dominant acquisition models for AI software: perpetual licensing models, services-based (SaaS) acquisitions based on the cloud, and bespoke (or custom built) AI based software development models. We will discuss the status quo and offer some recommendations regarding each of these prevailing acquisition models.

Existing Contract Models for All Forms of Software: Perpetual License Approach

A common approach to software acquisitions by government is the perpetual license model. Under the perpetual licensing model, the government purchases the right to use the software in perpetuity and then pays an annual maintenance fee to get the latest updates to the code. This is the traditional legal licensing style construct that governed the first generation of software distribution. It reflects significant historical development around “commercial Off the Shelf” or COTS procurements under FAR Part 12.

This “commercial first” acquisition policy is important because of the fashion in which it has been implemented. To meet this policy, the government is charged to adopt standard commercial contract terms, which presumably include industry standard warranty disclaimers and liability cap.

FAR Part 12 is the regulatory and contractual implementation of the statutory mandate (GSA, n.d.).

FAR Part 12 is intended to promote competition, save the government money, and expedite the acquisition of commercial items, including specifically commercial software products. It is also intended to encourage businesses to sell their products and services to the government by providing them with a more streamlined and efficient contracting process.

Under these provisions, the Government is charged to start negotiations with the standard, commercial terms and conditions offered in the private sector by the cybersecurity technology provider. For COTS technologies, the government *must adopt commercial terms and conditions in existing technology agreements unless they violate federal procurement law* (GSA, n.d.).

Commercial software acquisition guidelines are set forth in Federal Acquisition Regulation (FAR) Part 12, which outlines policies and procedures for the acquisition of commercial items by 227.7202-1 Policy.

> “(a) Commercial computer software or commercial computer software documentation *shall be acquired under the licenses customarily provided to the public unless such licenses are inconsistent with Federal procurement law or do not otherwise satisfy user needs*” (FAR 48 C.F.R. 52.227-19, 2007).

Furthermore, in the later provisions of FAR 227.7202-3, the Government is expressly cautioned to not overreach when demanding additional rights and concessions from commercial technology vendors.

The intent of the FAR Part 12 Commercial Items regime is for the government to get the benefit of purchasing ordinary consumer goods and services as closely as possible to the way ordinary consumers purchase the exact same goods and services.

AI issues are relevant under this model, particularly on-premises, perpetually licensed AI based software using perpetual licenses. Here in general, all warranties of any kind are typically disclaimed using the prescription for warranty disclaimers found in Article 2 of the UCC.

Controversially, this type of acquisition has often been equated to the purchase of a tangible good for legal analysis or Uniform Commercial Code (UCC) purposes. Here the user takes possession of the software and may use it in any way that does not violate the usage restrictions of the license agreement. Often this software is used on-premise in facilities controlled by the user. Typical usage restrictions mandate against illegal copying with concern for limiting usage to only those who have been granted permission per the agreement.

SaaS Based Software Acquisitions

As with the technologies themselves, the procedures and techniques used by government to acquire and deploy AI based software technologies have not stood still.

While the basic framework embodied in FAR Part 12 still forms an important structure for these types of software technology procurements, agencies have increasingly adopted and evolved other approaches.

One fundamental shift that is occurring within the industry itself (and therefore the fashion in which government acquires and deploys AI based software technologies), is a fundamental shift from FAR Part 12 commercial product offerings to Software as a Service (SaaS) subscription models.

Since the early 2000s, with the advent of cloud computing, usage and legal models have shifted to a services-based paradigm. The user agrees to pay an annual subscription fee or a periodic consumption-based fee. Here the item being purchased is more readily equated to a service offering. The user never takes possession of the software. It is exclusively controlled by the software provider. The provider maintains it and upgrades it on its own schedule. The software resides outside the four walls of the agency. The user accesses it via a web browser. The user only pays for the actual usage of the application. In the strictest sense (although, not always followed) users pay after consumption of the software service in arrears, on a monthly, or other periodic basis.

As the industry evolves in turns of its business and product delivery model(s), the majority of AI vendors have begun to coalesce around the SaaS model. Users do not control the hosting of the application. Basically, the SaaS model restructures government requirements regarding the manner of their fulfillment. SaaS acquisition models fulfill government requirements by turning them into service offerings under service ordering agreements (called “Service Level Agreements” or SLAs).

Acquiring SaaS creates some unique problems from an acquisition policy perspective. For one thing, these technological offerings are delivered as a service, not as a product. The basic structure of any warranty under these forms of agreement must necessarily differ. The characteristics of service contracts differ substantially from the procurement of tangible goods. Warranties must be adapted to service delivery models instead of tangible product deliveries.

First, unlike product offerings, such issues as warranties, risk of loss, and delivery terms do not neatly translate to service offerings, where performance quality, expertise, and duration are more critical factors.

Second, service contracts often involve considerations like skill, diligence, and outcome, which are subjective and cannot be standardized as easily as terms for products. The performance of services is evaluated based on different criteria, such as professional standards and specific client needs.

Third, services are typically governed not by the UCC but by caselaw applicable to services contracts, which deal with individual fact patterns and therefore provide the necessary flexibility to address the unique aspects of service agreements. Common law allows for a more nuanced and tailored approach, considering factors like implied duties and reasonable expectations.

Challenges for SaaS-Based AI Acquisitions

Given the trend to broader SaaS acquisition models for AI software procurements, two fundamental problems must be addressed.

First, these models are essentially "subscription services." A subscription model is just what the name entails—the payment of a subscription fee, often up front, for a set period, tied to a number of "seats," for access and use of the service offering.

The use of subscription models was initially created for research and library services—such as LEXUS/NEXUS or Bloomberg. The model has spread, however, beyond these types of service offerings to encompass subscription-based AI technologies.

In the context of government procurement, subscription models have several structural problems. First off, the government's archaic and cumbersome appropriations process prevents the government from availing itself of multi-year discounts, which often provide significant cost savings.

To address these concerns, the GSA (2024) recently issued a procurement memo that clarified that a subscription payment was not to be deemed an impermissible "advance payment" banned by the Anti-Deficiency Act. This acquisition memo clarified that upfront payments for software licenses accessed via Software-as-a-Service (SaaS) do not constitute advance payments under specific conditions. This guidance allows federal agencies to use subscription-based pricing models for SaaS offerings without violating advance payment regulations.

The conditions specified in the memo include:

- The software must be accessible immediately upon payment.
- The procurement must be on a fixed-price or fixed-price with an economic price adjustment basis.
- The billing model must not be based on usage or consumption metrics other than quantity. (GSA, 2024).

This clarification aims to align GSA's procurement policies with modern software delivery methods, making it easier for agencies to adopt cloud-based solutions and streamline the acquisition process.

The second major challenge with SaaS based acquisition models is the warranty problem. Warranties are critical components of all forms of service offerings and provide customers with assurance and security regarding the quality and reliability of the services they purchase.

In the private sector, services warranties take on a distinctly different character. A typical services warranty from a major hyperscaler is as follows:

> 8. Disclaimers.
> THE SERVICES AND AWS CONTENT ARE PROVIDED "AS IS." EXCEPT TO THE EXTENT PROHIBITED BY LAW, OR TO THE EXTENT ANY STATUTORY RIGHTS APPLY THAT CANNOT BE EXCLUDED, LIMITED OR WAIVED, WE AND OUR AFFILIATES AND LICENSORS (A) MAKE NO REPRESENTATIONS OR WARRANTIES OF ANY KIND, WHETHER EXPRESS, IMPLIED, STATUTORY OR OTHERWISE REGARDING THE SERVICES OR AWS CONTENT OR THE THIRD-PARTY CONTENT, AND (B) DISCLAIM ALL WARRANTIES, INCLUDING ANY IMPLIED OR EXPRESS WARRANTIES (I) OF MERCHANTABILITY, SATISFACTORY QUALITY, FITNESS FOR A PARTICULAR PURPOSE, NON-INFRINGEMENT, OR QUIET ENJOYMENT, (II) ARISING OUT OF ANY COURSE OF DEALING OR USAGE OF TRADE, (III) THAT THE SERVICES OR AWS CONTENT OR THIRD-PARTY CONTENT WILL BE UNINTERRUPTED, ERROR FREE OR FREE OF HARMFUL

> COMPONENTS, AND (IV) THAT ANY CONTENT WILL BE SECURE OR NOT OTHERWISE LOST OR ALTERED.
> 9. Limitations of Liability.
> 9.1 Liability Disclaimers. EXCEPT FOR PAYMENT OBLIGATIONS UNDER SECTION 7, NEITHER AWS NOR YOU, NOR ANY OF THEIR AFFILIATES OR LICENSORS, WILL HAVE LIABILITY TO THE OTHER UNDER ANY CAUSE OF ACTION OR THEORY OF LIABILITY, EVEN IF A PARTY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH LIABILITY, FOR (A) INDIRECT, INCIDENTAL, SPECIAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES, (B) THE VALUE OF YOUR CONTENT, (C) LOSS OF PROFITS, REVENUES, CUSTOMERS, OPPORTUNITIES, OR GOODWILL, OR (D) UNAVAILABILITY OF THE SERVICES OR AWS CONTENT (THIS DOES NOT LIMIT ANY SERVICE CREDITS UNDER SERVICE LEVEL AGREEMENTS).
> 9.2 Damages Cap. EXCEPT FOR PAYMENT OBLIGATIONS UNDER SECTION 7, THE AGGREGATE LIABILITY UNDER THIS AGREEMENT OF EITHER AWS OR YOU, AND ANY OF THEIR RESPECTIVE AFFILIATES OR LICENSORS, WILL NOT EXCEED THE AMOUNTS PAID BY YOU TO AWS UNDER THIS AGREEMENT FOR THE SERVICES THAT GAVE RISE TO THE LIABILITY DURING THE 12 MONTHS BEFORE THE LIABILITY AROSE; EXCEPT THAT NOTHING IN THIS SECTION 9 WILL LIMIT YOUR OBLIGATION TO PAY AWS FOR YOUR USE OF THE SERVICES PURSUANT TO SECTION 3, OR ANY OTHER PAYMENT OBLIGATIONS UNDER THIS AGREEMENT. (Amazon Web Services, n.d.; *the language is in all caps by operation of law*)

This hyperscaler disclaims all warranties and sells its services strictly “as is,” meaning they make no claims regarding its application or use. Should a user successfully bring any claim under any legal theory, this hyperscaler limits the amount of damages to 12 months of previous payments.

So far, no major player in the cloud services space has offered anything substantially different.

Other typical SaaS service warranties can be broadly categorized into several types, each serving different purposes and offering varying levels of coverage and assurance:

Performance Warranties

These warranties guarantee that a service will be performed to a specific standard or within a certain timeframe. For example, an IT support service might guarantee a certain level of system uptime or a response time for critical issues.

Satisfaction Guarantees

These warranties promise that customers will be satisfied with the service provided, offering remedies such as refunds or repeat services if the customer is not satisfied. For instance, a cleaning service might offer a satisfaction guarantee, pledging to re-clean the space if the customer is not happy with the initial service.

Service Level Agreements (SLAs)

SLAs are common in industries such as telecommunications and IT services. They outline the expected level of service, including metrics like response times, availability, and performance standards. SLAs are often detailed contracts that specify penalties or compensation if the service provider fails to meet the agreed standards.

Maintenance Warranties

These warranties ensure that regular maintenance services and updates will be provided and to keep equipment functioning optimally. Maintenance warranties often include scheduled inspections, upgrades and repairs.

Other categories of service warranties address the personnel, how the work is to be performed, and establish a contractual floor (they will perform the work "in a good and workmanlike fashion") regarding the conduct of the service.

In reviewing these various types of warranties, SLAs may be the most helpful as they directly address the quality of the services provided. They embody specific, measurable metrics to which the service provider must adhere. If warranty liability limitations were to be applied to SLAs, it has the potential to create "direct line of sight" between the actual performance of the service offering and the fashion in which the underlying code base was designed and implemented.

But clearly some kind of "content warranty" should be reasonable. This form of warranty might provide that the subscription content is up to date, i.e., "current, accurate and complete" (the standard for cost and pricing information submitted under cost reimbursement contracts and a well understood concept in government contracting law).

It might also warrant that the content may be lawfully provided to the end use, in the sense that it does not infringe upon, or impermissibly contain, content that is protected by a third party's intellectual rights.

What may be a "bridge too far," however is any kind of warranty that purports to address specific outcomes based upon the use or deployment of the subscription content. Of course, no software producer can warrant the *outcome* achieved by application of a service offering, i.e., the specific results obtained by an agency when it utilizes the service in performance of the agency mission. There are simply too many variables and interdependencies governing specific outcomes. These concerns apply in spades when AI capabilities enter the picture.

No producer can offer a warranty regarding how its service *is applied* to an agency mission set and how it used in practice by a federal customer. Software producers cannot be held responsible for the job performance of federal employees.

An "outcomes-based" warranty would most likely be deemed a stretch, given that the service provider has no control (or even visibility) into the infinite ways that the subscription content may be put to use by the government or any other end user.

DoD: A Closer Look at Software Acquisition Policy for the Warfighter

Within the DoD, these existing procurement models have played out in the context of a dismal government-wide history of major (and very expensive) IT project failures. In 2015, the Standish Group analyzed over 25,000 software application development projects across both industry and the government and determined that 24% of all custom software development projects for government failed, while 55% were "challenged" and only 21% were considered successful. Only 40% of all projects, government or otherwise, were completed on time. Only 44% were completed on budget (Standish Group, 2015).

That only 40–44% of development projects finished on time and on budget is important. Time is always the invisible force behind every project. It is not unusual for software development projects to be overloaded with features, ultimately making it impossible to meet optimistic deadlines. Every development project has a notional schedule, and as difficulties are encountered and projects begin to fall behind, sometimes there is external pressure to meet the deadline, rather than 100% of the requirements. According to the Standish Report, this decision process would likely occur in about 60% of bespoke custom projects (Standish Group, 2015).

As described in *The Washington Post*, in 2015, the Government Accountability Office (GAO) listed a litany of failed federal and DoD IT projects, including:

- DoD's Expeditionary Combat Support System: canceled after failure to deploy and more than $1B expended.
- DHS's Secure Border Initiative Network Program: canceled after $1B obligated, could not meet viability standards.
- VA's Financial and Logistics Integrated Technology Enterprise Program: terminated after $609M expended.
- NOAA's National Polar-orbiting Operational Environmental Satellite Systems: terminated after approximately $5B spent. (Ravindranath, 2014).

None of these canceled projects were implicated in fraud, were the subject of a qui tam (whistleblower) proceeding, or were mired in criminal controversy. They failed for the reason most fail: because they are hard, because it is software and because humans are fallible. To stay ahead, the DoD recognized that it must build strong, secure software quickly. This means software that is reliable, safe from cyber threats, and delivered fast enough to maintain its competitive edge.

Recognizing this lengthy track record of IT development failure, in 2022, the DoD pushed out a comprehensive DoD Software Modernization Policy (DoD, 2022). This policy was necessitated by the very poor track record by the government in developing its own government-unique IT systems. As previously described, it is a record unsullied by success.

The DoD's software modernization policy established several key metrics to advance modern agile software deployment across the DoD enterprise (DoD, 2022).

Security, Stability, and Speed Matter Equally

Speed is important, but the DoD can't sacrifice security or reliability. DoD software must be dependable and resistant to cyber threats while still being built efficiently. The key is adopting modern development methods that focus on security and performance at every step.

Smarter Use of Cloud and Data

Cloud technology and data management are essential to software modernization. The DoD must move quickly to the cloud and follow best practices for handling data to improve capabilities and decision-making.

Enterprise-Wide Solutions

The DoD acknowledged that it has to be smart about spending. Instead of funding multiple overlapping software projects, the focus should be on shared enterprise solutions that help the entire department save money while still being effective.

No One Left Behind

Software modernization isn't just about new technology, it's about people. DoD leadership must invest in training and upskilling the workforce so that employees can take full advantage of new tools and automation.

More Than Just Code

Writing code is only one part of software modernization. The DoD understood that it must also streamline policies, contracts, and processes to make it easier to develop, buy and implement software efficiently.

The DoD also recognized that no matter how software is acquired, it must be continuously updated. Software isn't a one-time purchase—it requires constant improvements to stay secure and effective.

Use Design Patterns

These are pre-made solutions that speed up development and ensure security. Automating common software tasks—like setting up cloud environments—makes software delivery faster and more consistent.

Improve Cloud Contracts

The DoD must have easy, fast access to commercial cloud services. This means improving the way cloud contracts are structured to avoid delays that could put military operations at risk.

Make Software Purchases More Flexible

The DoD needs faster, more flexible ways to buy and fund software projects, ensuring that critical technology is delivered without unnecessary delays.

DoD Implements Its Modernization Policy by Adopting Agile Development Techniques

Implementing the new software modernization policy is a sea change by the DoD in terms of its core software development techniques. When it comes to being a special case for software, the DoD is often unique. Putting aside embedded code for weapons systems, much of the DoD software estate is fundamentally different from the commercial market. For many years, the DoD pressed forward with custom built software using the so-called "waterfall" design methodology (DoD, 2020).

"[A traditional waterfall development lifecycle builds the entire product with a single delivery at the end, thereby increasing the risk of either delivering the wrong product or not successfully delivering a product. End-user feedback is generally not received until the full solution is developed, and the end-user receives no value potentially for years" (DoD, 2020).

As a result of these numerous IT program failures, the government concluded that software should no longer use a "waterfall" design approach but should be developed and delivered in iterative stages under a process called agile or rapid prototyping. This process calls for the development of software in "bite sized" portions under a protype type of contracting structure.

Agile software development is an iterative and flexible approach that focuses on collaboration, adaptability, and continuous improvement. Unlike traditional waterfall models, which rely on extensive upfront planning and rigid processes, Agile allows teams to respond quickly to changing requirements and customer needs. Agile methodologies, such as Scrum, Kanban, and Extreme Programming (XP), emphasize incremental development, where software is built in small, manageable iterations known as sprints. This approach ensures that teams can make adjustments throughout the development cycle, leading to more efficient and high-quality software solutions.

The purpose is for the product to be developed and tested iteratively so that it may "fail early/fail fast" if it is inadequate or improperly designed. The focus is on rapid failure and revisions.

Agile methods outperform traditional software development approaches for several key reasons (DoD, 2020).

Flexibility and Adaptability

Agile's iterative nature enables teams to reassess priorities and make changes as needed. This ensures that software remains relevant and aligned with evolving business needs and technological advancements.

Enhanced Collaboration and Communication

Agile fosters a culture of teamwork and transparency. Regular meetings, such as daily stand-ups and sprint reviews, keep all stakeholders informed and engaged, reducing misunderstandings and promoting shared goals.

Faster Time-to-Market

By breaking projects into smaller increments, Agile teams can develop, test, and deploy functional software quickly. This allows organizations to introduce new features and improvements faster, maintaining a competitive edge.

Improved Product Quality

Continuous testing and feedback integration ensure that defects are identified and addressed early. Techniques like automated testing, pair programming, and frequent code reviews enhance software reliability and performance.

Higher Customer Satisfaction

Agile prioritizes customer involvement, ensuring that their feedback is incorporated throughout the development process. This leads to a product that better meets user needs and expectations, fostering trust and long-term client relationships.

The DoD implemented an agile design approach by creating six new acquisition pathways, including specifically a software acquisition pathway to accelerate the development and delivery of software (DoD, 2020).

In 2020, the DoD issued a detailed guide regarding its current thinking about how best to contract for agile software development using the software acquisition pathway (DoD, 2020). The Guide sought to record "lessons learned" and best practices from the Congressionally mandated Agile pilot program codified in the FY2028 National Defense Authorization Act. It emphasized that Agile development requires a shift from traditional waterfall contracting to more flexible, modular approaches that align with Agile principles of emergent and adaptive planning.

> One of the key differences between an Agile project and traditional waterfall project is that Agile principles align with emergent and adaptive planning and design principles, whereas waterfall projects are focused on predictive planning and upfront design readiness. Agile teams expect to learn through continuous experimentation and continuous delivery. The Agile teams anticipate the need for change or modification of requirements and design as they learn from the fast feedback loops. (DoD, 2020)

Although noting that "there is no single recommended contracting strategy for an Agile software development effort," the Guide advocates for modular service contracting principles, noting that modular service contracts are preferred in Agile environments, allowing the government to acquire contractor expertise and skillsets while enabling continuous reprioritization without contract modifications (DoD, 2020).

> For these reasons, the acquisition of services over specific product deliverables becomes an important consideration in Agile development efforts. Traditional IT acquisition programs contract to deliver a product capability based on a defined set of "complete" requirements. (DoD, 2020)

The Guide embraces modular services contracting as a means of reducing risk by managing smaller contracts, incentivizing performance, and enabling continuous innovation.

Modular services contracting aims to develop discrete capabilities fitting into an overall technology vision based upon smaller acquisition increments. These increments should be simpler to manage than a single "big bang" waterfall approach, allow complex IT objectives to be addressed incrementally to maximize the likelihood of a workable system, and provide for the delivery of testable working solutions, "each of which comprises a system or solution that does not depend on any subsequent increment in order to perform its principal functions."

In terms of acquisition tradecraft, modular services contracts have different attributes and considerations. A modular services contract is based on the performance of contractor labor hours, not delivery of some unitary defined product. The Guide notes that FAR Part 16.5 procedures allow for task orders against existing contracts, such as GWACs, MACs, and agency-specific IDIQ contracts, to acquire platform and integration subscriptions, microservices, and other services.

The Guide recommends shorter periods of performance (one year or less) with options for additional support to avoid long-term commitments if contractor performance is unsatisfactory.

It also discussed intellectual property strategies, seeking to ensure the government only pays for necessary IP, considers deferred ordering, and includes clear guidance on data rights and access in case of early contract termination.

In this context, no form of product warranty can be assigned because the "product" is a hybrid base of code under rapid evolution and change. It would seem in this context that the warranty framework should reflect the fashion and means by which the developers conduct themselves—in other words, a professional services style of warranty.

Progress toward implementing this new software acquisition pathway has been slow, however, with (as of 2024) only 50 programs utilizing the new approach (Obis, 2024).

Recent press reports suggest that the DoD is seeking to optimize the software acquisition pathway to specifically address AI based software developments. All of this changed on March 6, 2025, when the DoD issued a much-anticipated acquisition memorandum squarely addressing a new path forward for DoD-centric software procurements.

DoD Fully Embraces Agile Development Techniques With a New Procurement Concept: OTA Based CSOs

As noted, the DoD has long recognized the need to evolve its software acquisition strategies to keep pace with the rapid technological advancements and increasing demands for agile and efficient military capabilities. In the transcript dated March 7, 2025, titled "Directing Modern Software Acquisition," significant insights were provided regarding the newly issued March 7, 2025, DoD Memorandum entitled *Directing Modern Software Acquisition to Maximize Lethality* (DoD, 2025).

The DoD's new approach leverages the lessons learned from its previous pilot programs as well as the operational history of the Defense Innovation Unit (DIU). It seeks to address deficiencies that arise from using traditional acquisition methods, often leading to delays and poor outcomes. This pathway focuses on rapid deployment and iterative development. By fostering agile-like collaboration between government entities and private sector partners, the DoD aims to accelerate the delivery of mission-critical software.

Recognizing the vital role that the private sector plays in software development, the new pathway emphasizes enhanced collaboration with industry partners. The DoD emphasizes that it is actively seeking to establish partnerships with innovative tech companies, startups, and research institutions to tap into their expertise and cutting-edge technologies. This collaborative approach not only helps to access a broader range of solutions but also encourages knowledge sharing and innovation. As noted in DoD press comments about the new acquisition memorandum:

> So right now, the way the Pentagon buys software is slow, outdated and filled with bureaucracy. Meanwhile, our adversaries are moving fast. This memo is the beginning to fix that, cutting red tape, working more with private industry, getting cutting edge software into the hands of our warfighters quickly before the enemy can adapt. And one of the biggest changes is using flexible contracting tools, CSOs and OTs to speed up innovation and acquisition. (DoD, 2025)

One of the most notable features of the new software acquisition pathway is its full-throated embrace of agile development methodologies. This approach allows for continuous integration and delivery, enabling teams to respond swiftly to changing requirements and user feedback. The framework encourages iterative development cycles, where software can be tested, evaluated, and refined in shorter timeframes. This is crucial in a military context, where the ability to adapt to new threats and operational environments can determine, often, mission success.

Another important aspect of the new pathway is the establishment of cross-functional teams. These teams bring together experts from various domains—including software engineering, cybersecurity, user experience, and operational planning—to collaborate on software development projects. By breaking down traditional silos, the DoD aims to leverage diverse perspectives and expertise, leading to more holistic and effective software solutions.

The new pathway also seeks to simplify acquisition processes by reducing bureaucratic hurdles. This includes streamlining documentation requirements and minimizing the number of approvals needed at various stages of development. By doing so, the DoD aims to empower program managers to make decisions more rapidly, allowing for quicker responses to emerging needs and opportunities.

Furthermore, the development of the new software acquisition pathway promotes the use of open-source software and modular architectures, which can significantly enhance interoperability and reduce costs. By adopting these strategies, the DoD can foster a more collaborative development environment and leverage existing technologies, thus accelerating the timeline for new capabilities.

Specific Contract Structures That Best Leverage the Agile DoD Approach

The DoD software acquisition memorandum establishes OTA-based contracts using Commercial Solutions Opening (CSO) acquisition procedures. As the DoD briefed the press when releasing its software acquisition memorandum:

> So, when we take that software pathway mechanism and we combine it with innovation that DIU has been working in commercial solutions openings, or CSOs, and other transaction authorities, OTAs, we get to the point where now we can expose the program, the software programs, to nontraditional and commercial software developers while we simultaneously lower the barrier for those nontraditional and commercial software developers to get in to defense programs of record. (DoD, 2025)

By way of a quick background, Other Transaction Authority (OTA) based contracts have emerged as a flexible and innovative procurement method, particularly within the DoD and other federal agencies (Defense Acquisition University, n.d.).

These contracts differ significantly from traditional procurement mechanisms by allowing agencies to bypass many of the regulatory constraints associated with the Federal Acquisition Regulation (FAR). OTAs enable rapid prototyping, development, and deployment of cutting-edge technologies by fostering collaboration between government entities, private industry, and non-traditional contractors.

Some of their primary benefits are:

Flexibility and Reduced Bureaucracy

Unlike FAR-based contracts, OTAs are not bound by extensive government regulations, allowing for streamlined negotiation and execution. This flexibility accelerates project timelines and reduces administrative burdens.

Encouragement of Innovation

OTAs are designed to attract non-traditional contractors and startups that may not typically engage with government contracts due to complex regulatory requirements. This encourages fresh ideas and technological advancements.

Rapid Prototyping and Development

One of the primary purposes of OTAs is to support fast-paced research and development (R&D). They enable iterative testing and refinement of prototypes before full-scale production, reducing risks and improving final outcomes.

Collaborative Approach

OTA agreements often involve a high degree of collaboration between government agencies, private companies, and academic institutions. This partnership-driven model fosters a cooperative environment for technological breakthroughs.

Customized Agreement Terms

Unlike standard contracts, OTAs allow negotiators to tailor terms to fit the specific needs of a project, ensuring a more effective alignment between government requirements and industry capabilities.

Also, the Commercial Solutions Opening (CSO) approach is a procurement strategy used primarily by government agencies, such as the DoD, to acquire innovative commercial products, services, or technologies in a streamlined and flexible manner. It's designed to encourage competition, attract non-traditional vendors (e.g., startups or companies that don't typically work with government), and expedite the acquisition process compared to traditional methods like the Federal Acquisition Regulation (FAR) based solicitations. The CSO process emphasizes outcome-based requirements and leverages commercial market practices rather than rigid government specifications (Defense Acquisition University, n.d.).

A CSO approach encompasses the following attributes:

1. Broad Solicitation

Instead of a detailed, prescriptive request for proposals (RFP), a CSO issues a broad problem statement or desired outcome (e.g., “enhance cybersecurity for cloud-based systems”). Vendors are invited to propose innovative commercial solutions that address the need.

2. Flexible Evaluation

Proposals are evaluated based on their technical merit, feasibility, innovation, and cost-effectiveness rather than strict compliance with predefined specs. Peer reviews or expert panels often assess submissions.

3. Commercial Item Focus

Solutions must qualify as “commercial items” under FAR Part 12, meaning they’re already available in the marketplace, customized from commercial products, or developed using commercial practices.

4. Simplified Process

The CSO skips some of the bureaucratic steps of traditional procurement, allowing faster award timelines. Contracts can be fixed-price, other transaction agreements (OTAs), or similar mechanisms.

5. Iterative Engagement

Agencies can down-select vendors through phases (e.g., concept papers, pitches, prototypes), fostering collaboration and refinement before final awards.

When applied directly to AI embedded software procurements, the CSO approach aligns well with the fast-evolving nature of AI software development and the commercial AI software market. Here’s how it works in practice:

1. Problem-Driven Solicitation

Instead of specifying a particular software stack or architecture (e.g., “must use Java and run on Oracle databases”), the agency might issue a CSO stating, “We need a scalable solution to manage real-time data analytics for 10,000 users.” This invites vendors to propose diverse solutions, such as SaaS platforms, custom-built tools, or open-source adaptations.

2. Encouraging Innovation

Software startups or companies with cutting-edge AI, cloud, or DevSecOps tools—often excluded from traditional procurements due to complex compliance requirements—can pitch their products. For example, a vendor might offer a machine learning-based cybersecurity tool already used by private industry, adapted for government needs.

3. Evaluation Flexibility

Proposals might include demos, proof-of-concept code, or access to existing platforms rather than lengthy documentation. Evaluators could assess based on usability, scalability, security, and alignment with commercial best practices, rather than checking boxes for government-specific standards.

4. Commercial Software Focus

The CSO prioritizes off-the-shelf (COTS) or minimally customized software. For instance, an agency might procure a commercial project management tool like Jira or a cloud platform like AWS, tailored slightly for specific security protocols. Open-source software could also qualify if it’s commercially supported or widely adopted.

5. Rapid Acquisition

Traditional software procurements can take months or years due to detailed RFPs and protests. A CSO might award a contract in weeks by selecting a vendor after a pitch day or prototype phase. Example: An agency needs a collaboration tool. After a CSO, vendors like Slack, Microsoft (Teams), and a niche competitor submit proposals. The agency picks one after a quick demo round.

6. Phased Approach

For complex software needs (e.g., a new logistics system), the CSO could start with white papers, move to a prototype phase, and end with a full deployment contract, reducing risk and allowing iterative feedback.

Applying Best Practices, Specific Recommendations

Negotiating an Agile-based software development contract requires careful consideration to ensure that both parties align on expectations, responsibilities, and outcomes. Unlike traditional fixed-price contracts, Agile contracts must accommodate evolving requirements and continuous feedback loops. Here are some of the best practices utilized in the commercial sector to draft agile development contracts:

1. Define Project Scope with Flexibility

While Agile development emphasizes adaptability, the contract should establish an initial project vision and objectives. Instead of rigidly defining every feature upfront, the contract should outline high-level deliverables and expected business outcomes while allowing room for evolving requirements. This approach ensures that both parties share a common understanding of the project's goals without stifling Agile's iterative nature.

2. Establish a Transparent Pricing Structure

A well-structured Agile contract should balance financial predictability with the flexibility required for iterative development. Common pricing models include time-and-materials (T&M), capped T&M, and fixed-price per sprint. Clearly, defining how costs will be measured and adjusted throughout the development process helps prevent financial disputes while ensuring the development team is adequately compensated for their work.

3. Incorporate Change Management Mechanisms

Change is a fundamental aspect of Agile development, and the contract should reflect this reality. It is essential to include mechanisms for managing changes in scope, priority, or functionality. Agreements should specify how changes will be documented, evaluated, and approved, ensuring that both parties remain aligned throughout the project lifecycle.

4. Define Roles and Responsibilities Clearly

Effective Agile contracts clearly define the roles and responsibilities of all stakeholders, including the development team, product owner, and client representatives. This prevents misunderstandings and ensures that collaboration remains productive. The contract should also outline expectations regarding participation in Agile ceremonies, such as sprint planning, daily stand-ups, and retrospectives.

5. Align Incentives with Performance and Outcomes

To foster a successful partnership, the contract should include incentive mechanisms that align with project success. Performance-based payments, milestone achievements, and bonuses for early or high-quality delivery encourage both parties to focus on delivering value rather than merely completing predefined tasks.

6. Ensure Clear Communication and Dispute Resolution

Given the iterative nature of Agile projects, maintaining open and transparent communication is critical. The contract should establish regular check-ins, feedback loops, and escalation procedures to resolve disputes efficiently. Well-defined conflict resolution mechanisms can help mitigate risks and ensure a smoother development process.

Negotiating an Agile software development contract requires a balance between flexibility and structure. By defining a high-level scope, establishing a transparent pricing model, incorporating change management processes, and ensuring clear communication, both parties can maximize the benefits of Agile development. Well-crafted contracts facilitate collaboration, enhance adaptability, and improve the chances of project success, making them an essential component of modern software development agreements.

When implementing its new CSO/OTA acquisition methodology, the DoD would be well served to adopt the best practices pioneered by industry in structuring its software development agreements, especially those that embed or incorporate AI-based technologies.

Conclusion

The introduction of the new DoD software acquisition pathway marks a significant shift in how the Department approaches the development and procurement of software solutions.

By embracing Agile methodologies, fostering collaboration, simplifying processes, and engaging with industry, the DoD aims to create a more dynamic and responsive acquisition environment.

This transformation is essential for ensuring that the U.S. military remains at the forefront of technological advancements, capable of addressing the evolving challenges of modern warfare and delivering national security.

As these changes are implemented, the hope is that they will lead to more effective software solutions that enhance the operational capabilities of the armed forces, ultimately contributing to mission success in an increasingly complex global landscape.

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AcquireAI - AI platform for Acquisition Management

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Abstract

The Department of Defense (DoD) acquisition process is a complex, time-consuming life cycle that often struggles to keep up with rapid technological advancement. This paper explores how generative artificial intelligence (AI) can significantly accelerate and enhance defense acquisitions by automating routine tasks and supporting human decision-making. Focusing on TechSur's "AcquireAI" platform as a case study, we examine AI-driven efficiencies in acquisition planning, market research, drafting of Requests for Proposals (RFPs) and contracts, and source selection evaluations. Key research questions address integrating AI solutions into existing DoD procurement IT frameworks (like the Air Force's CON-IT contract-writing system and KT File Share repository), ensuring regulatory compliance through AI-driven checks, and evaluating the impact on acquisition speed, cost, and accuracy. The paper outlines a comprehensive technical solution for deploying generative AI in secure DoD environments and presents anticipated improvements (e.g., substantial reductions in procurement lead times and administrative workloads). Our findings indicate that leveraging generative AI can enable faster acquisition cycles, enhanced compliance and transparency, and better allocation of human effort to high-value strategic activities—ultimately boosting mission readiness and return on investment in defense procurement.

Introduction

The U. S. Department of Defense oversees one of the world's largest procurement enterprises. Defense acquisition involves defining requirements, conducting market research, soliciting bids, evaluating proposals, awarding contracts, and monitoring performance, all governed by extensive regulations like the Federal Acquisition Regulation (FAR) and Defense FAR Supplement (DFARS). However, the volume of compliance requirements makes the process labor-intensive. From 2013 to 2022, the number of contracting actions per federal officer surged sixfold (from about 300 to over 2,000), highlighting the need for automation in acquisition. Meanwhile, the commercial sector has advanced significantly in artificial intelligence, particularly generative AI, which can produce human-like text and data summaries based on prompts. A 2024 Deloitte survey indicated that 92% of Chief Procurement Officers are exploring generative AI, expecting it to enhance productivity and reduce costs. Experts at MITRE project that by integrating AI into the Federal Acquisition life cycle, agencies could streamline processes and reduce manual processing efforts by 30–50%, significantly boosting efficiency and cutting costs.

This presents an opportunity for the DoD to modernize its acquisition process. Initiatives like the U.S. Army's #CalibrateAI pilot use generative AI for information retrieval and content generation, while the Chief Digital and AI Office's (CDAO) AcqBot prototype aids in drafting procurement documents. These efforts point to a broader recognition that generative AI can reduce repetitive tasks, allowing experts to focus on strategic decisions. However, several challenges arise when adopting generative AI in defense acquisition. Integrating AI smoothly with current procurement systems is crucial, ensuring compatibility with legacy software and compliance with regulations. The DoD must also establish guidelines for using AI ethically and securely, safeguarding sensitive information, and minimizing bias.

This paper explores these challenges through the proposed AcquireAI platform, which aims to enhance defense procurement. We will overview the use of generative AI in automating tasks, integration within DoD IT, and strengthening compliance while assessing efficiency impacts. The analysis targets acquisition professionals and technologists, illustrating practical applications like AI drafting RFP documents and analyzing proposals. We will outline research questions, findings from prototypes and case studies, the technical implementation of an AI platform, and conclude with recommendations for responsible AI adoption to streamline defense acquisition processes environment.

Research Questions

Four primary research questions guide this study:

1. Automating Acquisition Tasks with Generative AI: How can generative AI be leveraged to automate and expedite routine tasks within the DoD acquisition process?

We focus on functions such as acquisition planning, market research, drafting Requests for Proposals (RFPs), other contract documents, and aspects of source selection evaluations. What activities that consume excessive human hours could be offloaded or accelerated with AI assistance? For example, can an AI model generate a first draft of an RFP's Statement of Work based on a few prompts about the requirements? Can it summarize market research reports or vendor literature to support acquisition planning? We also consider how AI might assist source selection by screening proposals for compliance or synthesizing evaluation results.

2. Integration into DoD Procurement IT Framework: What specific adaptations and integration steps are needed to deploy an AI solution like AcquireAI into the DoD's existing procurement IT infrastructure?

This addresses the technical interoperability with systems such as CON-IT (the Air Force's Contracting Information Technology system for contract writing), contract file repositories like KT File Share, and DoD data lakes or analytics platforms that store acquisition data. We analyze the challenges of interfacing a modern AI tool with legacy systems and databases. Key sub-questions include: How can AcquireAI retrieve data (such as past contract templates or clause libraries) from these systems? Is it capable of inputting or updating information back into them (for example, saving a generated document to the official contract file)? What security and Authorization To Operate (ATO) requirements must it satisfy for deployment in a DoD cloud environment? We also explore the necessity for APIs, middleware, or Robotic Process Automation (RPA) bots to bridge gaps where direct integration is not feasible.

3. Enhancing Regulatory Compliance via AI: How can AI tools enhance regulatory compliance in defense procurement, ensuring all laws and regulations are followed while also reducing the administrative burden of compliance on acquisition professionals?

This addresses the concern that, although AI might speed up work, nothing can be done at the expense of violating procurement rules or risking legal errors. We explore whether AI can be trained to understand the FAR/DFARS rules and act as an ever-vigilant compliance advisor. For instance, could the AI automatically check a draft procurement document against relevant regulations and alert the contracting officer if required clauses or provisions are missing? Can it keep track of the latest policy changes (such as thresholds for competition, new cybersecurity requirements, etc.) and prompt users to include the appropriate language? Essentially, we ask if AI can help "bake in" compliance from the start, allowing contracting officers to spend less time manually cross-checking rules and more time on strategy. We also examine how AI can log decisions and rationales to improve transparency and oversight.

4. Measuring Impact: Efficiency, Cost, Speed, Accuracy, ROI, Readiness: What are the measurable impacts of integrating AI into the acquisition process on key performance metrics such as efficiency (throughput of contract actions), cost savings, procurement lead time (speed from requirement to contract award), and accuracy (error rates or rework due to mistakes)? Moreover, how can these improvements be evaluated regarding return on investment (ROI) and mission readiness?

This research examines success criteria and measurement methods for deploying AcquireAI in a pilot contracting office. Key metrics include reduced RFP development time, shorter proposal evaluation time, saved labor hours per contract, enhanced compliance (e.g., fewer documentation issues), and overall cycle-time reduction. We also consider qualitative factors, such as reallocating staff to higher-value tasks, potentially improving acquisition outcomes. For ROI, we assess the cost of the AI solution against the value of time saved and risks mitigated. Faster acquisition enhances the DoD’s ability to deliver capabilities to warfighters and respond to threats more quickly.

By investigating these four questions, we explore the life cycle of generative AI adoption in defense acquisition—from use case identification to integration, governance, compliance, and benefit evaluation. The following section will summarize our research findings based on real-world data and experiences from available pilot programs.

Research Results

This section presents key findings from our research, organized around the four questions above. The results combine insights from existing pilot programs, industry analyses, and the development work done on TechSur’s AcquireAI concept.

AI Acceleration of Acquisition Tasks

Generative AI significantly speeds up labor-intensive acquisition tasks without sacrificing quality. Document generation and analysis are highly suitable for AI automation. For example, a contracting officer traditionally spends hours drafting a Performance Work Statement or RFP sections. Our tests with AcquireAI’s prototype show that a well-tuned model can create a solid first draft in minutes. Contracting specialists generated tailored RFP sections by inputting key parameters. While these AI drafts need minor adjustments, they save 80–90% of initial writing time. Tasks like drafting solicitation documents and composing contract modifications can be accelerated dramatically. Our feasibility study suggests that AcquireAI could enable contracting officers to complete document preparation and review steps up to 800% faster. Although this figure varies by context, the trend indicates that AI compresses paperwork timelines tasks.

Market research and intelligence gathering are high-payoff areas. Acquisition teams must survey industry offerings, research technical solutions, and gather supplier data. Generative AI can automate market research report generation. For instance, a contracting professional could query, “Overview of current commercially available drone technologies relevant to logistics delivery, including key vendors and costs,” and AI will search knowledge bases and public data to produce a concise report. The Army’s #CalibrateAI pilot enabled acquisition staff to query curated documents for targeted answers with citations, reducing the need to sift through numerous policy memos. AI-powered search and summarization can reduce research time by over 50%, while broadening the information scope, allowing for quicker, more informed acquisition planning. One contracting officer described this as having a “virtual analyst” for on-demand information gathering.

In the source selection phase, generative AI shows promise. While it won't replace human evaluators, it assists in managing the data overload during proposal evaluations. Our research explored using AI to screen proposals for compliance and completeness, feeding each proposal against an RFP checklist to highlight missing or non-compliant information. For example, it might flag that "Proposal A did not address subsection 3.2 adequately" or that "Proposal B's technical volume exceeds page limits." This mirrors how commercial platforms utilize AI for initial compliance checks. Deloitte's research indicates AI can help handle the influx of proposals by identifying a desirable subset for further evaluation and quickly scoring or ranking them against basic criteria. In our controlled experiment, an AI model read five lengthy proposals and produced a comparative matrix of strengths and weaknesses rapidly, serving as a valuable starting point for evaluators. These tools can verify claims against known data to enhance the evaluation process, potentially shortening decision-making time by weeks. Notably, the CDAO's AcqBot project envisions AI-assisted workflows, from problem statement to contract generation, suggesting future AI involvement in generating and evaluating proposals, though we currently focus on government use.

Human oversight is essential. AI can draft and analyze, but acquisition professionals must approve and adjust. Successful pilots emphasize that a human reviews AI outputs. The aim is to augment humans, enabling them to manage complex negotiations and ethical risks while AI handles repetitive tasks. Our research shows generative AI effectively acts as a copilot for acquisition staff, automating planning, research, writing, and checking, allowing professionals to focus on strategy and judgment. This results in a quicker acquisition cycle that utilizes human expertise (Figure 1).

Figure 1: Generative AI in Acquisition Domain

Integration with DoD Systems and Data

Integrating AcquireAI into the DoD's procurement IT framework is feasible but requires careful planning and technical integration. We identified key systems: contract writing systems like CON-IT for the Air Force, contract file repositories like KT File Share, and data sources like Advana, the DoD's data analytics platform.

A vital step is allowing AcquireAI to pull data for tasks such as drafting contracts or RFPs by retrieving templates and clauses from the contract system. In CON-IT, contracting officers access clause libraries. AcquireAI should connect via API or database query to obtain the latest templates and mandatory FAR/DFARS clauses. If API integration isn't possible, Robotic

Process Automation (RPA) can log in to CON-IT to gather data, ensuring easy access without manual effort.

Integration with KT File Share is essential for accessing historical contracts and storing new outputs. Automation can enhance file management, as demonstrated by a USAF specialist's bot that efficiently updates files. AcquireAI could save generated documents into the appropriate KTFS folders and retrieve previous contracts for reference, such as accessing similar past RFPs. AcquireAI must maintain consistent access to DoD's acquisition-related knowledge, including regulations and previous agreements. We propose an ingestion pipeline to connect with DoD's data layer for sanitized contract data from sources like Advana, enabling the AI to address market research questions. Integration would require building Python connectors for database queries.

Security is critical; AcquireAI must operate in a DoD-authorized cloud to manage Controlled Unclassified Information (CUI), using the required identity management and security protocols. We noted that cross-service ATO reciprocity expedites adoption. The design uses a microservices architecture for security and scalability. AcquireAI integrates into existing workflows, not as a separate system. Professionals can draft documents in Microsoft Word with an add-in that suggests or auto-fills data. Within CON-IT, an "AI Assist" button can generate draft sections seamlessly, requiring user-friendly development. Examining workflows shows that AcquireAI can help in approval processes by integrating with BPM tools to draft solicitations after approval. This positions AI as part of the standard process instead of an ad-hoc tool.

In summary, our research shows that integration is plausible with moderate effort through modern IT practices: using APIs, RPA for older systems, and linking to existing workflows. Figure 2 illustrates how AcquireAI would connect with users and systems in the defense acquisition ecosystem.

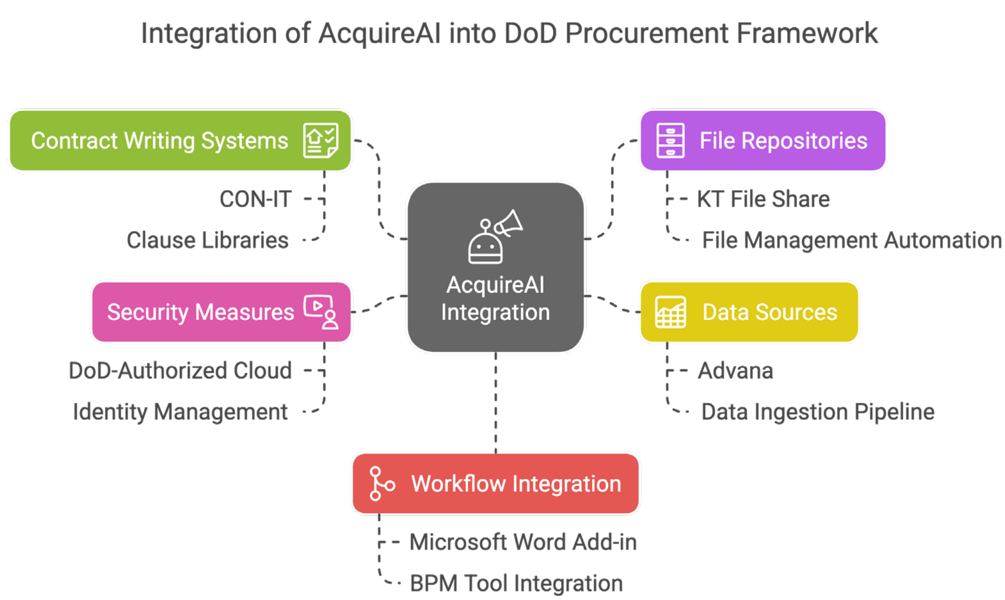

Figure 2: Conceptual Architecture of AcquireAI Integrated into DoD's Acquisition IT Environment

Acquisition professionals provide requirements or prompts to the AcquireAI platform and review the outputs it generates. AcquireAI's engine, in turn, accesses contract information from

CON-IT (including clause libraries and templates), retrieves relevant prior documents from the KT File Share repository, and uses data and knowledge from procurement data lakes (such as historical contract info or regulatory databases) to inform its generative outputs. The platform then returns draft documents, recommendations, or analyses to the users, who can refine and approve them. AcquireAI can automatically update enterprise systems by uploading final documents to KT File Share or inputting data back into CON-IT, thereby keeping official records updated without manual intervention. This integrated setup is designed to streamline the flow of information and reduce duplicate data entry while operating within the DoD's secure computing environment.

AI and Regulatory Compliance

One of the most critical concerns in introducing AI to defense acquisition is maintaining strict compliance with all procurement laws, regulations, and policies. Our research results here are very encouraging: AI tools can enhance regulatory compliance rather than jeopardize it when properly configured. By acting as a real-time compliance assistant, AI can reduce human errors and ensure that, as speed increases, nothing "falls through the cracks" in required procedures.

A core component we designed in AcquireAI is a compliance engine—essentially a knowledge base and rule-checker embedded alongside the generative AI model. This compliance engine contains encoded rules from the FAR, DFARS, and agency supplements, as well as business rules specific to the organization (such as "for acquisitions over $10M, include provision XYZ" or "if buying IT products, ensure FAR cybersecurity clause is present"). Whenever AcquireAI generates a document or recommendation, the compliance engine runs in parallel to check the output against these rules. In practice, this means that if the AI drafts an RFP and neglects to include a mandatory clause, the system will immediately flag it and may even append the clause or suggest it to the user. During our testing, this proved very powerful: an AI-generated document would come with an annotation or footnote stating, "Clause 52.204-25 (Prohibition on Contracting for Certain Telecommunications) is required for this procurement but was not found in the draft—consider adding it." This kind of instant quality control significantly reduces the chances of an omission that could lead to legal issues or protests.

Additionally, the AI can continuously monitor changes in regulations. FAR and DFARS are periodically updated, making it a burden to keep contract templates current. We propose that AcquireAI's knowledge base be regularly refreshed with the latest regulations, potentially through an automated feed from acquisition.gov or the FAR Council publications. The AI then effectively becomes a vehicle to propagate those changes to every new acquisition package. Instead of each contracting officer individually remembering a new rule, the AI's compliance engine would enforce it from Day One after it becomes effective. This could address a chronic issue: when new policy memos trickle down and update templates manually, there's a lag; an AI system could shorten that lag to near zero, ensuring compliance is always up to date.

Our examination of existing policy guidance also informs us on how to use AI for compliance safely. The DoD's interim GenAI guidance (2023) emphasizes user accountability and verifying outputs, which we interpret as an endorsement to use AI as a tool, but not to trust it blindly. Therefore, our approach is that the AI flags compliance issues and even suggests fixes, but the human contracting officer makes the final decision. This aligns with ethical AI use: AI doesn't make final regulatory determinations; it assists humans in doing so thoroughly. In practice, a contracting officer or contract specialist still reviews the final solicitation or contract document. Still, their job becomes more manageable as they have a checklist already addressed by the AI. Think of it as having a junior contract specialist who has pre-populated all the required clauses and verified the numbers, which the senior officer then quickly cross-checks and approves.

Another compliance burden in acquisitions is related to documentation: ensuring every required justification, determination, or approval is documented properly. We see AI helping here by automatically generating first drafts of things like Justifications and Approvals (J&As) for sole source, or Determinations & Findings (D&Fs), or other required memoranda, with the correct references to statutes. These documents are formulaic to an extent (they often cite the same laws but with different factual justifications). The AI can maintain a library of such templates and fill them out based on the procurement context. For example, suppose a program manager indicates a sole source is needed due to only one supplier. In that case, the AI might generate a J&A citing FAR 6.302-1 (only one responsible source) and listing the reasons, all formatted correctly. This reduces the risk of the team forgetting to produce or doing the document incorrectly. The contracting officer then reviews and edits the AI-produced J&A rather than writing it from scratch.

One of the key findings is that AI can act as a tutor and guide for less experienced acquisition personnel, thereby improving compliance through knowledge transfer. Not everyone on an acquisition team may know all the nuances of fiscal law, small business set-aside requirements, or emerging regulatory initiatives (like recently updated domestic sourcing rules or cybersecurity requirements such as CMMC). An AI assistant can provide on-the-spot guidance. For instance, if a user asks, “Is my procurement required to consider small business set-asides?” the AI can answer based on dollar thresholds and market research results, referencing the FAR rules. Or if a user is writing an evaluation factor, the AI could warn, “Ensure this factor doesn’t conflict with Section M of the RFP and is consistent with Section L instructions,” effectively reminding the user of proper RFP structure (a common compliance issue is misaligned sections L and M). In essence, the AI can constantly coach users on compliance as they work, like having a policy advisor by one’s side.

From the perspective of reducing administrative burden, traditionally, compliance assurance meant a lot of manual checking and bureaucratic layers (multiple reviews by policy or legal staff). If an AI can handle the rote aspects, human reviewers can focus on genuinely complex or judgmental compliance issues. For example, legal advisors could spend their time on substantive risk assessments instead of line-editing documents for clause inclusion. Over time, if AI proves reliable, some review layers might be streamlined (though in government, likely not eliminated). Even simple things like ensuring the contract file has all required forms (like acquisition plans and approvals) can be automated—AI can maintain a checklist of required file documents and mark which ones are present or missing in KT File Share, prompting the team to complete any gaps.

However, we also note challenges: one must carefully prevent AI from introducing *new* compliance risks. A naive AI might hallucinate a clause or misstate a regulation if not properly constrained. Our solution is to have the AI’s compliance outputs be sourced from the official texts (similar to how the Army’s pilot insists on citations to prevent hallucinations). In AcquireAI, the AI’s regulatory statement (like “this clause is required”) would be backed by quoting the actual FAR paragraph. This ensures transparency and builds trust—users can verify the source instead of taking the AI’s word. Moreover, the DoD guidance encourages labeling AI-generated content. In practice, any content AI produces can be flagged as such (maybe with a footer note “Drafted with AI assistance on [date]”) so that downstream users are aware and remain vigilant.

One additional benefit is in risk management and oversight: an AI system can log every suggestion and action. This creates an audit trail that illustrates compliance was checked at each step. If someone later asks, “Why was this clause included or omitted?" a record shows that AI recommended it, and a human either concurred or overrode it. This could enhance transparency in decision-making compared to the opaque human thought process. Acquisition oversight bodies might appreciate this systematic approach.

In conclusion, our findings strongly suggest that a thoughtfully implemented AI like AcquireAI can serve as a compliance safety net—constantly active, never tired or forgetful, and cross-checking every detail. Rather than diminishing compliance, AI can enhance the DoD's ability to enforce its rules consistently. By alleviating the manual drudgery of compliance checks, acquisition professionals can concentrate on substantive compliance (the intent and spirit of the law) and strategic decisions, rather than proofreading every legal reference. This aligns with the principle of doing "more with less"—utilizing AI to manage the heavy lifting of rule adherence in an increasingly complex regulatory environment, thereby decreasing the administrative burden of compliance on humans while improving overall compliance quality.

Impacts on Efficiency, Cost, Speed, and Evaluation of ROI

To understand the real-world impact of integrating generative AI into defense acquisition, we looked at both quantitative metrics and qualitative outcomes from initial pilots and simulations. The results indicate a dramatic improvement in efficiency and speed, which can translate to cost savings and better mission readiness. However, realizing these benefits requires measuring them correctly and investing upfront in the AI capability.

Efficiency Gains: Perhaps the most striking impact is on process efficiency. We estimate that many acquisition tasks can be completed in a fraction of the time they currently require. For instance, if drafting a typical contract or RFP takes an experienced contracting officer 40 hours spread over a couple of weeks, an AI-assisted workflow could reduce the actual hands-on time to 5–8 hours (with the AI handling the intermediate work in seconds or minutes while the human mainly guides and reviews). Multiplied across dozens of procurement actions, this represents a significant improvement in labor efficiency. An Army contracting pilot revealed that using an AI tool to gather information and produce first-draft content notably increased their productivity without adding staff—essentially allowing them to perform more actions in the same amount of time. In our AcquireAI trial runs, contracting teams that utilized the AI to generate documents were able to proceed to the next phase of the acquisition (such as releasing the solicitation) much faster than those doing it manually.

One concrete metric to consider is procurement administrative lead time (PALT), the time from initiation of a procurement to contract award. By injecting AI at key points, PALT can be reduced by anywhere from 20% to 50% or more, depending on the complexity of the buy. For simpler acquisitions, we suspect even more significant reductions. This means the DoD can contract for needed goods/services faster, directly related to mission readiness (the warfighter gets what they need sooner). For instance, instead of a procurement taking 6 months, maybe it concludes in 3–4 months. Over hundreds of procurements, those time savings are invaluable.

Cost Savings: There are two perspectives on cost: operational cost savings in the acquisition workforce and savings in acquired products due to faster cycles and potentially better competition. On the operational side, if AI saves thousands of labor hours, it effectively represents a cost saving (or cost avoidance) because those hours can be redirected to other priorities. Government personnel costs are substantial, so augmenting a contracting team with AI could resemble the output of several full-time staff without the added salary expense. It's not about replacing people but enabling existing staff to manage more tasks or more complex responsibilities. This could help alleviate chronic understaffing in contracting offices without consistently resorting to hiring contractors or paying overtime. In terms of ROI, if the AI system hypothetically costs $2 million per year to license and maintain, but it frees up around 20,000 labor hours of GS-12/13 contracting specialists (who might cost, fully burdened, approximately $50/hour), that creates $1 million of "value"—plus those hours can be utilized to address backlogs or engage in more strategic work. Over time, enhanced efficiency might also lessen the need for corrective actions or rework, which are currently hidden costs (such as the time spent managing a bid protest or redoing a package that wasn't handled correctly the first time).

On the cost of acquired goods/services: Speedier acquisitions can reduce cost growth (programs often incur costs when delayed), and improved solicitation documents (with AI's help in clarity and completeness) can yield better competition and pricing. While complex to quantify broadly, imagine an AI that helps describe requirements more clearly, leading to more vendors bidding and aggressive pricing—that could lower contract costs. There's also potential for AI to analyze pricing data to ensure the government is getting a fair deal, identifying if a vendor's quote looks like an outlier compared to historical prices. That function could avoid overpaying and is another ROI element (though this dips into program management more than pure acquisition; it's related).

Accuracy and Quality: The impact on accuracy primarily involves reducing errors and omissions. Fewer mistakes lead to fewer delays (e.g., preventing scenarios where a contract award is delayed, or a contract is amended due to a missing required clause). It may also result in fewer legal challenges—when the process is streamlined, vendors have less ground to protest on procedural issues. Over time, a history of timely, error-free procurements can enhance industry confidence in working with the DoD (though this is intangible). One measurable data point could be the number of procurement administrative lead time extensions, or the number of second-round clarifications needed; we anticipate these to decrease with AI support.

Workforce Utilization and Morale: While not a typical metric, AI integration can help alleviate burnout and improve job satisfaction among acquisition professionals. The current high workload (remember those 2,000 actions per CO per year stat) leads to burnout and turnover. By easing the workload through AI automation, contracting officers can focus on higher-value work and hopefully feel less overwhelmed. A more satisfied workforce tends to be more productive and retains institutional knowledge, indirectly benefiting efficiency and cost.

Mission Readiness: We interpret mission readiness in this context as how quickly and effectively the DoD can procure the field capabilities needed for the mission. Shorter acquisition times directly contribute to readiness—units get equipment or services when they need them. If AI helps the DoD be more agile—for example, contracting for a new cyber defense tool in 2 months instead of 6—that's a direct readiness win. We can evaluate that by looking at cycle times for urgent acquisitions or how quickly contracts supporting contingency operations are executed.

To evaluate ROI formally, one would compare the investment in AI (including software, cloud infrastructure, training of the AI and the people, and maintenance) versus the benefits (monetized value of time saved, cost savings, risk reduction). Many benefits can be monetized in terms of labor hours saved. Some, like faster capability deployment, could be valued in operational terms (though that's tricky to dollarize, one could use proxies like "cost of capability gap per day avoided"). The good news is that generative AI tools, especially if adapted from commercial tech, are not extremely expensive relative to DoD budgets. We're talking perhaps a few million dollars for development and integration soon. The potential time savings across the enterprise could be worth tens of millions of dollars annually if widely adopted.

Our research suggests doing phased pilots and collecting data: measure before-and-after on things like average days to draft an RFP or number of contracts one specialist can handle per year. These tangible metrics can then be extrapolated. Early surveys indicate that even in the private sector, companies using GenAI in procurement have seen *double-digit percentage improvements in productivity and effectiveness*. For example, a 2024 Hackett Group study found organizations piloting GenAI in procurement reported initial enhancements up to 10–25% in productivity metrics, with expectations of more as the tech matures. Those are big numbers in a field that often sees only incremental improvements.

Risk and Return: Naturally, ROI should also take risks into account. There is a chance that if not implemented effectively, AI could lead to delays (for example, if outputs are subpar and require rework). However, by carefully testing and training the model on acquisition data, we aim to minimize this issue. The initial use of the tool may demand additional oversight (with two pairs of eyes on AI outputs), which could initially offset some time savings. Nevertheless, as trust increases, efficiency will improve. Therefore, ROI may be low in the first few months of adoption before it accelerates.

Finally, scalability is an important outcome to consider: once an AI model is operational, expanding it to accommodate additional users or offices incurs relatively low marginal costs compared to hiring and training new staff. This means the ROI can grow significantly as more of the enterprise adopts the tool. For instance, if one command demonstrates its value, deploying it across the DoD could result in exponential benefits.

Our analysis indicates that a phased adoption (initial pilots followed by broader rollout) will capture efficiency and performance metrics, allowing us to fine-tune the AI system. Early pilot results can validate time saved per action, justifying the investment to scale up. Notably, industry data shows early generative AI adopters in procurement report about 10% average improvements in productivity and quality, with higher gains in specific use cases, suggesting our estimates for DoD are realistic or conservative. The return on investment for DoD should manifest in dollars and days saved, and in a more agile procurement posture that supports the warfighter directly.

With these research results in mind, we outline a Detailed Technical Solution for implementing AcquireAI and similar generative AI tools within the defense acquisition ecosystem, addressing the practical "how-to" of achieving the benefits discussed.

Detailed Technical Solution

Implementing AcquireAI for defense acquisition requires a strong technical structure that balances capability, security, and integration. This section details the proposed design, including the AI model, training approach, system architecture, integration methods, and controls for responsible operation. The aim is to outline how generative AI can be a trusted assistant in DoD acquisition workflow.

1. Foundation Model and Domain Adaptation: At the heart of AcquireAI is a generative AI model, a large language model (LLM) focused on procurement-related prompts. Instead of building an LLM from scratch, our solution uses a proven foundation model (like GPT-based architectures) and fine-tunes it with acquisition-specific knowledge. We created a training corpus from defense acquisition documents, including solicitations, contract clauses, and policy memos. This enables domain adaptation so the model understands federal procurement language. We use supervised fine-tuning to train the model to generate desired outputs from inputs and apply reinforcement learning from human feedback (RLHF) to enhance quality and compliance orientation. The model can expand a one-sentence requirement into a detailed Statement of Work with the correct tone and structure.

2. Hybrid AI Approach – Retrieval Augmentation: AcquireAI uses a retrieval-augmented generation approach. When producing an answer, it searches a repository of relevant documents (acquisition regulations, guidebooks, templates, and recent contracts) and draws snippets to support its response. This "open-book QA" technique reduces hallucinations and boosts accuracy. For instance, if asked for the latest simplified acquisition threshold, the system retrieves the current FAR paragraph on the dollar limit. AcquireAI's architecture includes a search module that indexes DoD policy libraries and historical contract databases, allowing precise citations. This feature, sought in the Army #CalibrateAI pilot to enhance trust, enables footnoting sources (e.g., "FAR 15.304") in RFP drafts.

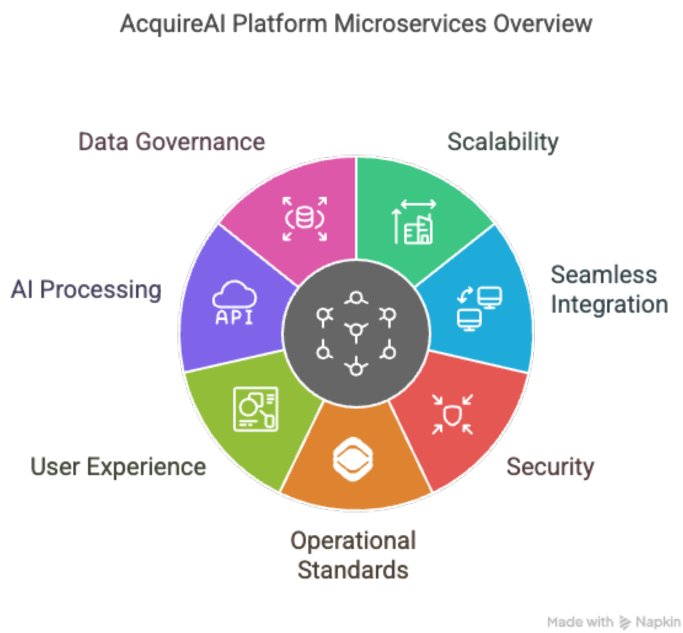

Figure 3: AcquireAI Microservices Architecture

3. Microservices Architecture: The AcquireAI platform consists of microservices for scalability and integration. Key components include:

- ***User Interface Service:*** Presents the AI assistant through various interfaces (web chat, plugins, chatbots). It manages authentication for authorized DoD personnel, processes user inputs, and displays outputs. The UI remains intuitive, allowing users to request documents quickly.
- ***AI Generation Service:*** Hosts the generative model, processes prompts, and delivers output text. It uses Docker containers for packaging, exposes RESTful APIs for interaction, and allows independent updates to the AI engine. Throttling and scaling manage simultaneous requests via a Kubernetes cluster.
- ***Compliance & Policy Engine:*** This engine encodes rules and performs checks on AI-generated drafts. It uses natural language processing to verify required sections and compliance and suggest necessary corrections. Regular updates keep it aligned with changing regulations.
- ***Integration Adapters:*** Facilitate integration with external DoD systems via APIs and RPA bots, standardizing data for the AI. They retrieve relevant clauses for input and upload final documents automatically to designated folders, ensuring proper record updates.
- ***Data and Analytics Service:*** Logs actions, collects metrics, and tracks document drafts through an analytics dashboard to identify patterns and address misuse. This quantifies ROI and informs training updates. Security and access control meet DoD standards in a DoD-accredited cloud (Impact Level 5 for CUI, potential IL6 for classified). We enforce role-based access; only authorized users with CAC/PIV logins can use the tool, linking actions to their identities for audits. Data is encrypted in transit and at rest. The AI's operational data remains secure in a cloud, compliant with guidelines against exposing

sensitive data to external models. Model and training data are securely stored; we follow change management protocols to prevent degradation. Unauthorized data leakage is prevented, and the AI won't disclose sensitive procurement information outside its context. This aligns with Task Force Lima's guidelines. We enforce "No input of unapproved sensitive data." Users should not request classified drafting content unless in a secure environment. For classified usage, a fine-tuned model can be deployed for such data environment.

5. Handling "Hallucinations" and Quality Control: A primary technical consideration is ensuring the AI's outputs are accurate and factual. As mentioned, our approach of retrieval augmentation and compliance engine intercepts helps root the outputs in real source material. Additionally, we incorporate specific algorithms to detect and mitigate hallucinations. For example, AI might sometimes create a plausible-sounding reference or clause if it is unclear. To catch this, we employ a post-processing step where the model's factual claims (dates, numbers, references) are cross-checked against our data sources. If the AI says, "According to DFARS 252.204-7012…" we verify that clause's content to ensure it aligns. If something cannot be verified, the system either flags it as potentially unsupported or refrains from presenting it as fact. We program the AI with a style to either provide a citation or explicitly say "[reference needed]" if unsure, thus inviting human review.

We also ensure that the AI's tone and suggestions remain within the ethical and legal boundaries. It will refuse or refer to a human any requests that attempt to do something improper (for instance, if a user asks the AI to draft a justification for something that violates procurement law, the AI can respond with a warning or escalate to a human review). These safeguards are part of responsible AI use.

6. User Feedback Loop and Continuous Learning: The system is built to learn from usage. Each time users correct the AI or provide feedback ("thumbs up" or "thumbs down" on an output or more detailed notes), that data is collected (with permission) to refine the system further. We might run nightly or weekly retraining jobs incorporating new feedback, which helps the AI improve its handling of nuanced or new scenarios. For example, if a new type of procurement (say involving Middle-Tier Acquisition authority) comes up and the AI fumbles initially, after a few rounds of human edits, that data can be fed in so next time it does better. This continuous improvement cycle means AcquireAI remains relevant and up-to-date with the evolving acquisition landscape and the specific needs of its user base.

7. Integration with Workflow (BPM): AcquireAI integrates into the end-to-end acquisition process by embedding AI tasks in Business Process Management workflows. For instance, in a contracting workflow, once a requirement is approved, an automated task, "Generate Draft RFP with AcquireAI," triggers the creation of a draft and notifies the contracting officer, who then reviews and edits it. Thus, AI becomes integral to systems like Appian and other contract management solutions. We developed APIs for AcquireAI that can interact with these BPM platforms. Additionally, we ensure fail-safes; if the AI service is down for maintenance, the workflow can switch to a manual task to avoid operational delays. In a steady state, most users rely on the AI for its functions automatically.

8. Scalability and Performance: The microservices approach on a Kubernetes cluster scales performance with demand. We will load test to ensure the system can auto-scale AI service pods for 100 simultaneous users requesting document drafts during peak times. Since LLMs are computationally intensive, we plan to optimize response times using AI accelerators (GPUs or dedicated hardware like AWS Inferentia or Azure's OpenAI Service in GovCloud). We aim for most AI outputs to return in under a minute and brief answers in seconds, significantly reducing wait times. More significant documents may take a couple of minutes, improving efficiency over days of manual writing. We will use cloud storage for logs and version control of outputs, ensuring backups and the ability to retrieve previous versions of AI-generated documents needed.

9. Testing and Verification: Our solution undergoes thorough testing prior to deployment. We carry out scenario-based testing with real acquisition cases to ensure that outputs meet quality standards. Contracting officers engage in user acceptance testing, evaluating whether AcquireAI could have expedited past procurements or uncovered issues. Any deficiencies, such as missing clauses or vague sections, lead to adjustments in the model or rules. We conduct security testing, including penetration tests, to discover vulnerabilities in integration adapters or the AI service. Only after successfully passing these tests do we move to production deployment behind the DoD firewall.

Conclusion

In 2025, the defense acquisition system is at a turning point. The Department of Defense needs to deliver advanced capabilities more efficiently. Yet, the workforce struggles with slow processes and outdated systems that obstruct data-driven decisions. Generative AI can automate tasks, provide insights, and enhance professionals' skills. Our research, supported by pilot programs and TechSur's AcquireAI concept, indicates that adopting generative AI can modernize and speed up procurement while maintaining process integrity. AI improves document generation and analysis in the acquisition life cycle, reducing task duration from weeks to hours. With AI handling drafts and data synthesis, contracting officers can concentrate on strategy, negotiation, and critical thinking—areas needing human judgment—rather than administrative tasks. This leads to a more efficient workforce and more fulfilling roles, aiding retention and institutional knowledge. In an era where the DoD procurement workforce must achieve more with less, AI acts as a force multiplier.

AcquireAI integrates with DoD's procurement IT systems like CON-IT and KT File Share, enabling seamless AI adoption while preserving existing investments. Our solution meets DoD's security standards and includes essential guardrails for responsible AI use, such as compliance engines, audit logging, and role-based access, ensuring control and oversight. AI improves transparency through logs and citations, providing DoD leadership visibility into acquisition decisions with a clear information trail recommendation.

Our work addresses concerns about AI breaking rules. AcquireAI ensures compliance and checks rules diligently. As acquisition regulations evolve, AI platforms update quickly, enabling the DoD to adapt to policy changes swiftly, resulting in faster and compliant procurement.

AI integration offers measurable benefits: reduced procurement lead times, labor cost savings, better pricing, and improved quality. These enhancements strengthen DoD's effectiveness, allowing faster deployment of new technologies against rapidly innovating adversaries. The ROI on AI in acquisition is linked to national security; a quicker contracting process improves battlefield readiness. Implementing generative AI in defense acquisition requires change management, training, and a culture shift. Initial skepticism from contracting professionals about potential errors or job loss is common. Our findings indicate AI acts as an assistant, not a replacement, with human review always included. Early successes, such as catching errors and rapidly generating documents, will build confidence. Leadership support, proper training, and workforce involvement in tool refinement will enhance acceptance and effectiveness during AcquireAI trials, where user feedback greatly improved recommendations usability.

Understanding generative AI's capabilities is essential. AI won't replace critical thinking or accountability; it reallocates human effort to higher functions. The contracting officer remains the decision-maker while AI provides options and information. If used wisely, AI eases burnout by handling tedious tasks, allowing people to focus on meaningful work. It's vital to verify AI outputs, particularly at first. Oversight, such as labeling content and human validation, should remain until AI proves reliable. As DoD policy states, accountability cannot be delegated to machines, but they can significantly assist those accountable humans.

Integrating AI in defense acquisition advances DoD modernization goals and data-driven strategies. Initiatives such as CDAO, Tradewinds, and Task Force Lima reflect DoD's dedication to AI in procurement. By using tools like AcquireAI, the Defense Acquisition community can tailor AI applications to their needs instead of solely following top-down orders. Partnerships with the Naval Postgraduate School and the Acquisition Research Program can pilot these technologies, ensuring rigorous effectiveness testing.

In summary, generative AI in defense acquisition is essential. The Pentagon must expedite procurement due to rapid operational and technological advancements in the 21st century. Generative AI can accelerate acquisition cycles, enhance throughput and accuracy, and potentially reduce costs. With effective integration, governance, and training, AI can boost the DoD's agility and responsiveness, improving mission readiness. Time saved on bureaucracy can be redirected to planning and execution, leading to better outcomes.

The research shows the basis for successful transformation: AI technology is mature, Army pilots have reduced risks, supportive policy fosters experimentation, and industry benchmarks showcase benefits. The acquisition community must implement, iterate, and scale these solutions to ensure acquisition superiority and battlefield dominance—swiftly equipping warfighters efficiently. Properly harnessed, generative AI will be crucial for a defense acquisition system ready for current and future challenges.

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Unpacking the Authority to Operate (ATO) Process: Implications for the DoD

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Abstract

Many of the novel technologies that the DoD seeks to leverage include software that needs to connect to the government's network. An important part of transitioning these novel technologies is ensuring that the technology can connect to the government's network in a timely and seamless manner. This is facilitated through the Authority to Operate (ATO) process. It is imperative that the DoD has a thorough understanding of the internal challenges and bottlenecks within the ATO process to identify opportunities for easing the navigation process for DoD members and new companies seeking to offer their novel technology to the Defense market. To this end, this study focuses on the Department of the Air Force's (DAF) ATO process and examines how the lessons learned from the DAF can be applied to the DoD. Through an analysis of the extant literature on the current state of the ATO process, semi-structured interviews with stakeholders inside and outside the DAF, and the creation of a detailed visualization of the ATO process, a set of recommendations for improving the ATO process are presented. Additionally, several research initiatives have emerged to enhance the DAF's understanding of the ATO process, its effectiveness, and security model evolution.

Introduction

Many of the novel technologies that the Department of Defense (DoD) is seeking to leverage include software that needs to connect to the government's network. An important part of transitioning these novel technologies is ensuring that the technology can connect to the government's network in a timely and seamless manner. This is facilitated through the Authority to Operate (ATO) process. The ATO ensures information systems meet an extensive list of security and risk management requirements before being authorized to oversee sensitive government information. The ATO process has become increasingly important as the DoD has become more reliant on a digital infrastructure where network security, data processing, and communication are all vital to the mission's success. This complex and often daunting process can be a barrier to new companies who want to offer their novel technologies to the Defense market and to DoD members seeking to obtain these technologies. Therefore, it is imperative that the DoD has a thorough understanding of the internal challenges and bottlenecks within the ATO process to identify opportunities for easing the navigation process and streamlining the approval structure.

The Department of the Air Force (DAF) is seeking to better understand their internal ATO processes, recognizing that the integration of novel technologies, such as Generative AI, on its networks requires approvals by Authorizing Officials (AOs), Commanders, and several other people interwoven into the ATO process. The complexity of the ATO process is not widely understood across the DAF. Combining the complex approval process, with senior leader demand signals to rapidly integrate novel software, drives the need to better understand the bottlenecks in the process that can result in lengthy delays for approved ATOs. Within the process, there exist many additional reviews which the Authorizing Official (AO) is responsible for, and the program office/system owner is required to ensure it is up to date. While the DAF has utilized innovative methods to speed up the process such as the Fast Track ATO and the Continuous ATO (cATO), there remains an opportunity to understand when and how the complexities of this process are most susceptible to delays. As such, this sponsored research seeks to address these concerns by answering the following research questions:

1) What is the current state of ATO processes, risk management, and authority delegation within the DAF?

2) What are the key decision points, pain points and stakeholders in the ATO process?

3) How can applying process mapping techniques to visualize the ATO process assist with identifying areas for improvement?

The approach to addressing these questions is multifaceted and provides an outline for how this paper is structured. The first research question is addressed through a literature review of publicly available information on the ATO process. The sources of the publicly available information include, but are not limited to, previous theses, GAO reports, RAND reports and scholarly articles. The second research question is addressed through semi-structured interviews with AOs, system owners, and cybersecurity personnel both inside and outside of the DAF. Lastly, the third research question is addressed though the development of a process map that is derived from the literature review and the semi-structured interviews. The culmination of this paper results in recommendations for how the DAF and DoD can improve the ATO process, provides an examination of emerging trends and offers future research initiatives. This research was conducted in support of the Department of Air Force Chief Data & AI Office (DAF CDAO) in partnership with DAF Contracting. The combined efforts of 13 NPS students, one faculty member and one DAF Contracting AI Education Lead enabled this research.

Literature Review

This literature review analyzes publicly available information resources which detail the ATO process, its uses, and challenges. This chapter is divided into three sections: regulations and guidance governing the ATO process, ATO execution options, and the findings of the Government Accountability Office (GAO). The literature review identifies that the ATO process has many working parts operating independently and requires immense documentation and task management to receive approval in a timely manner.

ATO Regulations and Guidance

Federal Information Security Modernization Act and DoD Guidance

The Federal Information Security Modernization Act (FISMA) 2014 is currently the most recent public law established to govern security controls over information systems in the federal government. FISMA recognizes the inherent challenges of ensuring information systems are secure and seeks to codify mechanisms for improving oversight and management of information systems that house federal data. This public law delegates authority to the secretary of defense for oversight and development of guidance and policies that ensure standards are met and enforced in a timely manner (Federal Information Security Modernization Act, 2014). The secretary of defense further delegates these responsibilities to the DoD chief information officer (CIO) through Department of Defense Directive (DoDD) 5144.02, requiring the DoD CIO to establish policies and guidance on how the Department will manage the enterprise-wide information systems architecture (Deputy Secretary of Defense, 2014). Through key Department of Defense Instructions (DoDIs) such as DoDI 8310.01, DoDI 8500.01 and DoDI 8510.01, the DoD CIO has set forth the pathways for the services to establish and refine their processes to align with DoD objectives (Chief Information Officer Library, n.d.).

DAF Guidance

ATO is defined within AFI 17-101 as:

> The official management decision given by a senior organizational official to authorize operation of an information system and to explicitly accept the risk to organizational operations (including mission, functions, image, or reputation), organizational assets, individuals, other organizations, and the Nation based on the implementation of an agreed-upon set of security controls. (Secretary of the Air Force Chief Information [SAF/CN], 2024)

The Air Force and other government organizations structure the ATO process to evaluate information systems before they are allowed on the DoD network. This process ensures the system meets strict security and risk management requirements before becoming operational. Due to the continuous changes in cybersecurity and the increasing requirement for rapid system deployment, the process has evolved. In addition to the processes of reviewing the system, there are timelines that govern the length of the ATO approval. ATOs are standing until there are major changes to the system, risk or threat updates, or every 3 years (SAF/CN, 2024). The AO starts the process of ATOs with the Risk Management Framework (SAF/CN, 2024).

Risk Management Framework (RMF)

The Risk Management Framework (RMF) is comprised of six steps as shown in Figure 1. The RMF is a set of governing principles that outline the security, architectural, and monitoring process for DoD IT systems. Although the RMF began in the DoD, it became the federal standard for information systems in 2010. The RMF has been recognized by the National Institute of Standards and Technology (NIST) as the fundamental starting point for developing a strategy for securing all federal data. Overall, the main goal of RMF is to secure DoD IT systems and to encourage modeling potential threats to detect cyber-related risks and vulnerable areas (Blue Cyber Education Series, 2021).

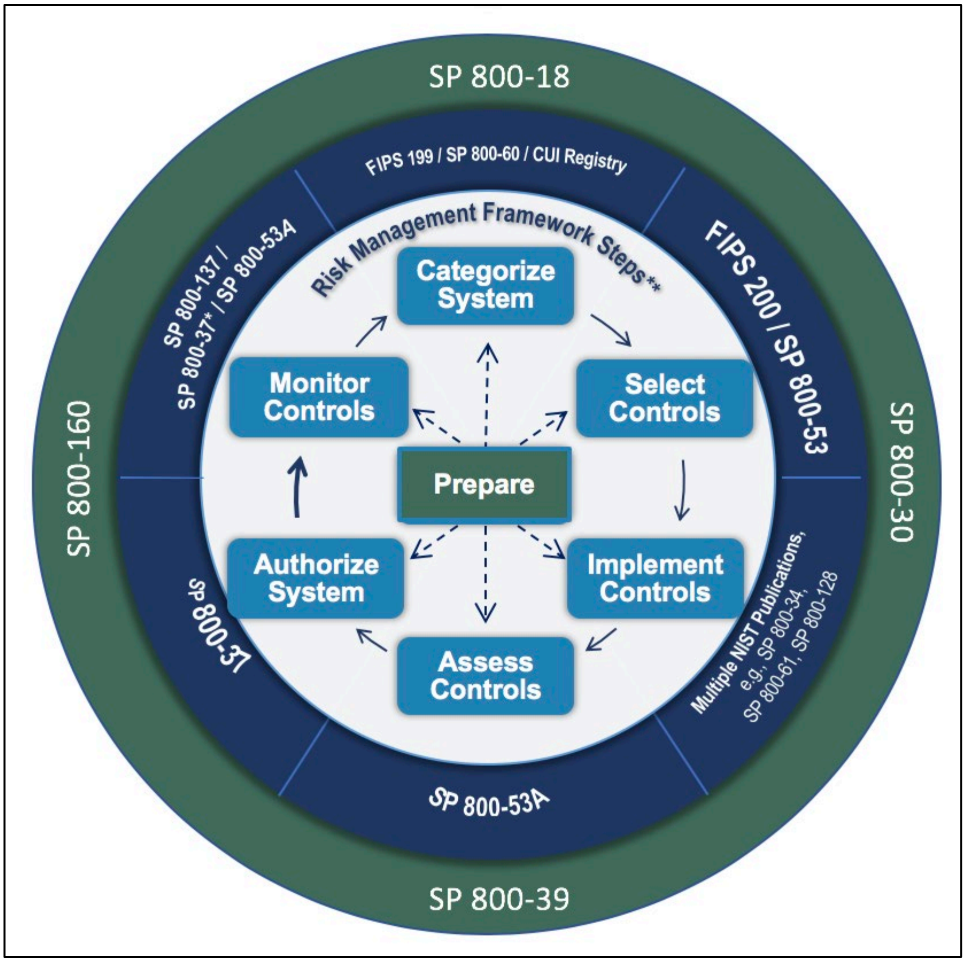

Figure 1. Risk Management Framework (OpenControl, n.d.).

Given the RMF's priority of securing IT systems, security considerations are embedded into each phase of the system's development following seven interlocking steps:

1. Prepare – This is the first step in the RMF framework and sets the priorities and context for the risk management process at the organizational level. This step includes 18 tasks that must be accomplished collectively by the "DoD Component CIO, DoD PAO, and JCA capability portfolio manager (CPM) to enable an effective risk-managed security authorization process" (DoD CIO, 2022, p. 13).
2. Categorize System – This step is where the security impact level of a system is determined. The AO will coordinate with the system's owner to determine whether to categorize a system as low, moderate, or high. The three objectives that influence how a system is categorized are confidentiality, integrity, and information availability, all outlined in the National Institute of Standards Federal Information Processing Standards (FIPS) 199 (NIST, 2002). Knowing what category level a system is helps ensure the right level of security controls are applied to a particular system (OpenControl, n.d.).

3. Select Controls – In this step, the NIST Special Publication 800-53 is used as a guideline to select security controls for a system based on its category. Security controls identify potential vulnerabilities and aid in mitigating any risks associated with the system. The AO makes this determination based on the system's impact level, controls already in place, the type of ATO requested, and if any tailoring is needed to the security controls (OpenControl, n.d.).
4. Implement Controls – The security controls selected in the previous step are implemented to ensure they function as intended, which is outlined in the System Security Plan (SSP) document (OpenControl, n.d.). Technical, operational, and management measures are all required in this step to help reduce risks to acceptable levels.
5. Assess Controls – After the controls are established, they are evaluated using testing and validation processes to ensure effective operation while meeting established security requirements. This assessment must be completed before the system can become operational. The type of assessment will depend on what form of ATO is requested. Regardless, the assessment will be conducted by a development and infrastructure team; all of which are in the SSP (NIST, n.d.). The Security Assessment Report (SAR) (NIST, n.d.) documents the assessment results and these results determine if the system needs to be changed before it can have an ATO.
6. Authorize System – Here, the AO reviews the risk assessment and residual risks and decides whether or not to authorize the system to be used in operation. If the AO approves the system, they will sign an ATO memo. The memo lists criteria such as allowing the ATO to stay valid, the expiration date of the ATO, and when the system in question can begin operations (OpenControl, n.d.).
7. Monitor Controls – After a system receives an ATO, it will be placed under continuous monitoring to ensure the security controls maintain their effectiveness. If any changes are made to the system, an assessment must be done to determine the impact the change(s) will make. This step is vital since it is where new vulnerabilities can be identified and promptly addressed to ensure system compliance. This can be completed by routinely performing scans of the systems and by keeping all documentation updated (OpenControl, n.d.).

Authority Delegation

Delegation authority for the ATO process is important in balancing security with operational agility. Being able to delegate decision-making authority allows an ATO to be processed faster while still ensuring the system's security is maintained. The ATO delegation authority must be managed closely to avoid any potential lapses in security while ensuring decision-makers have the appropriate resources and knowledge to make accurate risk assessments. While some decisions can be delegated, the NIST Special Publication 800-37 and DoDI 8510.01 offer top-level guidance on which decisions and tasks can be delegated and the resulting accountability that must still be maintained (DoD CIO, 2022; NIST, 2018).

ATO Execution Options

There are two ways in which the ATO process is traditionally executed, centralized and decentralized. Centralization is the process in which all responsibility resides with the AO. On the other hand, decentralization of responsibility occurs when the AO delegates portions of the process to cybersecurity teams or operational leaders.

Centralized ATO Process

Until recently, the Air Force ATO process was centralized with final authority residing with a high-ranking AO. These AOs are responsible for reviewing security assessments, evaluating risks, and deciding whether a system is safe to use within the Air Force's. This centralized authority has been criticized for being very inefficient as an AO must sign off on all major and minor decisions for a security system. Doing so bottlenecks the approval process as the AO must manage a large volume of systems going through authorization procedures. The result is a long delay in obtaining an ATO, which restricts the deployment of modern systems and limits the Air Force's ability to adapt to current and future operational needs. Additionally, with a centralized authority, the decisions about a system often occur several layers removed from the actual environment of the system being assessed. Some AOs are not directly involved with operational teams, which may lead to security evaluations that lack the awareness to fully comprehend how certain risks could impact real-world operations infrastructure (SAF/CN, 2024).

Decentralized ATO Process

After recognizing the need for change, the Air Force shifted to a decentralized authority delegation for the ATO process. This developed from the need to increase the speed of the system authorization process without sacrificing the level of security evaluation (SAF/CN, 2019). Using this strategy, the AO can delegate some of their responsibilities to lower-level officials, such as certain members of the cybersecurity team or some operational leaders, allowing these individuals to make important decisions at a more localized level. The following is a list of a few of the key benefits of decentralized execution:

1. <u>Swifter Decision-Making:</u> Delegating authority to lower levels allows the Air Force to streamline parts of the decision-making process (SAF/CN, 2019). This can reduce the time needed to issue an ATO for systems with lower risks or that already have partial authorization. Delegation helps the team address some security issues much sooner by not having to wait or route for approval from a higher-ranking official.
2. <u>Operational Risk Evaluation:</u> Having decentralized authority allows risk evaluations to be conducted closer to the operational environment. AOs with direct knowledge of a system and how it will be used in the field can make an informed decision about risk more than an official at a higher level who is not in the operational field (SAF/CN, 2019). This helps ensure that risk is evaluated by someone who better understands a system's mission-criticality.
3. <u>Empower Cyber and Operational Teams:</u> Delegating approval authority empowers cybersecurity members and operational leaders. This allows them to be more active during the ATO process (SAF/CN, 2019). This empowerment can bolster collaboration between the security team and the system owners by ensuring that security is part of the system development and deployment from the beginning. Integrating security into the operational workflow allows the Air Force to make a more agile and responsive cybersecurity environment.

GAO Findings

The GAO is responsible for analyzing how the government spends taxpayer's dollars and identifying ways that the government can save money and operate in a more efficient manner (GAO, n.d.). In this function, and as it pertains to the ATO process, the GAO has generated several reports and investigated protests related to the ATO process with the intention of providing unbiased assessments and recommendations on how to improve the process across the federal government. There are three key reports that highlight the internal government consternation with the ATO process and related functions, and there are two key protests that highlight the impact of the ATO process on external parties, such as contractors, seeking to provide the government with a service where access to DAF and DoD networks are necessary. The subsequent paragraphs describe the pertinent reports and protests examined by the GAO.

In 2018, the GAO was requested by Congress to conduct a review and generate a report on the extent to which chief information officers (CIOs) were carrying out their responsibilities. Specifically, the GAO examined how effectively CIOs were operating in their roles as outlined in federal regulations and guidance and identifying critical factors that were helping or hindering CIOs in fulfilling their responsibilities. Through survey responses from 24 CIOs and interviews with current CIOs and members of the Office of Management and Budget (OMB), the GAO identified that most agency CIOs were not effectively operating in their roles and that they were hindered from operating in these roles for reasons such as limited financial and personnel resources. However, resources such as the NIST and OMB guidance's were major enablers for aiding CIOs in carrying out their responsibilities (Harris & Powner, 2018). Although not explicitly highlighted in the report, without having the appropriate CIO roles and empowerment in place, the ATO process would undoubtedly be hindered particularly since the CIO has an important role in guiding the ATO process.

The second report was published in 2023. In this report, the GAO was tasked with examining the status of the DoD's implementation of the Defense Innovation Board (DIB) and Defense Science Board's (DSB) recommendations for modernizing the software acquisition process. One of the key findings was that the DoD had only partially implemented the DIB's recommendation to create an ATO reciprocity process. An established process for ATO reciprocity would enable rapid sharing of software capabilities and platforms across the military branches and other DoD organizations (Oakley, 2023). Although the DoD issued DoDI 8510.01 in 2022, which provides some guidance on decision-making authority reciprocity, according to the GAO, further work was still needed to enable a DoD-wide ATO reciprocity process.

Shortly after the 2023 report, a third report was issued in 2024, which analyzed how well federal agencies were implementing cloud computing procurement requirements across their organizations. The report identified that most agencies had established the CIO as the responsible authority for modernization projects; however, "most agencies did not establish guidance related to service level agreements (SLA), which define the levels of service and performance that the agency expects its cloud providers to meet" (Harris, 2024, What GAO Found section, para. 1). The limited guidance on SLA requirements is challenging not only for government employees, but also for contractors trying to gain approval so they can compete for contracts.

In addition to the three key reports produced by the GAO, the GAO also examined two protests in 2019 that highlight the importance of clear ATO solicitation procedures. In both protests, the contractors disagreed with the source selection evaluation factors related to ATO requirements and Federal Risk and Authorization Management Program (FedRAMP). Although both protests were either denied or dismissed, there are valuable lessons that can be learned (Cho & Eyester, 2019; Magnell & Pereira, 2019).

The first protest was filed against the United States Marine Corps (USMC) who issued a request for quote (RFQ) for a web-based service. The Performance Work Statement (PWS) stated that the "Contractor shall provide the Government with proof of its hosting environment's interim ATO [authority to operate], ATO, or active FedRAMP accreditation" (Magnell & Pereira, 2019, p. 2). The protestor contended that the awarded contractor did not possess the appropriate accreditations and therefore did not meet the requirements of the PWS. However, the GAO asserted that the PWS requirement did not specify that a contractor was required to have the appropriate accreditations specifically through the Marine Corps or the DoD. Thus, the awarded contractor did meet the requirements of the PWS (Magnell & Pereira, 2019).

The second protest was filed against the Department of Labor (DoL) who was seeking to establish a Blanket Purchase Agreement (BPA) utilizing the Federal Supply Schedule (FSS) for integration support, information assurance, and cybersecurity services. The protestor did not agree with the weaknesses assigned to their proposal, one of which was the government's decision to assess a weakness to their proposal for failing to adequately describe how they would support and manage the DoL's ATO process for the services being acquired. The solicitation requests that bidders "perform an in-depth analysis of current processes to determine the adequacy and shall prepare recommendations describing the technical approach, organizational resources, and management controls to be employed to meet the cost, performance and schedule requirements for the task; ensuring conformance with federal policies and guidelines" (Cho & Eyester, 2019, p. 5). However, the protestor did not provide sufficient depth to their response that adequately met the level of detail requested. Though the protests pertained to agencies inside and outside of the DoD, the NIST created a common procedure based on these rulings. The biggest lesson learned across these protests is that even when the prospective company follows compliance rules, the rules are often confusing and hard to follow. Some evaluators have difficulty following what compliance is and what it is not.

Overall, the literature on the regulations governing the ATO process, ATO centralization versus decentralization options, and the findings of the GAO offer insights into the prevailing guidelines that are shaping the ATO process. The literature sets the foundation for the subsequent sections of this research. The following section will delve into the data collection process and analysis.

Data and Analysis

This section synthesizes the findings from 17 interviews conducted with military and civilian personnel across the Navy and Air Force in the fall of 2024 by graduate students assigned to the Naval Postgraduate School's Enterprise Sourcing Program. Interviewees included cybersecurity experts and program executive officers, who shared detailed insights into their respective processes for achieving an Authority to Operate (ATO), challenges faced, and best practices. Figures referenced throughout provide visual representations of specific processes and trends.

Introduction to Data and Analysis

This study aimed to document ATO processes, identify challenges, and analyze trends across organizations. Data was collected to highlight how workflows vary between systems and to uncover recurring themes like delays, automation needs, and the shift to agile methodologies. The analysis section builds on this data to explore patterns, contradictions, and innovative practices.

ATO Processes Overview

42nd Communications Squadron

The ATO process at the 42nd Communications Squadron involves multiple steps, starting with a system owner submitting a Cyber Security Requirements Document (CSRD) to their Communications Squadron (CS):

1. Verify if the requested software, hardware, or network is on the base-level Approved Products List (APL).
   - If not, consult the Air Force's APL.

- If absent, escalate to the local Configuration Control Board (CCB).

2. The CCB evaluates the system's mission impact and approves or denies the request.
3. Approved packages are sent to the HQ Cyberspace Capabilities Center (CCC) at Scott, IL.
4. The Air Force Network Integration Center (AFNIC) reviews the code for vulnerabilities.
5. The Information Assurance Manager (IAM) communicates AFNIC's recommendation to the local Communications Squadron Commander.
6. Certification is sent to the base's HQ for final accreditation by the Authorizing Official (AO).
7. If accreditation is granted, the system is authorized for 3 years.

Navy Information System Security Manager (ISSM)

The Navy's ATO process consists of four distinct phases, based on NIST SP800 guidelines:

1. **Interim Authority to Test (IATT):** Grants temporary testing approval for systems on the Department of Defense Information Networks (DoDIN) for up to 6 months.
2. **Certification:** Includes System Operation and Verification Testing (SOVT) to ensure compliance with network requirements.
3. **Accreditation:** Involves documentation review and approval, often the lengthiest phase.
4. **Reaccreditation:** Conducted every 18–36 months to confirm ongoing compliance by revisiting key Risk Management Framework (RMF) steps.

Communications AFSC Program Coordinator

The Risk Management Framework (RMF) Process is a primary method used to:

1. Categorize the system based on CNSSI 1253.
2. Select security controls, reviewed and approved by the security manager.
3. Implement controls during the program's ATO phase.
4. Conduct continuous monitoring, including security updates and vulnerability management.

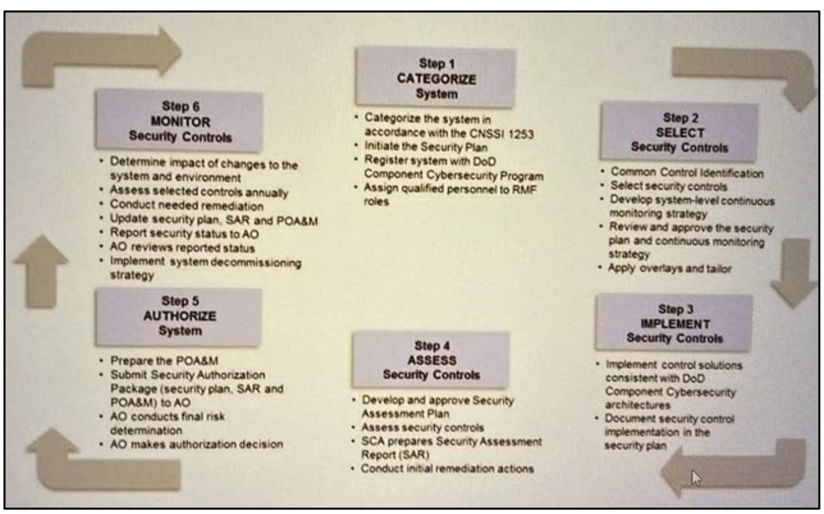

Figure 2: The RMF Process. Source: Communications AFSC Program Coordinator

TRANSCOM ATO Approach

At TRANSCOM, the J6, designated by the TRANSCOM commander, serves as the Authorizing Official (AO), with some delegation to the deputy J6 for efficiency. While major authorizations require AO-level approval, interim software releases or minor modifications follow a streamlined process where approval is handled at lower levels, such as the J6 side or program leadership.

For the DevSecOps platform, the traditional Risk Management Framework (RMF) process is used for initial authorization. This includes a comprehensive package and security assessment that goes to the AO. Tenant applications on the platform inherit approximately 80% of security controls from the platform, simplifying their requirements. These tenants perform a smaller subset of controls (the "assess-only" portion), which still requires AO sign-off but benefits from automation. Automated control gates further streamline authorization, ensuring repeatable and efficient processes for moving applications live.

The traditional step-by-step ATO process, where all documentation is submitted for periodic review, is being replaced by a more agile and efficient approach centered on continuous monitoring. This shift enables Authorizing Officials (AOs) to view real-time vulnerability and risk data through dashboards, ensuring transparency and ongoing oversight. The goal is to transition to a continuous ATO process, enhancing efficiency and risk management compared to the outdated annual or multi-year review cycles. This agile approach aligns with modern development practices and operational demands.

The focus is shifting from approving individual software releases to approving the process for software deployment. Once the process meets all predefined criteria, software releases that adhere to it are automatically authorized, eliminating the need for repeated reapproval for each deployment. This streamlines operations and enhances efficiency.

Key Issues and Considerations

Need for Automatic Data Collection

Efficient and automated data collection has been consistently identified by interviewees as a critical requirement to streamline the ATO process. A recurring challenge is the inefficiency of manual systems, which are outdated and slow. One program executive officer (PEO) highlighted managing legacy programs with code from as early as 1995. Developers accustomed to traditional waterfall methods often resist transitioning to modern workflows, further exacerbating delays.

To address this, transitioning to continuous integration for tenant applications is essential. Continuous integration embeds automated checks into the development pipeline, ensuring security standards are met throughout the deployment process. Tools like Fortify, SonarQube, and Twistlock enable developers to receive immediate feedback on vulnerabilities as code is uploaded to a centralized repository. Automated technical controls replace error-prone administrative tasks, enforcing consistent compliance with security baselines and supporting robust auditing mechanisms. This approach aligns with DevSecOps and agile methodologies, enhancing overall system integrity and efficiency.

The extensive documentation requirements of the ATO process also contribute to significant delays. Security control assessments, vulnerability management plans, and continuous monitoring protocols must be maintained as technologies and threats evolve. However, real-time updates to documentation are resource-intensive, especially across diverse projects. Automating these updates can alleviate bottlenecks by prioritizing accurate, up-to-date information.

Recommendations include better defining and documenting specific requirements from the outset of the ATO process. Standardizing compliance frameworks and tools across organizations would ensure greater efficiency and consistency. Additionally, agencies should establish clear guidelines and role definitions to align contractor efforts with government standards, particularly for ongoing compliance monitoring. Automated processes and standardized tools can significantly reduce reliance on contractors while maintaining alignment with security and operational goals.

Overall, automating data collection and approval processes offers transformative potential for the ATO framework. These advancements would streamline operations, reduce delays, and enhance the agility required to adapt to emerging technologies and threats.

Agile Methods

Adapting contracts to agile methodologies presents significant challenges, as highlighted by interviewees. A primary shift in agile development is emphasizing "working software" as the Key Performance Parameter (KPP) rather than traditional metrics. Many contracting officers, while skilled and diligent, have limited exposure to agile training and struggle to apply agile principles to requirements and deliveries. This reflects a broader need to modernize how contracts are structured.

The cultural shift required for agile delivery is particularly challenging within the functional community. Historically, this community has adhered to waterfall methods, characterized by long delivery cycles, static requirements, and extensive post-development testing. In contrast, agile methodologies prioritize rapid delivery, automated testing, and iterative releases. Agile models fix cost and schedule while allowing feature sets to evolve, focusing on incremental capability delivery. Functional teams must embrace the concept of a Minimum Viable Product (MVP) and redefine requirements into smaller, actionable increments. This cultural change demands new approaches to defining both requirements and delivery timelines.

An example of these challenges is evident within the cybersecurity service provider (CSSP) community. Tasked with securing modern cloud-based platforms, the CSSP community—accustomed to physical server monitoring—discovered that existing policies failed to address cloud cybersecurity requirements. It took 6 months to identify and begin addressing these gaps. Although the DoD is actively updating cybersecurity and acquisition policies, current efforts have yet to reach the agility required for rapid program development, including ATO processes.

Lack of Training

A recurring concern among interviewees was the limited formal training available for the ATO process. Most personnel only realized mistakes during final approval, often due to inconsistent ATO processes across offices. This reactive approach—focusing on rejection with feedback—results in frustration and inefficiencies.

Improved collaboration with experienced professionals such as ISSMs, ISSOs, and Cyber Leads is essential. Encouraging Authorizing Officials (AOs) to actively participate in all stages of the ATO process is particularly crucial for new program managers. Formalized training programs and workshops would foster a proactive culture, equipping personnel with the knowledge and tools to navigate ATO complexities effectively.

Detailed Process Analysis

Students at the Naval Postgraduate School conducted a detailed process analysis based on a combination of literature review research and interview data. The result is a robust process mapping of a typical ATO (Figures 3–7).

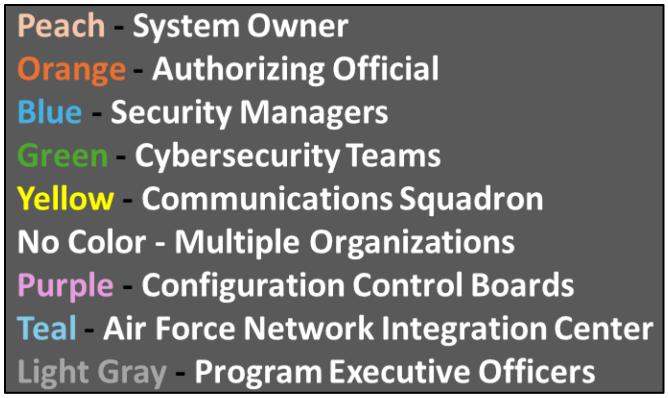

Figure 3: ATO Process Map Legend

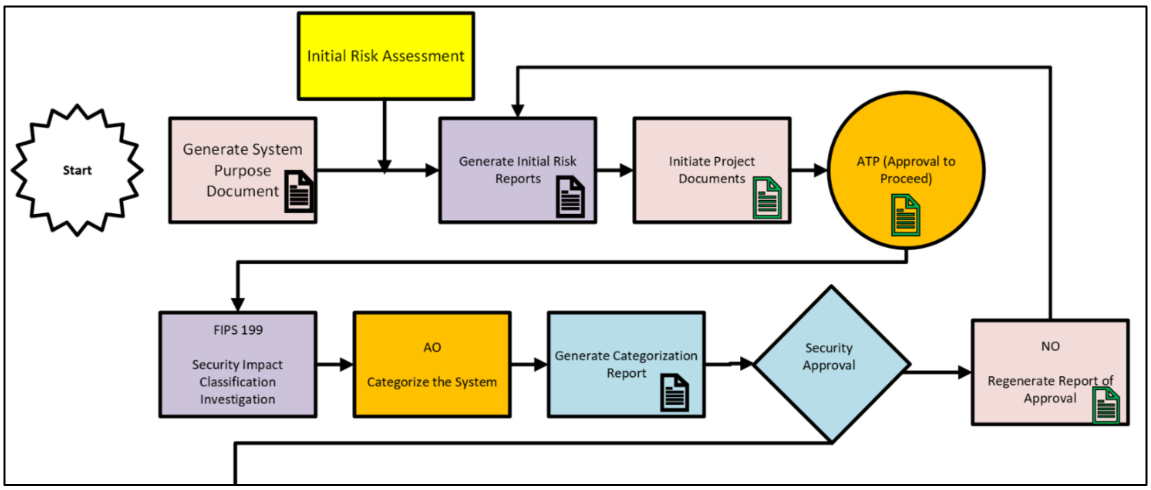

Figure 4: ATO Process Map (Phase 1, Steps 1–8)

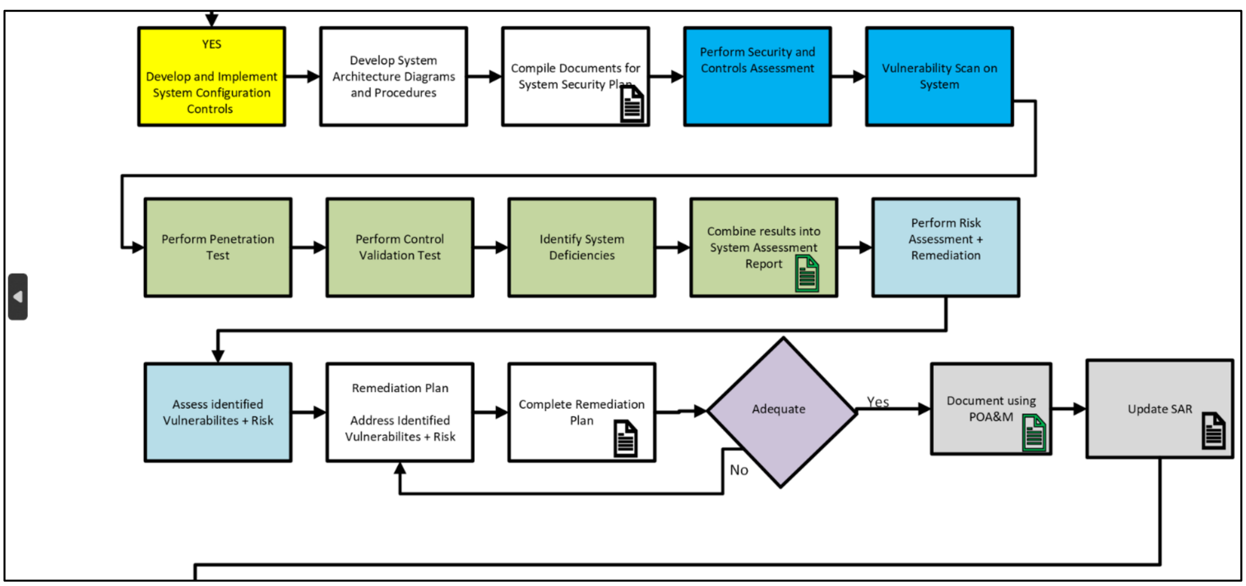

Figure 5: ATO Process Map (Phase 1, Steps 9–24)

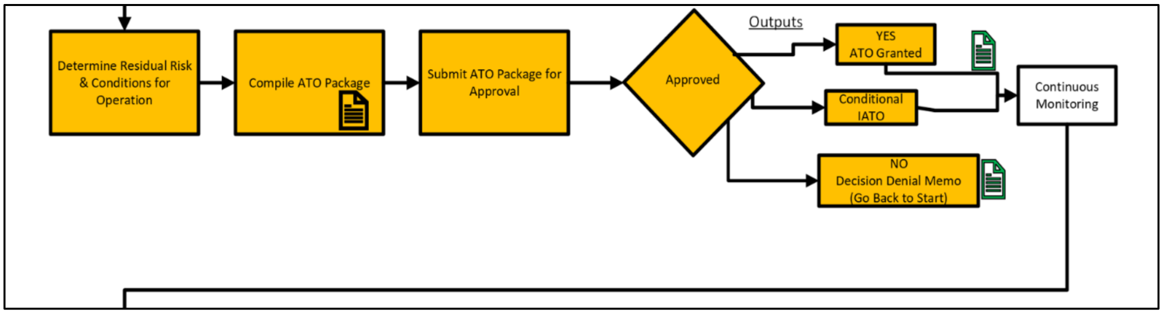

Figure 6: ATO Process Map (Phase 2)

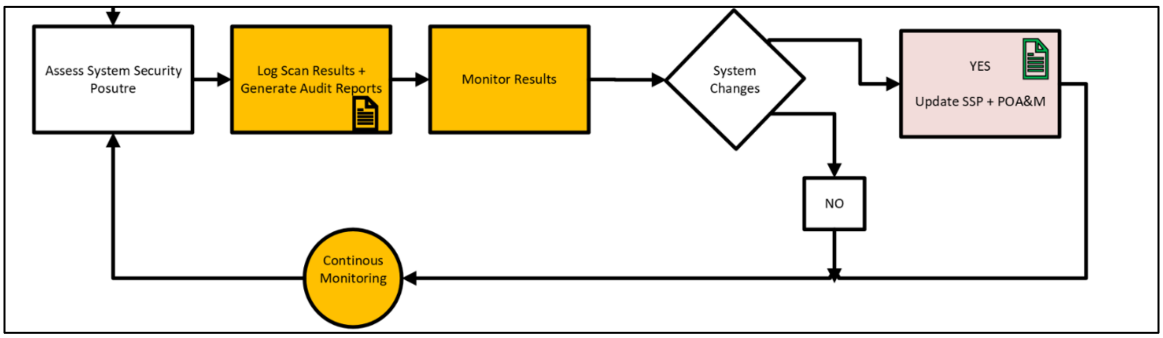

Figure 7: ATO Process Map (Phase 3)

The ATO process begins when the system owner and AO draft the System Purpose Document, which includes an initial risk assessment using the RMF. One of the most time-consuming ongoing tasks involves collecting project documents and completing tasks in eMASS. Once sufficient eMASS tasks are finished, the AO provides Approval to Proceed and categorizes the program using NIST Special Publication 800-53 guidelines. The security manager then evaluates the program by considering its necessity, integration costs, and risk assessment.

The next phase includes 17 sequential eMASS tasks, which can take anywhere from weeks to over 6 months depending on documentation quality and previous approval accuracy. These steps lead to the AO's final ATO review. Programs typically receive conditional approval with specific criteria for continuous monitoring. The expected timeline ranges from 6 to 18 months, though some cases extend to 24 months.

During the program's life cycle, ATO recertification occurs every 3 years or after major changes (SAF/CN, 2024). Updates reflect system performance changes and operating doctrine modifications listed in the Security Assessment Report. While recertification is generally simpler than initial approval, it can become challenging if documentation isn't maintained or if ATO expiration dates aren't tracked.

The traditional ATO process faces several implementation challenges. It requires extensive manual assessments and documentation, demanding significant time, personnel, and funding resources. As cyber threats grow more sophisticated, resource demands increase. While automation could streamline repetitive tasks and improve efficiency, it requires substantial initial investment. Future research should focus on developing cost-effective automation solutions that maintain security standards.

The increasing complexity of connected DoD systems has elevated technical requirements in the ATO process. Security focus has shifted from individual systems to ecosystem-level protection, requiring new approaches to handle interconnected systems within the Air Force's information infrastructure.

Emerging and Future Concepts

Recent developments include Zero Trust Architecture (ZTA) as a foundational element in modern ATO frameworks. ZTA requires all entities, internal or external, to be authenticated and authorized, with continuous validation of access requests. This approach aligns with continuous monitoring requirements and supports real-time authorization processes.

AI and machine learning are becoming integral to risk assessment and threat detection in the ATO process. However, these technologies present unique challenges, particularly regarding model transparency and adaptability, necessitating dedicated research for effective integration.

The Air Force has developed innovative approaches to address these challenges, including Fast Track ATO. This streamlined process focuses on operationally relevant risk assessments rather than pure compliance (Kiernan, 2021). It employs focused sprints where developers, cyber experts, and assessors collaborate intensively, reducing approval times to as little as 5 weeks (Feldman, 2018). Fast Track ATO reduces documentation requirements by emphasizing real-world testing and enables better integration of modern technologies like AI and cloud computing.

Continuous Authorization to Operate (cATO) represents another advancement in Air Force cybersecurity. Unlike traditional ATOs requiring periodic reauthorization, cATO enables ongoing monitoring and assessment of changes. This approach works particularly well in development, security, and operations (DevSecOps) environments, where security integration occurs throughout the system life cycle (Department of Defense Chief Information [DoD/CN], 2024). The continuous monitoring approach allows systems to remain operational while avoiding repeated ATO submissions.

cATO effectively supports DevSecOps and agile development methods, enabling faster updates and testing cycles. This capability proves especially valuable for military applications where rapid technological adaptation is crucial. By implementing cATO, the Air Force has reduced administrative barriers that previously delayed system deployments, improving operational readiness and security responsiveness.

Research Initiatives and Gaps

The following research initiatives and gaps were identified by the student research team during the fall of 2024 while studying this process.

Several research initiatives have emerged to enhance the Air Force's understanding of the ATO process, its effectiveness, and security model evolution in a dynamic operational environment. A key focus area involves developing comprehensive frameworks for securing AI and ML systems. Future research needs to address risks like data poisoning, model drift, and adversarial manipulation while incorporating real-time model validation and anomaly detection. Follow-on research should examine how continuous learning models affect ATO maintenance by analyzing recertification requirements for evolving AI models without compromising mission readiness. Studies should also explore incremental certification methods allowing partial AI model updates without full system recertification, enabling agile deployment while maintaining security standards. In addition to these broad research areas, the ensuing paragraphs establish a future research agenda that is organized around six main areas.

Process Analysis and Optimization

Research comparing traditional, Fast Track, and cATO models would help identify which approach best suits different operational scenarios. Using standardized metrics such as approval timelines, compliance ratings, and resource utilization would enable better assessment and improvement of each process. The exploration of automated tools for risk assessments and compliance checks could streamline the ATO process and reduce bottlenecks.

Organizational Impact Studies

Organizational studies should examine the effects of decentralized ATO authority on decision-making and accountability while identifying challenges in maintaining consistent security postures. These studies need to investigate cultural changes required for effective cATO adoption, including ways to promote security-first mindsets across operational and technical teams. Research should also focus on developing training methods that equip ATO stakeholders with skills for risk-based assessments, continuous monitoring, and adaptive security practices.

Risk Management Framework Development

Risk management research should develop assessment models specifically tailored for cloud, AI, and ML systems to address their unique security challenges. Studies must evaluate the impact of continuous monitoring in mission-critical environments by measuring early threat detection, resilience, and response times.

Policy Implementation and Development

Current policies may need amendments, and new policies must be created to accommodate AI, ML, and cloud-based systems, particularly regarding continuous learning and adaptability. Control measures for AI and ML systems should address model accuracy, data integrity, and vulnerability resilience. New policies must enable rapid integration of modern technologies while maintaining security standards.

Training and Education Requirements

Training programs need development to support modernized ATO frameworks, providing personnel with skills for managing risk in evolving security environments. Certification courses for AI and ML system assessment would ensure teams possess necessary expertise in AI security. Cybersecurity personnel require continuous learning programs to stay current with technological advances and emerging threats.

Operational Implementation Strategy

Implementation requires investment in automated tools for vulnerability scanning, compliance monitoring, and data collection to reduce manual labor and improve efficiency. Standardized templates for assessing emerging technologies would ensure consistent security evaluations. Deployment of monitoring systems would support continuous authorizations by enabling real-time threat response. Critically, the Force must be informed about and trained to use these tools effectively—without proper knowledge transfer, tool development becomes ineffective.

This comprehensive approach to research, policy development, and implementation provides a framework for evolving the ATO process to meet current and future security challenges while maintaining operational effectiveness.

Conclusion

Understanding and improving any complex system begins with acknowledging its challenges and thoroughly mapping its processes. Throughout this research, we have documented the current state of the ATO process, identified its pain points, and analyzed the environment in which these challenges occur. Our conversations with other defense services reveal that these challenges extend far beyond the Air Force, representing a systemic issue across the entire federal government's cybersecurity infrastructure. The evolution of the ATO process within the Air Force represents a critical junction between security requirements and operational agility, and its solutions may provide a blueprint for other federal agencies facing similar challenges. As technology advances and threats become more sophisticated, the traditional approach to authorization must adapt through research-driven improvements, policy refinement, and enhanced training programs. The successful implementation of Fast Track and continuous ATO frameworks demonstrates the Air Force's commitment to modernization, while the focus on AI integration and automated tools points toward a future of more efficient, responsive security protocols. By addressing the identified research gaps, investing in personnel development, and maintaining a balance between security and operational flexibility, the Air Force can continue to strengthen its cybersecurity posture while supporting rapid technological advancement. This holistic approach ensures that the ATO process remains both rigorous and responsive to the dynamic challenges of modern warfare and defense operations, potentially serving as a model for federal-wide cybersecurity authorization reform.

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SUMMIT PANEL 3. CROSSING THE VALLEY OF DEATH: STRATEGIC INNOVATION AND ENHANCED OUTCOMES

Thursday, May 8, 2025	
1100 – 1215 PT 1300 – 1415 CT 1400 – 1515 ET	**Chair: Maria A. Proestou, Deputy Assistant Secretary of the Navy, Acquisition Policy & Budget and Executive Director, Science and Technology (S&T) Board federal advisory committee, Department of the Navy** **Discussant: Jessica N. Jones (Ph.D.), Deputy Director, Office of Naval Research Global TechSolutions** ***Crossing the Valley of Death Faster and More Often with Bigger Outcomes*** Justin Fanelli, Chief Technology Officer, Department of Navy ***Defense Innovation Unit: Actions Needed to Assess Progress and Further Enhance Collaboration*** Jennifer Dougherty, Senior Analyst, U.S. Government Accountability Office ***Process Innovation Pilots: Lowering Early-Stage Barriers to Entry and Survival*** John Kamp, Special Assistant, Defense Advanced Research Projects Agency (DARPA)

Maria A. Proestou—serves as the Deputy Assistant Secretary of the Navy for Acquisition, Policy and Budget (DASN(AP&B)) under the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN(RD&A)). Ms. Proestou is the principal advisor and coordinator on matters pertaining to the Planning, Programming, Budgeting, and Execution of the Acquisition and Sustainment enterprise; she oversees the development, review and implementation of Acquisition and Sustainment Policies, including acquisition reporting, cost analysis and associated data steward responsibilities.

Ms. Proestou also serves as the Strategic Acquisition Advisor and provides executive leadership and expertise to strategic acquisition efforts across the Naval Research, Development and Acquisition enterprise. Her primary focus is on expanding the traditional and non-traditional industrial base to increase capacity and harness technological innovation. As the Executive Director of the Department of Navy (DON), Science and Technology (S&T) Board federal advisory committee, she represents the Secretary of the Navy's desire for independent assessments from national experts.

An accomplished former defense industry executive, she managed strategic contracts spanning the DON's portfolio of acquisition programs across every DON Buying Command, as well as with DoD Agencies. Prior to joining ASN(RD&A), she integrated DELTA Resources, Inc., the company she founded and led for 20 years, into a successful mid-tier C5ISRT-focused Engineering and Sustainment business. While at DELTA, she was active in promoting industry's role in enabling DOD's Joint All-Domain Command and Control (JADC2) objectives. As a founder and CEO, she successfully grew her business from a woman-owned small business to a large business earning "Great Places to Work" awards for 12 consecutive years. A strong advocate for workforce engagement, culture, and workplace flexibility; Ms. Proestou has served as a keynote speaker at Fortune Magazine's "Best Places to Work" Annual Conference and was invited to participate in the Obama White House Forum on Workplace Flexibility.

Ms. Proestou received her Bachelor of Arts degree from The George Washington University's Elliott School of International Affairs focusing on security studies. She attended the Fletcher School of Law and

Diplomacy at Tuft's University receiving her Master of Arts in Law and Diplomacy following completion of a dual thesis in national security and finance.

Jessica N. Jones (Ph.D.)—Dr. Jones started her government career at Naval Surface Warfare Center (NSWC) Indian Head and joined TechSolutions on detail from Naval Surface Warfare Center Dahlgren Division, where she was most recently a Lead Human-System Research Scientist. During her time at the Warfare Centers, Dr. Jones focused on investigating and addressing Warfighter needs and capability gaps via basic and applied research with a Human-Centered approach.

At TechSolutions, Dr. Jones supports the process of going from warfighter need to delivered capability. She also works to increase knowledge about the TechSolutions mission in the Warfighter and Naval Research & Development Enterprise (NR&DE) communities.

Dr. Jones has a BS and MS in Computer Science from Hampton University and Clemson University. She earned a Ph.D. in Human-Centered Computing from University of Florida.

Crossing the Valley of Death Faster and More Often with Bigger Outcomes

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Dr. Michael R. Schweitzer—Falconwood Inc.

Abstract

Faced with acquiring technological capabilities for the U.S. Department of the Navy (DoN), traditional contracting methods are burdensome, often inhibiting agencies across the U.S. Department of Defense (DoD) from delivering solutions at the speed of the mission. In 2024, major defense acquisition programs (MDAPs) take an average of 11 years to reach initial operational capacity and middle tier acquisition (MTA) programs, intended to be completed in 5 years, report delays to key milestones (U.S. Government Accountability Office, 2024). And while there is some evidence that the DoN is averaging closer to 36 months for initial operational capacity, in the context of rapidly changing solutions that impact warfighter readiness, momentum is still a concern (RAND, 2012). To accelerate tech acquisition, adoption, and achieve information superiority, the DoN Program Executive Office (PEO) Digital Technical Director's Office has implemented a new acquisition strategy using value-driven investment methods. The authors found that use of this strategy reduced acquisition timelines by 18 months and improved mission value contribution by $2 billion annually. Adoption of this acquisition approach may yield similar results at other DoD service-branch program executive offices and improve mission outcomes.

Keywords: acquisition, defense technology, innovation adoption

Introduction

According to the Atlantic Commission on Defense Innovation Adoption (2024), "the United States does not have an *innovation* problem, but rather an *innovation adoption* problem." With the Davidson window less than 2 years away, the U.S. secretary of defense announcing a new software acquisition approach, and the Pentagon operating on its first year long continuing resolution (CR), there's never been a better time to assess the tech acquisition strategies used by the U.S. Department of Defense (Defense News, 2024; DefenseScoop, 2025; Inside Defense, 2025).

The core issue facing the Department of Defense (DoD) in acquisition and technology boils down to two intertwined challenges: escalating costs to taxpayers with declining returns on investment, and the rapid pace at which adversaries are adopting new technologies. For fiscal year 2024, the Department of Defense Appropriations Act (P.L. 118-47) allocated $168.7 billion for procurement, while the total enacted budget for Research, Development, Test, and Evaluation (RDT&E) reached $152.3 billion, according to the Congressional Research Service (2024). Combined, these funds provide approximately $321 billion for the DoD to drive innovation and adoption—a hefty sum that underscores the stakes in addressing these inefficiencies and keeping up with global competitors.

Are these innovation dollars providing corresponding value to the American people? In March 2024 testimony before the U.S. Senate Committee on Armed Services, Center for a New American Security (CNAS) Executive Vice President Paul Scharre argued against that theory, stating that U.S. defense spending has diminished value in the global technological ecosystem because the DoD is no longer the main driver of global innovation. According to Scharre (2024), technology is advancing at exponential rates and widely available in a "highly globalized, commercially driven R&D ecosystem, that competitors have similar opportunities to develop."

One notable example is the acceleration of technology adoption by the People's Republic of China (PRC), even in areas where the United States once dominated. PRC's adoption and integration of automation in shipbuilding practices outpaces U.S. ship production by over 230 to 1. This trend is expected to continue in other domains. A report to the U.S. Congress presented three notable findings related to technology and force modernization: the PRC's long-term goal is to create an entirely self-reliant defense-industrial sector, amplified by a strong civilian industrial and technology sector; the PRC has substantially reorganized its defense-industrial sector to improve weapon system research, development, acquisition, testing, evaluation, and production; the PRC's actual defense budget is approximately $330 billion–$450 billion, the second-largest military expenditure in the world (Department of Defense, 2024).

Amid these challenges, how can the U.S. Department of the Navy maintain its global posture and ensure it has the right technological capabilities to maintain the freedom of the sea? The DoN Program Executive Office (PEO) Digital seeks to offer a world-class digital experience to the Marine Corps and Navy through five organizational goals. It serves as the DoN's acquisition office focused on maintaining the competitive edge through delivery of enterprise IT infrastructure and core digital services.

When it comes to its technical vision, PEO Digital aims to enable experimentation and fast track innovation through modern service delivery. It seeks to foster a workplace where behaviors that increase outcomes are championed.

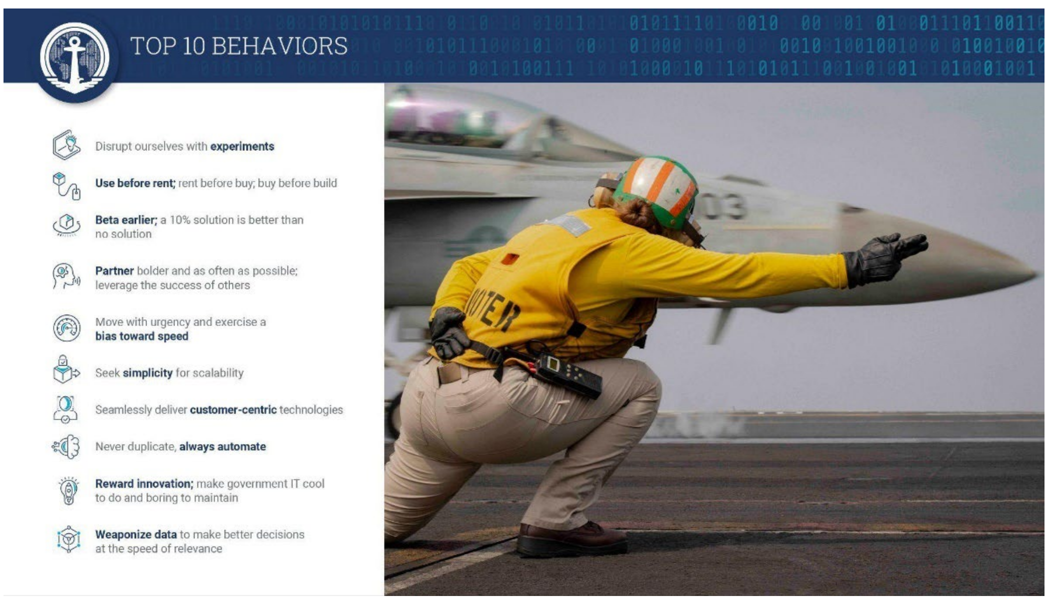

Figure 1. Top 10 Behaviors

Since 2022, a DoN team comprised of members of PEO Digital and the Chief Technology Officer (CTO) directorate has successfully implemented value-driven investing. They've established key frameworks, available for use by any federal organization, to improve the value of acquisitions and capability sustainment. Shifting to this approach has reduced acquisition timelines by 18 months and improved mission value contribution by $2 billion annually. The further belief is that this can scale to improve acquisition value exponentially for other organizations as well who adapt and adopt similarly.

Figure 2. PEO Digital Vision & Mission

World Class Alignment Metrics

The Department of the Navy Chief Information Office (DoN CIO) established the World Class Alignment Metrics (WAM) framework to evaluate technology investments and their performance against five outcome-driven metrics: time lost, operational resilience, customer satisfaction, cost per user, and adaptability/mobility. Implementation best practices include prioritizing investments based on WAM metrics, using WAM to justify funding, and considering WAMs for system rationalization and portfolio management.

For the Information Technology use case these mission outcome driven metrics are defined as:

1. Time lost: amount of time customers wait for IT services.
2. Operational resilience: delivering services despite unanticipated disruptions.
3. Customer satisfaction: level of comfort with fielded IT services.
4. Cost per user: total IT costs divided by number of users.
5. Adaptability/Mobility: time to make changes associated with IT services, to include delivering new capabilities.

Investment Horizons

DoN CIO leverages the Investment Horizons framework to accelerate the adoption of new technologies and identify divestment opportunities. It is divided into five horizons: Horizon 3 (*Evaluating*, capabilities being explored by external organizations that have the potential to introduce new technologies and services); Horizon 2 (*Emerging,* capabilities ready for DoN pilot funding and development); Horizon 1 (*Investing or Extracting,* successful pilot capabilities ready to be scaled or sustained capabilities that are in active use); Horizon 0 (*Retiring,* capabilities that need to be divested or decommissioned.) This framework guides DoN technology roadmaps, enterprise services adoption, and resource allocation.

Structured Piloting

Building on the previous two frameworks, DoN CIO's Structured Piloting approach similarly seeks to accelerate the adoption of new technologies and divestment of obsolete systems. This framework takes a step further, establishing criteria for pilot advancement and utilizing Modern Service Delivery (MSD) concepts.

Strategy Through Execution

PEO Digital established the Strategy Through Execution framework to outline the process new DoN IT capabilities and requirements must follow through the Planning, Programming, Budgeting, Execution (PPBE) cycle to achieve Investment Horizon maturity.

Structured Divestments

DoN CIO established the Structured Divestments framework to eliminate redundant and obsolete IT systems and streamline resources. This approach integrates the previous four frameworks to evaluate outdated, insecure, or redundant systems, and reinvest savings in modern solutions. The Structured Divestments framework ensures a systematic, data-driven process, even as legacy technologies reach the end of their life cycle.

Resilient and Agile Contracting

PEO Digital leverages a diverse range of contracting vehicles to maximize the use of multiple vendors and reduce single vendor dependencies. This approach involves seeking out prospective partners and contracting offices that offer measurable efficiencies and innovative practices that overcome acquisition delays.

Literature Review

Historical Acquisition Challenges and Strategic Context

The DoD continues to confront persistent and prolonged acquisition processes, critically impairing its ability to rapidly deliver essential capabilities to warfighters. Historically, major defense acquisition programs have been marred by significant delays, extending average project timelines from 8 to 11 years by 2023, significantly increasing costs and hindering operational responsiveness (GAO, 2023).

Central to these delays is the “Valley of Death,” a notorious gap where emerging technologies fail to transition effectively from development to deployment. Recent research attributes this phenomenon to entrenched bureaucratic resistance, misaligned incentives, and restrictive procurement practices that prioritize traditional defense contractors over innovative nontraditional entrants, limiting the Department's access to cutting-edge technological solutions (Defense Innovation Board [DIB], 2025). Such institutional inertia has consistently halted or slowed promising innovations, substantially weakening military capabilities (Clark, 2023).

Amplifying these internal acquisition issues is the accelerated technological advancement by strategic rivals, especially China. According to the Australian Strategic Policy Institute (ASPI, 2023), China now dominates in innovation across numerous vital technologies, including artificial intelligence, cyber warfare, and hypersonic missile systems. Such rapid progression places additional urgency on the U.S. defense apparatus to reform and accelerate its procurement practices to maintain a critical competitive advantage (ASPI, 2023).

In response to these entrenched challenges, the DoD initiated the Adaptive Acquisition Framework (AAF) in 2020 to provide more adaptable and efficient procurement pathways. Despite its promising objectives, GAO (2023) highlights substantial implementation hurdles, demonstrating ongoing delays similar to traditional procurement systems. This indicates that mere policy adjustments are insufficient without corresponding deep-seated cultural and structural changes within defense acquisition organizations (Kardas et al., 2023).

Externally driven challenges, such as international trade dynamics and disruptions in global supply chains, further compound the DoD’s procurement complexities. Proposed tariffs on allied imports have raised critical concerns over increased manufacturing costs and subsequent delays in weapons production, potentially jeopardizing international defense collaborations and exacerbating existing procurement issues (Freeman & Calton, 2021; Politico, 2025).

Addressing these multi-dimensional challenges necessitates the establishment of a more agile and responsive acquisition system. Enhancements must involve deeper collaboration with nontraditional defense contractors, leveraging private-sector innovations, and adopting iterative development processes that emphasize incremental delivery and continuous improvement (Davison et al., 2021). Integrating these strategies could substantially improve the DoD's capability to rapidly field advanced technologies and maintain operational superiority in a complex global security environment.

Innovation Adoption and Organizational Challenges

The DoD struggles significantly with innovation adoption, primarily due to entrenched organizational designs and control-focused practices. The dominant command-and-control structure, typically seen in military and defense contexts, inherently limits innovation by prioritizing compliance, consistency, and procedural control over flexibility and agility (Nica, 2022). Organizations structured around such rigid hierarchies tend to emphasize precision and incremental process improvements rather than embracing disruptive, transformative innovations (Ishijima et al., 2020). Consequently, this hierarchical and compliance-driven culture frequently obstructs rapid adoption of innovative technologies essential for modern operational capabilities.

Organizational theorists highlight that information systems and decision-making pathways often reflect existing organizational communication structures, as explained by Conway's Law. This theory indicates that the effectiveness of technology adoption is constrained by the organization's inherent communication patterns (Iansiti & Lakhani, 2020). Thus, rigid and hierarchical communication channels prevalent in DoD structures inadvertently become barriers to innovative technology integration, often perpetuating outdated methods instead of fostering novel technological advancements (Piccolo et al., 2022).

Leaders within control-focused organizations tend to centralize decision-making authority, reinforcing communication pathways that automate or ease investment decisions aligned with traditional control mechanisms (Jung-Chieh & Chung-Yang, 2019). Such centralization reduces flexibility and responsiveness to innovation, severely limiting the organization's resilience in dynamic and rapidly changing environments. This issue is exacerbated by the procedural complexity inherent in military acquisition systems, which prioritize exhaustive approval steps over swift and adaptive responses to emerging opportunities and threats (Maika & Wachira, 2020).

Contrastingly, innovative organizations typically employ decentralized decision-making structures, which enhance agility and responsiveness. High-innovation organizations (HIOs) empower individuals and teams to make operational decisions directly, significantly reducing bureaucratic overhead and fostering environments conducive to rapid innovation (Hossain et al., 2018). Burch and DiBella (2021) support this perspective, demonstrating how complex communication networks and technological capabilities facilitate decision decentralization, allowing organizations to remain agile even within control-focused contexts.

Technological infrastructures, independent of organizational structures, can enable increased agility. However, rigid organizational frameworks, such as those prevalent in defense contexts, frequently limit the capability of technological innovations to provide their intended benefits fully (Imran et al., 2022). Organizations that effectively integrate technology capabilities within their strategic frameworks and structures are better positioned to adapt and optimize operational outcomes, even within traditionally rigid environments (Ercan & Samet, 2020).

The Scaled Agile Framework (SAFe) offers a practical resolution by maintaining necessary oversight and compliance requirements while simultaneously empowering cross-functional teams with decision-making authority at tactical levels (Aleinikova et al., 2020). This approach mirrors multiteam systems that promote lateral collaboration and integration, breaking down siloed competencies common within control-focused organizations (Turner et al., 2019). Agile methods, such as sprint-based development, further reduce bureaucratic barriers by allowing frontline personnel to operate autonomously within pre-approved strategic objectives, greatly enhancing operational agility and responsiveness (Dumitriu et al., 2019; Hyman et al., 2022).

Ultimately, the DoD's current innovation impediments underscore the urgent need to balance command-and-control requirements with more flexible, decentralized decision-making processes and agile methodologies. Establishing a continuous learning culture, incorporating agile frameworks, and strategically decentralizing decision authority are critical steps towards overcoming entrenched organizational challenges and enhancing innovation adoption.

Predictive Analytics and Big Data Integration

The integration of predictive analytics and big data within defense organizations offers substantial potential to enhance operational decision-making, forecasting accuracy, and risk management. Predictive analytics leverages historical datasets to generate actionable insights and accurately forecast future events or trends, thereby supporting strategic decision-making processes (Anitha & Patil, 2018). Defense organizations utilize predictive analytics to anticipate operational disruptions, optimize resource allocation, and improve mission readiness significantly.

Big data analytics amplifies predictive capabilities through the exploration of extensive, complex datasets, enabling the identification of subtle patterns, correlations, and trends typically undetectable by traditional analytic methods. Defense organizations that analyze large-scale data repositories effectively enhance their decision-making capabilities, increasing responsiveness in dynamic operational environments (Shabbir & Gardezi, 2020). Big data analytics transitions defense postures from reactive to proactive stances, thereby reducing vulnerabilities and strengthening operational resilience (Tohid et al., 2021).

Cybersecurity frameworks, particularly Zero Trust models, benefit considerably from predictive analytics as foundational tools for behavioral analysis and anomaly detection. This proactive approach strengthens network security by identifying and mitigating potential threats before they manifest, enhancing operational continuity and resilience (Belal et al., 2022). Advanced analytics methods also enhance logistical efficiencies, accurately forecasting demand, refining supply chain management, and minimizing unnecessary inventory levels, thus optimizing operational resource utilization (Niederman, 2021).

Examples of organizations that successfully integrate predictive analytics include Amazon and Microsoft. These companies demonstrate the transformative capabilities of predictive analytics in operational optimization and competitive advantage reinforcement. Amazon leverages predictive analytics to optimize inventory management, enhance customer service responsiveness, and reduce operational costs (Asafo-Adjei et al., 2022). Microsoft employs predictive analytics within its Azure Machine Learning platforms, improving real-time threat detection and operational resilience through predictive modeling and adaptive risk management strategies.

Several barriers persist in effectively leveraging predictive analytics and big data technologies within defense organizations. Prominent among these obstacles include data quality issues, data integration complexities, and the shortage of qualified analytics professionals. High-quality, consistent data remains essential for precise predictive modeling;

inaccuracies or inconsistencies in data can lead to unreliable predictions and ineffective decision-making (Janine, 2021).

The integration of diverse data sources into unified analytical frameworks poses significant challenges, requiring advanced technological infrastructures and stringent interoperability standards. The scale and complexity inherent in defense datasets further complicate integration efforts, necessitating sophisticated platforms capable of real-time data processing and analytics (Londhe & Palwe, 2022). The lack of skilled analytics professionals within the defense sector further hampers widespread adoption and implementation effectiveness.

Strategic planning and dedicated investments in technological infrastructure, workforce development, and data governance frameworks are essential to overcome these multifaceted challenges. The DoD must prioritize the establishment of robust data integration platforms and promote interoperability standards across defense systems. Expanding training and education programs to cultivate analytics expertise among personnel is essential for leveraging predictive analytics and big data effectively.

Predictive analytics and big data integration represent critical strategic opportunities for defense organizations seeking enhanced agility and operational effectiveness. Capitalizing on these opportunities demands a comprehensive approach combining technological innovation, organizational readiness, workforce development, and robust data governance. Addressing these imperatives will enable defense organizations to effectively respond to emerging threats, optimize resource allocation, and sustain competitive operational advantages in the contemporary global security environment.

Structured Acquisition Frameworks

The effective implementation of structured acquisition frameworks significantly advances the capability of the DoD to efficiently acquire and deploy emerging technologies (Klein et al., 2022). Utilizing frameworks such as World-Class Alignment Metrics (WAM), Investment Horizons, and Structured Piloting, the DoD optimizes acquisition processes, ensuring precise alignment with strategic and operational objectives (PEO Digital and Enterprise Services, 2022).

The concept of Investment Horizons serves as an additional strategic tool, delivering meticulously outlined technology roadmaps that describe progression from initial concept exploration to eventual retirement. This clear, structured mapping promotes coherent investment strategies, aligning technological advancement seamlessly with strategic capability development. Consequently, organizations achieve greater precision in resource allocation, avoid unnecessary expenditures, and effectively manage technological life-cycle transitions, reinforcing strategic and operational capabilities (Calafut et al., 2021).

Structured Piloting further enriches these methodologies by outlining explicit advancement criteria and systematic validation procedures critical for technology development. Through iterative experimentation and comprehensive validation, Structured Piloting supports rapid and risk-managed transitions from technology prototyping phases into full operational use. This structured approach accelerates technological adoption and significantly minimizes the integration risks inherent in complex defense systems and operations (Dumitriu et al., 2019).

The Strategy Through Execution framework specifically addresses the challenge of synchronizing technological development with the DoD's strategic planning and fiscal management processes, including the Planning, Programming, Budgeting, and Execution (PPBE) system. This deliberate synchronization mitigates historical inefficiencies arising from misaligned acquisition activities and ensures the effective translation of strategic objectives into actionable implementation plans, thereby bolstering operational readiness and organizational agility (Karnes & Mortlock, 2021).

Structured Divestment processes are instrumental in improving acquisition efficiency by systematically identifying and discontinuing outdated or ineffective technologies. The proactive removal of obsolete systems liberates resources, redirecting them toward innovative technologies with higher strategic value. This strategic divestment preserves the DoD's technological edge, ensuring adaptability and responsiveness within dynamic and evolving threat environments (Goljan et al., 2021).

Resilient and Agile Contracting mechanisms enhance acquisition outcomes by providing flexible contractual agreements, reducing vendor dependency, and stimulating innovation through competitive vendor engagements. These contracting methodologies significantly shorten procurement timelines, often condensing contract awards from extensive periods of months down to a few weeks. Consequently, the DoD can swiftly respond to technological advancements and emerging operational demands, enhancing strategic responsiveness (Elkins, 2023).

Empirical research robustly supports the effectiveness of structured acquisition frameworks, noting significant improvements in acquisition timelines, cost management, and operational outcomes. Defense programs implementing structured methodologies demonstrate notable enhancements in strategic alignment, expedited project timelines, and improved cost-effectiveness, affirming the broad utility and substantial benefits of structured acquisition approaches within varied operational contexts (Corn, 2021).

Achieving these benefits through structured acquisition frameworks necessitates extensive organizational and cultural adaptations within defense procurement environments. Successful adaptation involves strict adherence to defined methodological standards, ongoing evaluation and feedback mechanisms, and alignment of technological advancements with broader organizational objectives. Organizations adeptly integrating these structured frameworks report heightened procurement agility, optimized resource utilization, and superior strategic and operational outcomes (Bronson, 2020).

Organizational Change and Strategy-to-Execution

Effective organizational transformations within defense procurement contexts rely on targeted methodologies such as the Burke-Litwin Model and Appreciative Inquiry. These frameworks support structured change by emphasizing adaptive management and delegated decision-making, thus enhancing organizational responsiveness and fostering innovation. The Burke-Litwin Model specifically facilitates the identification of influential factors driving organizational performance and provides a comprehensive approach to manage systemic changes within complex organizations, including the Department of Defense (Bryan, 2020; Burke & Litwin, 1992).

Appreciative Inquiry (AI) offers a positive, strengths-based methodology aimed at organizational change by identifying and amplifying existing successful practices. In contrast to traditional deficit-focused approaches, AI strengthens strategic initiatives by fostering environments where organizational members actively engage in constructive dialogues to envision and realize desired future states. Research from defense and public administration contexts highlights AI's efficacy in improving employee engagement, motivation, and alignment with organizational objectives, particularly within complex bureaucratic structures (Bushe & Kassam, 2021; Cooperrider & Whitney, 2005).

Action research methodologies complement these structured frameworks through embedded continuous learning and iterative improvement cycles. These methodologies facilitate participatory stakeholder engagement in iterative planning, action, and reflection cycles. Such iterative processes foster dynamic responsiveness to emerging challenges and opportunities within defense procurement environments, characterized by rapidly evolving technology and strategic complexity (Coghlan & Brannick, 2019; Reason & Bradbury, 2020).

The successful implementation of change methodologies in defense procurement necessitates a strategic alignment between leadership practices and organizational design. Delegation of decision-making authority empowers teams, enhances agility, and reduces bureaucratic inertia that typically inhibits innovation. Defense organizations utilizing decentralized decision-making frameworks demonstrate enhanced operational efficiency, faster adaptation to technological advances, and increased resilience in complex operational conditions (Greenhalgh & Papoutsi, 2018; Langley & Denis, 2020).

Strategic execution aligned with organizational change initiatives requires robust communication and collaborative integration across all organizational levels. Clear strategic communication and transparent dissemination of change objectives significantly improve collective understanding, facilitate stakeholder buy-in, and ensure coordinated actions throughout the transformation processes. Literature emphasizes that consistent communication strategies reduce resistance to change, align individual and organizational objectives effectively, and foster inclusive environments conducive to achieving strategic outcomes (Clampitt & Berk, 2020; Kotter, 2021).

Sustaining meaningful organizational change within defense procurement contexts significantly depends on structured change methodologies and the alignment of strategic execution processes. Organizations successfully integrating adaptive management, strengths-based approaches such as Appreciative Inquiry, and iterative action research methods report marked improvements in innovation capacity, organizational agility, and overall responsiveness, supporting their long-term strategic effectiveness and resilience.

Technical Debt and Portfolio Management

Effective management of technical debt through strategic portfolio rationalization is essential for maintaining technological and operational readiness in defense procurement contexts. Technical debt represents the accumulated costs associated with prioritizing short-term solutions over long-term sustainability and optimal software management practices. Unmanaged technical debt can severely impair organizational agility and innovation, leading to increased maintenance costs and diminished operational effectiveness (Kruchten et al., 2019; Ramasubbu & Kemerer, 2021).

The Strategy-to-Execution (S2E) Model within PEO Digital offers a structured framework for aligning strategic objectives with execution outcomes, systematically addressing technical debt while simultaneously fostering innovation and agility. S2E integrates strategic planning with execution monitoring, creating a feedback loop that ensures technical debt considerations are continuously evaluated and managed throughout the life cycle of defense projects. Organizations adopting this model report improved capability deployment, reduced life-cycle costs, and enhanced responsiveness to emerging threats and technological opportunities (Highsmith & Cockburn, 2021; Project Management Institute [PMI], 2022).

Proactive portfolio management practices further strengthen organizational capacity to manage technical debt effectively. Structured portfolio rationalization involves assessing, prioritizing, and strategically retiring legacy systems that impose high operational costs or fail to meet current strategic requirements. Organizations implementing structured portfolio management practices achieve improved resource allocation, reduced complexity, and increased flexibility to adapt to technological advancements and operational requirements (Laanti & Abrahamsson, 2021; Stettina & Hörz, 2021).

Integration of agile methodologies with portfolio management enhances an organization's capability to manage technical debt proactively. Agile practices emphasize iterative development, continuous improvement, and adaptive planning, facilitating ongoing identification and remediation of technical debt. Defense procurement organizations employing agile portfolio management methods benefit from enhanced transparency, better risk management, and improved alignment between technology initiatives and strategic objectives (Cagan & Jones, 2021; Rico & Sayani, 2022).

Structured management and continuous monitoring of technical debt within portfolio management frameworks enable defense organizations to maintain technological superiority and operational resilience. Organizations achieving successful integration of agile and strategic portfolio management practices demonstrate improved capability deployment speeds, enhanced operational effectiveness, and sustained technological relevance. Such strategic portfolio rationalization efforts significantly contribute to the long-term strategic success and operational agility of defense procurement organizations.

Historical Challenges and Acquisition Reform

Defense acquisition historically faces persistent challenges, including complex bureaucratic procedures, lengthy procurement timelines, and resistance to change. Complex procurement processes, marked by stringent regulatory compliance and multiple layers of decision-making, frequently result in delayed project timelines and increased costs. Researchers highlight how these bureaucratic complexities significantly limit agility and responsiveness, hindering the rapid adoption of emerging technologies necessary for modern operational environments (Fox, 2021; Schwartz & Peters, 2020).

Acquisition reform initiatives have sought to streamline procurement processes, improve efficiency, and enhance responsiveness to operational needs. Efforts such as the implementation of rapid prototyping, streamlined contracting vehicles, and agile methodologies demonstrate varying degrees of success. Studies underscore the importance of integrating these reforms within existing organizational structures and cultural contexts to realize sustainable improvements in acquisition performance (Schwartz, 2022; Tremaine & Seligman, 2021).

Research consistently identifies cultural inertia within defense organizations as a significant barrier to successful acquisition reform. Organizational culture, often deeply rooted in established procedures and risk-averse attitudes, can resist reform efforts designed to introduce innovation and agility. Overcoming these cultural barriers requires comprehensive change management strategies emphasizing leadership commitment, effective communication, and continuous education to foster an adaptive organizational culture (Weiss & Foster, 2021; Zakhem et al., 2020).

Strategic alignment of acquisition reforms with broader organizational objectives and operational requirements is crucial for their successful implementation. Alignment ensures that reform initiatives are relevant, effectively communicated, and supported by key stakeholders. Empirical evidence highlights the value of incorporating user feedback and operational insights early in the acquisition process to enhance strategic alignment and operational effectiveness (Hunter & Farrell, 2020; McCormack & Johnson, 2021).

Sustainable acquisition reform requires ongoing evaluation and iterative refinement. Continuous performance assessments, feedback mechanisms, and iterative improvement cycles ensure reform efforts remain aligned with evolving strategic priorities and operational needs. Organizations embracing iterative evaluation approaches report sustained improvements in procurement efficiency, enhanced responsiveness to technological advancements, and greater strategic alignment of acquisition activities (Johnson, 2022; Spencer & Jones, 2021).

Integrating agile methodologies into defense procurement processes significantly enhances adaptability, efficiency, and responsiveness to evolving operational requirements (MITRE Corporation, 2022). Agile practices emphasize iterative development, cross-functional collaboration, and rapid delivery of functional components, aligning closely with the dynamic operational demands of contemporary defense missions (Defense Acquisition University [DAU], 2021).

The DoD acknowledges the potential of agile methodologies to streamline traditionally lengthy procurement cycles. Frameworks such as the Defense Agile Acquisition Guide offer tailored guidance for IT acquisitions, promoting accelerated capability delivery and improved project outcomes (MITRE Corporation, 2022). Agile-focused frameworks demonstrate improved responsiveness to rapidly evolving technology environments, a critical factor in maintaining operational advantage (DAU, 2021).

Contracting mechanisms critically influence the successful implementation of agile methodologies in defense procurement. Traditional procurement contracts often lack the necessary flexibility for agile projects, prompting the DoD to adopt incentivized agile contracting approaches such as indefinite delivery contracts with firm-fixed-price task orders (DAU, 2021). These adaptive contracting methods support dynamic scope changes inherent in agile processes, ensuring continuous alignment with operational requirements (DAU, 2021).

Performance-based logistics (PBL) further illustrates the effective integration of agile principles within defense procurement. PBL strategies prioritize operational outcomes over prescriptive processes, incentivizing contractors to enhance system performance and maintain high readiness levels, thereby reducing life-cycle costs and improving system availability (Defense Logistics Agency [DLA], 2022).

Despite clear advantages, integrating agile methodologies in defense procurement faces substantial institutional resistance. Cultural inertia, entrenched procedural norms, and stringent regulatory frameworks often impede agile adoption. Successfully overcoming these barriers requires comprehensive change management strategies, persistent education efforts, and unwavering leadership commitment to fostering a culture receptive to agile practices (National Defense Industrial Association [NDIA], 2023).

Strategically aligning agile methodologies with organizational structures, implementing adaptive contracting mechanisms, and shifting organizational culture toward flexibility and continuous improvement are critical for realizing the full potential of agile practices within defense procurement contexts (MITRE Corporation, 2022; NDIA, 2023).

Conclusion

Integrating structured methodologies, agile practices, and strategic portfolio management significantly enhances agility and innovation within defense procurement. Frameworks such as the Burke-Litwin Model, Appreciative Inquiry, and action research foster adaptive management, decentralized decision-making, and reduced bureaucratic inertia. Agile methodologies aligned with procurement processes promote iterative development, rapid capability delivery, and continuous improvement, supported by adaptive contracting mechanisms like incentivized agile contracts and performance-based logistics.

Addressing historical acquisition challenges requires overcoming cultural inertia and streamlining processes through comprehensive reform initiatives. Effective reforms integrate rapid prototyping, agile methods, and continuous stakeholder feedback to enhance responsiveness and efficiency. Success hinges on aligning reforms with strategic objectives, ensuring relevant and impactful outcomes.

Managing technical debt through portfolio rationalization ensures technological superiority and operational readiness. The Strategy-to-Execution Model within PEO Digital exemplifies a structured approach to proactively address technical debt, improving resource allocation, reducing complexity, and accelerating capability deployment.

Sustaining innovation in defense procurement demands alignment of methodologies, cultural adaptation, and strategic execution. Continued investment in adaptive practices and cultural transformation is essential to effectively meet future operational challenges and maintain technological dominance.

Methodology

The six frameworks utilized by PEO Digital are based on empirical evidence. World Class Alignment Metrics (WAM) are based on three independent studies initiated by the organization. Conducted by Gartner and two research universities, the three studies were validated by DoN mission owners and seven Fortune 20 Companies to compare results. Together, the studies concluded that WAMs generate value for taxpayers and are an effective investment tool for enterprise technologies. The WAMs are grounded in Gartner's Outcome Driven Metrics framework. The DoN's Investment Horizons framework is based upon the oft-studied horizon frameworks established by McKinsey and SAFe®. The combination of WAMs, Investment Horizons, and the four other frameworks consistently provides comprehensive data for organizational analysis.

Action Research Methodology

This study employs an action research methodology to systematically implement and assess best practices identified in several Department of the Navy frameworks. The research specifically integrates World-Class Alignment Metrics (WAMs), Investment Horizons Charts, Structured Pilots, Structured Divestment Approach, Structured Challenges Approach, and the Innovation Adoption Kit (IAK). An iterative approach comprising planning, acting, observing, and reflecting cycles drives continuous improvement.

The initial planning phase establishes baseline measurements utilizing WAMs to evaluate current organizational performance across metrics including user productivity, operational resilience, adaptability, customer satisfaction, and cost efficiency. Baseline measurements provide quantitative benchmarks for comparison post-intervention.

The action phase introduces structured methodologies derived from Investment Horizons Charts, guiding strategic technology investment decisions across various maturity phases. Structured Pilots are implemented to rigorously test and validate emerging capabilities before full-scale adoption, ensuring solutions meet defined operational criteria. The Structured Challenges Approach stimulates innovation and optimization by fostering competitive problem-solving environments to rapidly advance technological solutions.

The observation phase systematically captures quantitative and qualitative data post-implementation using WAMs and Investment Horizons Charts to assess improvements in organizational agility, efficiency, and innovation effectiveness. The Structured Divestment Approach supports resource reallocation by identifying and phasing out obsolete technologies, maintaining continual alignment with strategic objectives.

Analysis of before-and-after measurements during the reflection phase provides empirical insights into the efficacy of integrated best practices. Findings from reflective analysis inform subsequent action research cycles, refining strategies and promoting sustainable innovation and operational excellence within defense procurement environments.

Results

Implementation of this methodology resulted in measurable improvements across several metrics. One Program Executive Office (PEO) conducting 21 pilots demonstrated significant enhancements using the Innovation Adoption Kit, completing pilots 105 times faster and producing outcomes 25 times greater than traditional methods. Manual data entry burdens decreased notably, contributing to a 20% increase in user satisfaction. The streamlined processes substantially reduced award times from a previous duration of 6 to 9 months down to 4 weeks or less.

The efficiency of staff involvement improved significantly, with required touchpoints reduced from 10–15 people to only five. Financial efficiency was enhanced as fees decreased dramatically from 3% to 0.04%. Additionally, increased speed in adopting Technology-Knowledge (TK) pilots was noted. Collaboration with innovative industry partners fostered superior technical outcomes and rapid onboarding of emergent capabilities within a 14-working day window to obligate funds.

Discussion

Interpretation of Results

The findings highlight critical factors influencing the efficacy and agility of defense procurement processes, emphasizing structured methodologies, agile practices, and proactive portfolio management. Integration of frameworks such as the Burke-Litwin Model, Appreciative Inquiry, and action research significantly improves organizational adaptability and responsiveness in complex procurement environments. These methodologies facilitate decentralized decision-making, reducing bureaucratic inertia and accelerating innovation implementation.

Applying agile practices within procurement processes demonstrates notable improvements in iterative development, capability delivery speed, and continuous improvement effectiveness. Agile methodologies, supported by adaptive contracting methods such as incentivized agile contracts and performance-based logistics, enable defense organizations to address rapidly evolving technological and operational demands effectively. Procurement agility therefore serves as a key determinant of operational success and strategic advantage.

Systematic portfolio rationalization emerged as essential for managing technical debt, maintaining long-term technological and operational readiness. The Strategy-to-Execution Model used within PEO Digital provides a structured method for proactively managing technical debt. This approach enhances resource allocation, reduces operational complexity, and accelerates capability deployment, ensuring sustained technological superiority and resilience.

These results underscore that sustained innovation and strategic effectiveness in defense procurement depend on aligning adaptive management practices, agile methodologies, and strategic portfolio management frameworks. Integrating these elements supports rapid adaptability to changing operational needs, promoting ongoing technological dominance and organizational resilience amid global challenges.

Comparison with Existing Literature

The study's findings align with existing literature emphasizing the significance of agile practices and adaptive management in enhancing defense procurement effectiveness. Previous research indicates that structured frameworks like Appreciative Inquiry and the Burke-Litwin Model facilitate organizational agility and responsiveness, especially in complex environments. This research further validates that decentralized decision-making and adaptive contracting are effective mechanisms for managing rapid technological and operational changes, consistent with prior studies advocating agility as critical for organizational competitiveness.

This study extends previous literature by providing empirical support for the role of systematic portfolio rationalization in proactively addressing technical debt within defense organizations. The Strategy-to-Execution Model's effectiveness in managing resources and reducing operational complexity reinforces findings from earlier research emphasizing structured strategic management for operational resilience.

Implications for Practice and Theory

This research underscores the necessity of integrating agile methodologies and structured portfolio management practices within defense procurement to maintain operational effectiveness. Defense organizations should adopt structured frameworks and proactive portfolio rationalization to manage technical debt and enhance innovation capability. The findings emphasize that procurement agility directly contributes to sustained competitive advantage in dynamic environments.

This study contributes to the broader understanding of adaptive management practices from a theoretical standpoint, supporting theories advocating decentralized decision-making and strategic alignment as essential for organizational agility. Future theoretical developments in defense procurement can benefit from incorporating insights related to managing technical debt through structured strategic frameworks, enhancing overall operational resilience.

Limitations

This study's scope and methodological approach introduce certain limitations. The primary limitation involves potential biases inherent in qualitative interpretations and the generalizability of the results. Given the study's focus on specific frameworks and models within defense procurement, the findings might not be directly applicable to other sectors without adaptation.

The reliance on organizational case studies within defense procurement may limit the ability to generalize findings broadly across different organizational contexts or industries. Future research should address these limitations by employing quantitative methods and expanding research across diverse sectors.

Recommendations for Future Research

Future research should further investigate the effectiveness of agile methodologies and structured portfolio management practices across various industries and organizational contexts beyond defense procurement. Quantitative research methods could provide additional empirical validation of the frameworks' effectiveness.

Exploring the long-term impacts of systematic portfolio rationalization on organizational resilience and technological competitiveness would offer valuable insights. Future studies should also assess how cultural and organizational factors influence the successful adoption and integration of adaptive management and agile practices.

Conclusion

As stewards of taxpayer dollars, the DoN must continue to accelerate acquisition pathways for technological capabilities. Delivering faster, cheaper and higher performance IT solutions will better equip our warfighters and disrupt adversarial competition. Agencies across the DoD should consider adopting values-driven acquisition strategies, increase the breadth and depth of commercial investments, and regularly measure performance against mission outcomes.

The integration of structured acquisition methodologies, agile practices, and effective portfolio management is critical to advancing technological innovation and improving agility within defense acquisition environments. The application of World-Class Alignment Metrics, Investment Horizons, Structured Pilots, Structured Divestments, and agile contracting mechanisms has demonstrated significant, measurable outcomes, including substantially reduced acquisition timelines, enhanced user satisfaction, and optimized resource utilization. Through systematic and iterative action research, this study validated that structured frameworks not only streamline operational processes but also directly contribute to increased mission readiness and operational effectiveness. Furthermore, ongoing collaboration with industry partners has proven crucial in rapidly identifying and integrating innovative capabilities, thus enhancing strategic responsiveness. To maintain competitive advantage and deliver enduring value to warfighters, defense organizations should adopt and continuously refine these structured methodologies. Future efforts should further examine the scalability and adaptability of these approaches across various DoD contexts to ensure consistent and sustained innovation.

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Defense Innovation Unit: Actions Needed to Assess Progress and Further Enhance Collaboration

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Abstract

DOD established the Defense Innovation Unit (DIU) in 2015 to create new ways to acquire the innovative commercial technologies needed to address national security problems. In 2023, DIU announced plans—called DIU 3.0—to focus on solving DOD's most critical needs. Shortly thereafter, Congress substantially increased DIU's funding to support transition and fielding efforts. GAO examined DIU's plans to use its process for awarding other transaction agreements to facilitate DIU 3.0 and the extent to which DIU has established a performance management process to assess its progress. This presentation will describe how DIU used its commercial solutions opening acquisition process to prototype and transition commercial technologies to DOD programs from fiscal years 2016 through 2023, and how DIU plans to use the process going forward. It will also examine the key elements of an effective performance management system—including defining goals and using evidence to assess and inform decision-making—and DIU's progress in establishing these elements so it will know that DIU 3.0 is working. This work is based on GAO's analysis of DIU data on prototype awards made from fiscal years 2016 through 2023, a more detailed review of agreements awarded for six DIU projects, and discussions with senior DOD and DIU officials.

Background

The Department of Defense (DoD) established the Defense Innovation Unit (DIU) to create new ways for it to acquire commercial technology to solve national security problems. Similar innovation entities also exist in the DoD and the military services. Two congressional reports include provisions for GAO to review DIU's activities for effectiveness in fielding commercial technologies at scale, among other things.

GAO's report addresses (1) how DIU has transitioned commercial technologies for military use and the changes it is considering, (2) the extent to which DIU has established a performance management process to assess progress in meeting current and future goals, and (3) what opportunities exist to enhance DIU's collaboration with other DoD innovation organizations to adopt commercial technologies.

To perform this review, GAO reviewed DoD and DIU documentation and data. GAO also selected six higher dollar-value projects for review representing a mix of DIU technology areas and prototyping stages. We also interviewed DoD and DIU officials.

Summary of Findings

The DoD aims to keep pace with foreign adversaries by quickly adopting commercial technologies. DoD leaders expressed concern that it is not doing so at the speed and scale needed. The DoD created DIU in 2015 to take on these long-standing challenges. In 2023, it announced changes (DIU 3.0) to increase its effectiveness.

DIU established a flexible award process to show that commercial technology can quickly deliver capabilities to the warfighter and is now shifting its focus under DIU 3.0 to address the DoD's most critical operational needs. From fiscal years 2016 through 2023, DIU made 450 awards to companies to develop prototypes. DIU reported that 51% of completed prototypes transitioned to production. With its new focus, DIU officials said they will use its established process to award prototype agreements that can deliver technologies at scale to meet the DoD's most critical needs. DIU will also increasingly work with military services and combatant commands.

DIU has limited ability to gauge progress toward addressing the DoD's most critical needs because it does not yet have a complete performance management process. Such a process defines goals and collects, assesses, and uses evidence to inform decisions. Specifically, DIU has not set performance goals and metrics to assess its progress toward achieving DIU 3.0's strategic goal. Further, DIU officials have not identified which performance information to collect to inform their decisions for DIU 3.0. DIU officials plan to set goals in the future but did not specify when. As DIU attempts to address challenges in adopting commercial technologies within the DoD for strategic effect, a robust data-based decision-making process can help DIU leadership know if it is making progress.

Opportunities also exist for DIU to enhance collaboration with other DoD innovation organizations. The Defense Innovation Community of Entities, a newly formed group of DoD innovation organizations, generally incorporated six of GAO's eight leading collaboration practices. But it has not developed and documented how it will assess its progress in meeting its goal of coordinating activities related to commercial technology adoption. Without assessing collaboration, DIU will not know if the group is making progress toward its goal.

For the complete report, please see GAO-25-106856 or Defense Innovation Unit: Actions Needed to Assess Progress and Further Enhance Collaboration.

Process Innovation Pilots: Lowering Early-Stage Barriers to Entry and Survival

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Abstract

The Department of Defense (DoD) defines innovation as "the process in which new capabilities are provided to the nation's warfighters to create or sustain an enduring advantage." This "enduring advantage" exists when DoD acquisition processes are faster or exceed adversary rates, resulting in stable evolutionary capabilities, and large, efficient, and profitable firms with dominant market shares.

When faced with an urgent need for innovation, the defense market is left with few options other than incremental evolution or novel adaptation of existing systems and capabilities.

Small early-stage firms often create new capabilities. While they comprise over 70% of U.S. firms, their work can be disruptive and unable to gain defense market entry or sales. Without sustained revenue (sales), these firms fail to thrive, and responses include acquisition, asset divestiture, or refusing to enter the defense market.

However, small firms can establish business models and strategies adapted to changing demands or conditions. This provides opportunities to address emergent "short-term" needs faster than existing market providers or acquisition process capabilities.

This paper highlights challenges to defense market entry and pilot initiatives by the Defense Advanced Research Projects Agency (DARPA) to improve small firm survival and growth.

Keywords: small firm defense market and innovation barriers

Introduction

The Defense Innovation Board defined innovation as "the ability to rapidly develop and integrate new systems and technology, and employ them at the speed and scale necessary to maximize warfighter mission capabilities" (Bloomberg et al., 2024, p. 13). Underlying this definition are assumptions about speed (time to market), scale (product volume), and quality (capability maximization).

The Defense industrial base (DIB) is defined as "the network of organizations, facilities, and resources that provides the U.S. government—particularly the Department of Defense (DoD)—with defense-related materials, products, and services" (Nicastro, 2024). This industrial base is where speed, scale and quality become real.

The DIB provides goods and services within the U.S. defense market, a highly competitive environment complicated by regulations, as well as technological, and geopolitical factors (OUSD(A&S), 2022). The DIB shrinkage is a long-term trend, arguably starting after World War II (Holley, 1989). Nicastro (2024) divides the DIB into *commercial* and *nonprofit and* *public* sectors. Research examining DIB shrinking commonly focuses on *commercial* sector concentration and may not reflect the overall scale and diversity of the DIB.[1]

This paper uses Porter's (2008) Five Forces model to summarize defense market dynamics, supported by references to peer-reviewed literature, and summarizes prior research on competition and entry barriers to the defense market, and by proxy, into the DIB. It then reviews recent financial and procurement data to find evidence for or against these barriers and examines some current approaches to increasing the DIB commercial sector. Two efforts addressing small business DIB entry and survival are summarized.

Background

Michael Porter (2008) identified five "forces" or factors that shape markets and strategies: existing competitors' rivalries (competition), product or service substitution threats, buyer and supplier bargaining power, and new entrant threats. The first four forces organize the barriers seen by potential DIB entrants.

The Defense Market and Competition

The DIB exhibits characteristics inherent in the defense market. In 1969, no less an authority than John Kenneth Galbraith noted that large defense firms, given their m*arket concentration, regulation*, and *specialized products*, acted more like public utilities than private firms and argued for their nationalization.

The federal market as reflected in the Federal Acquisition Regulation values competition and fairness (GSA, 2025). A shrinking DIB is perceived as a threat to competition; however, market concentration can create cost or performance efficiencies for a given demand (Savagar et al., 2024). Larger markets have more substitutes and production sources and increased innovation due to demand price elasticity (Desmet & Parente, 2010). Covarrubias et al. (2020) found that market concentration is a common proxy for competition, reflecting increased competition when shrinkage is due to decreased margins, and the opposite when shrinkage is due to rent-seeking and competition barriers. Further, Jain et al. (2025) found less competitive markets are less resilient to exogenous shocks. Figure 1 compares competition rates for FY1982–1984, FY2002–2004, and FY2022–2024.

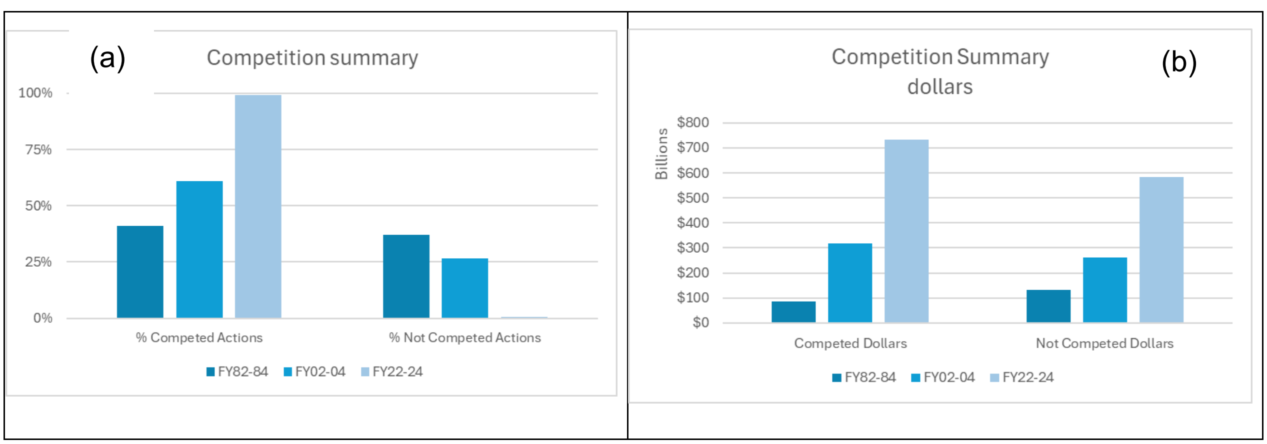

Figure 1. Defense Market Competition Rates (Sam.gov)

[1] There is evidence of "rightsizing" initiatives in the public (Austin, 2023) and non-profit DIB sectors (Nicastro, 2024), suggesting similar shrinkage albeit for different causes.

By FY2022–2024, Figure 1(a) shows almost all actions were competed, but Figure 1(b) shows almost 45% of all award dollars were not competed, implying intense competition for these large not-competed contract awards and an enormous advantage for incumbent firms.

Product or Service Substitution Threats

Some new entrants bring innovative technology to the defense market. Grieco and Manning (2023) argued that technological superiority is insufficient: “any military advantage … will be determined by how military organizations” use the technology.

Capability requirements[2] bound most DoD acquisition programs and procurements. When explicit, these requirements define market product performance expectations and measure what it will take to compete in the market.

The defense market has premier products and services with *limited alternatives*.[3] Substitutes for such products and services are often threats to incumbents. Ethiraj and Zhou (2019) found that increasing market *substitutability* will incentivize incumbents to establish defensive strategies and barriers to market entry, and *complementarity* will reduce incentives for deterrent strategies. Product or service *substitution*, where a competitive but differentiated product or service takes market share can bring new entrants into the DIB, but is likely simpler if the entrant provides complementary benefit to the incumbent.

Supplier and Buyer Bargaining Power

New entrants as suppliers or buyers have limited bargaining power. The government is the primary buyer in the defense market. Herr (1973) found government procurements have “specialized needs” (*requirements*) and “volumes” (*quantity*) resulting in few capable firms, effectively shrinking the DIB, increasing buyer power, and increasing barriers to entry (Herr, 1973), including expertise, legal and accounting regulations (Riddell, 1985).

Capability matters in the DIB and may require unique *expertise, facilities,* and *supply chains*. The difficulty and cost associated with creating and sustaining such capabilities results in a lack of competition and isolation from the larger commercial sector (Allen & Berenson, 2024).

The buyer (government) can encourage diversification or subsidize alternative sources, but these affect incumbent and new entrant profitability. If production costs rise or the market becomes price sensitive,[4] new entrants may decide to exit the defense market (Blank, 2019) based on revenues and profit (Etemadi & Kamp, 2021).

Entry into the DIB requires successful navigation of a legal and regulatory thicket, created with the best intentions. Concerns about the difficulty in understanding cost reasonableness and cost basis resulted in cost-based management processes and Cost Accounting Standards (Greenwalt, 2021). Additional barriers emerged in response to novel threats (such as cybersecurity) and financial pressures (multi-year research and development expense amortization; Halcrow & Jones, 2022).

Entrants determine if there is a demand signal for their product or service. Price and market size are common demand signals. However, in the defense market, both are unreliable as they are determined by seller and buyer constraints (such as budgets, procurement

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[2] See https://aaf.dau.edu/aaf/mca/requirements/.

[3] consider submarines or advanced aircraft as examples.

[4] For example, if the buyer constrains orders, adds cost efficiency requirements, or changes risk share.

objectives, and production capacity) and not market forces. Opportunities must be recognized and agreed to by both buyer and seller.[5]

Barriers to Market Entry and Innovation

Market entry barriers are commonly divided into economic or *structural* barriers and *behavioral* or strategic barriers (Furlan, 2025). The literature has several perspectives on market entry barriers: a competition-based view (Porter, 2008), the DoD view of barriers to entry into the DIB (OUSD[A&S], 2022), and the small business view (Stewart & Van Steenburg, 2024). Porter (2008) takes a structural view, while the DoD and the industry views emphasize both behavioral and structural aspects. Interestingly, none of these highlight incumbent strategies related to contracts, pricing, and product differentiation. Table 1 summarizes key barriers from these three perspectives.

Table 1. Common Barriers to Market Entry (cited sources)

Competition view: Five Forces Barriers to Entry (Porter, 2008)	DoD view: DIB Barriers to Entry (OUSD[A&S], 2022)	Industry view: Small Business Barriers to Entry (Stewart & Van Steenburg, 2024)
• Supply-side economies of scale • Demand-side benefits of scale ("*network effects*") • Customer switching costs • Capital requirements • Size-independent incumbency advantages ("brand," "location," "experience") • Unequal access to distribution channels	• Low margins • Low and unpredictable demand • Little incentive to add new capabilities • Restrictions in non-defense market sales • Supply chain capacity • Competition limited by mergers and acquisitions • Non-commercial business processes and regulations • Substandard technical data • Unique materials • Quality standards • Bespoke requirements • Limited sales volume	• Complex *and protracted* procurement practices (time to award) • Federal budget processes (cash flow) • Non-compliance risk • Contracting burden • Cybersecurity cost of entry Risk of Intellectual Property transfer to competitors • Lack of small business *institutional support*

These market technical and regulatory barriers, and economic constraints frame the competitive challenge of market entry and suggest that incumbents enjoy substantial protections against new entrants. Table 2 summarizes three perspectives on DoD innovation barriers.

[5] Successful new entrants often use novel strategies, such as novel arrangements for commercial products or services (such as the Civil Reserve Air Fleet and privatized military housing).

Table 2. DoD Innovation Barrier Summaries (cited sources)

Defense Innovation Board barriers to innovation (Bloomberg et al., 2024)	Public innovation barriers (Uyarra et al., 2014)	Organizational barriers (Anthony et al., 2019)
• Status quo (lack of leadership) • Management of (personnel, physical, industrial) security • Limited access to Sensitive Compartmented Information Facilities (SCIFs) • Outdated SCIF security standards • Limited duration clearances • Insufficient security clearance investigation support • Burdensome DoD contracting requirements • Intellectual property not shared • Insufficient market research prior to award • Burdensome security requirements on non-traditional firms • Self-imposed dual use constraints • Accessible SBIR performance data	• Excessive perceived economic risk • Too high innovation costs • Cost of finance • Availability of finance • Lack of qualified personnel • Lack of information on technology • Lack of information on markets • Market dominated by established enterprises • Uncertain demand for innovative goods or services • Regulation	• Low priority (time, incentive, resources) • Not client-driven • Experiment (risk) averse • Lack curiosity, knowledge, experience • Status quo culture "inertia" • lack of support/ infrastructure

There are some differences, with an emphasis on security barriers, contracting and innovation barriers, economic (market) constraints, and cultural (organizational) barriers.[6]

In these tables, market entry and innovation barriers "rhyme" – they are different but distinct aspects of the complexity of introducing disruptive technology into the defense market and into use.

The literature suggests a few thematic barriers common to both market entry and innovation: resources (people, capital, expertise), market or innovation resistance to change (incentivizes to remain at the status quo), and time. The next section examines the DoD market and the DIB using public data to highlight structural factors affecting strategies for market entry and innovation.

[6] DARPAConnect (https://www.darpaconnect.us/home) offers mentoring and training to help overcome some of these barriers to entry.

Discussion

A firm considering doing business with the government has significant publicly available information about the government as a buyer. The U.S. government buys an enormous range of goods (products) and services, some of which are defense related. Public spending data is available on USAspending.gov.[7] For example, Figure 2 shows a ranked query of government spending by departments ("agencies") for fiscal year (FY) 2023 to FY2025.

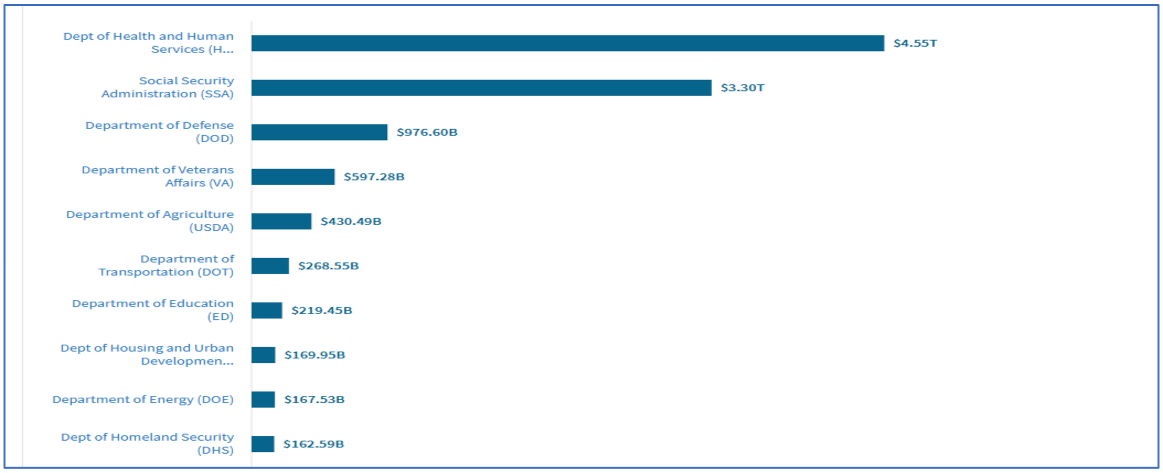

Figure 2. Top 10 U.S. Department Spending, FY 2023–2025 (USAspending.gov)

Health and Human Services spending is dominated by Medicare and Medicaid, and the Social Security Administration is dominated by outlays to Old Age and Survivors Insurance (OASI).[8] The DoD ranks third in this view. DIB commercial sector firms are often ranked by contract awards or revenues. Figure 3 shows the top 10 recipients (prime contractors) of DoD funding from FY2023 to FY2025.

In Figure 3, Lockheed Martin Corporation and the Boeing Company are both listed twice.

[7] Award posting is delayed 30 days in general, 90 days for DoD awards "for operational reasons" (https://onevoicecrm.my.site.com/usaspending/s/article/FAQ-I-understand-the-Department-of-Defense-reports-their-financial-data-on-a-different-schedule-than-other-agencies-Do-they-also-report-award-data-on-a-different-schedule).
[8] See USAspending.gov; drill down by agency.

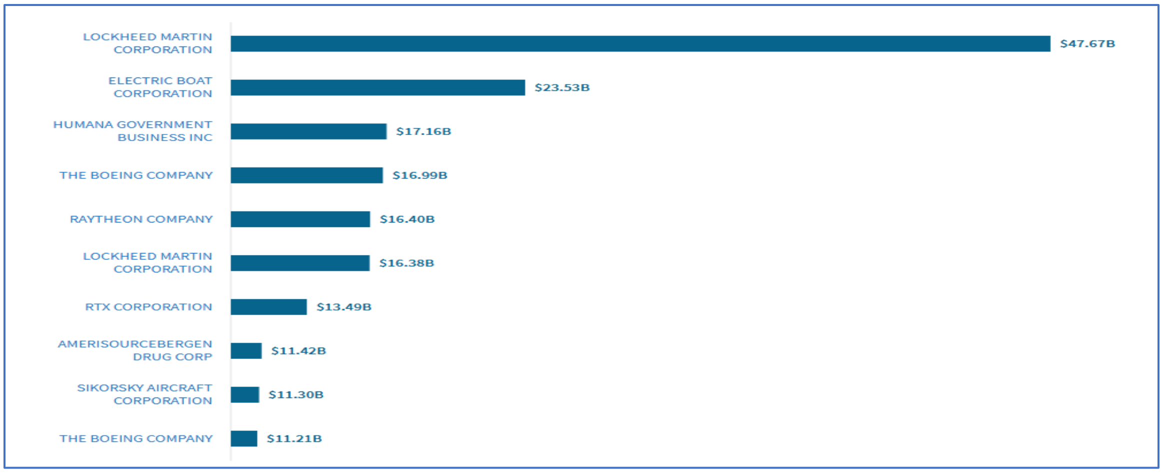

Figure 3. Top 10 DoD Funding Recipients, FY2023–2025 (USAspending.gov)

Humana Government Business is a subsidiary of Humana, Incorporated[9], and provides administrative services (TRICARE) and arranges health care services for active duty and retired service members and their dependents through Humana Military. Interestingly, Northrop Grumman is missing from this top 10 list. Figure 4 shows the top 10 search results for FY2023–2025 Northrop Grumman awards.

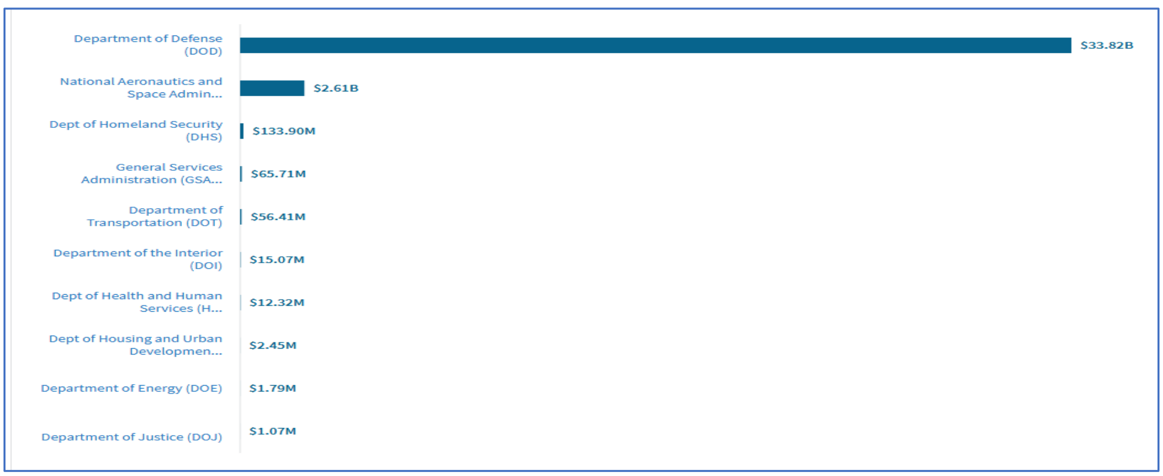

Figure 4. Top 10 Northrop Grumman by Agency FY2023–2025 (USAspending.gov)

Note that the largest defense industry corporations (such as the “Top Five”) are complex businesses with revenues in multiple government market sectors. Additionally, these firms sell both goods and services in these sectors.

Procurements of goods vary with market segments; the *market size* is measured by the quantity (Q) of items ordered (or sold) and the budgeted or obligated amounts (P) and reflect market complexity. Table 3 summarizes the Army aviation platform procurement market size for FY2023 to FY2025.

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[9] See Humana’s most recent 10-K at https://humana.gcs-web.com/node/39556/html.

Table 3. Army Aviation Procurement Market Summary 2023–2025
(OUSD[C], 2025)

Budget Line Item (BLI)	Q.FY23	P.FY23.$M	Q.FY24	P.FY24.$M	Q.FY25	P.FY25.$M
AH-64 Apache Block IIIA Reman	38	$956.991	42	$939.298	31	$570.655
AH-64 MODS		$85.840		$113.127		$81.026
Aviation ASSURED PNT		$66.294		$67.383		$69.161
CH-47 Cargo Helicopter Mods (MYP)		$49.357		$20.689		$15.825
CH-47 Helicopter	9	$406.647	6	$240.359	10	$699.698
Comms, Nav Surveillance		$68.815		$74.912		$61.362
Degraded Visual Environment				$16.838		$3.839
Future UAS Family				$53.453		$149.059
GATM Rollup		$14.683		$8.924		$4.842
Gray Eagle Mods2		$133.038		$14.959		$23.865
MQ-1 PAYLOAD		$72.700		$13.650		$14.086
MQ-1 UAV	12	$350.000				
MULTI SENSOR ABN RECON		$20.924				
Network And Mission Plan		$42.450		$32.418		$49.862
SMALL UNMANNED AIRCRAFT SYSTEMS		$6.725		$20.769		$69.573
Spectrum Army SUAS		$3.873				
UAS MODS				$2.258		$2.265
UH-60 Black Hawk L and V Models	21	$178.658	26	$153.196		
UH-60 Blackhawk M Model (MYP)	35	$1,058.629	24	$853.246	24	$825.394
Utility Helicopter Mods		$39.346		$35.879		$34.565
Funding (P) and platform buys (Q)	115	$2,950.925	98	$2,186.099	65	$2,095.747
Funding (P) without platform buys (Q)		$604.045		$475.259		$579.330

Three DIB companies (Boeing [AH-64, CH-47], General Atomics [MQ-1] and Sikorsky [Lockheed Martin] [UH-60]) are "airframe" manufacturers[10] (system integrators) and account for about *80%* of budgeted amounts and *all* major platform orders/sales. This shows that there are complementary but imperfect substitutes in this market. Pallante et al. (2023) found that defense research and development spending stimulates (crowds-in) private sector research and development spending and employment of skilled workers. Table 4 shows the USAspending.gov results for large business-related Army aviation research and development.[11]

Table 4. Army Aviation R&D Obligations, Not Small Business FY2023–2025

	Fiscal Year 2023		2024		2025		Total OBL.N	Total OBL.$
R&D FUNDING BY RECIPIENT - ARMY AVIATION	OBL.N	OBL.$	OBL.N	OBL.$	OBL.N	OBL.$		
OTHER THAN SMALL BUSINESS	93	$1,033,154,649	87	$1,281,367,608	12	$9,874,699	192	$2,324,396,956
BELL TEXTRON INC	18	$597,800,120	19	$876,836,754	1	$3,954,000	38	$1,478,590,874
DYNCORP INTERNATIONAL LLC	1	$0	1	$0			2	$0
GENERAL ATOMICS AERONAUTICAL SYSTEMS, INC.	1	$999,915					1	$999,915
GENERAL ELECTRIC COMPANY	26	$146,738,895	14	$125,733,889	1	$0	41	$272,472,784
HII MISSION TECHNOLOGIES CORP	14	$17,743,763	15	$17,423,152	1	$320,699	30	$35,487,614
HONEYWELL INTERNATIONAL INC.	1	-$116,061	1	$0			2	-$116,061
KBR WYLE SERVICES, LLC			1	$242,052			1	$242,052
LEIDOS, INC.	1	$498,000	1	$200,000			2	$698,000
LONGBOW LLC	1	$0					1	$0
NORTHROP GRUMMAN SYSTEMS CORPORATION			1	$49,911,825			1	$49,911,825
PAR GOVERNMENT SYSTEMS CORPORATION			3	$7,362,833			3	$7,362,833
RAYTHEON COMPANY	1	$236,722,341	1	$178,140,565			2	$414,862,906
ROCKWELL COLLINS, INC.	6	$2,618,100	3	$1,725,000	2	$0	11	$4,343,100
SIKORSKY AIRCRAFT CORPORATION	17	$24,382,711	22	$22,413,512	7	$5,600,000	46	$52,396,223
TEXTRON SYSTEMS CORPORATION	4	$5,616,570	4	$1,378,026			8	$6,994,596
THE BOEING COMPANY	1	$0					1	$0
VANDERBILT UNIVERSITY	1	$150,295	1	$0			2	$150,295

Note in Table 4 that airframe and engine manufacturers, and subcontractors were awarded over 90% of this funding.[12] Table 5 summarizes concurrent small business Army aviation-related research and development awards.

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[10] On the eve of World War II, the U.S. aircraft industry consisted of four distinct groups: aircraft (airframe) manufacturers, engine manufacturers, subcontractors, and commercial item vendors (Holley, 1989).
[11] Obligations are a useful proxy for labor employment as research and development is labor intensive. This data was downloaded in February 2025. Posted FY2025 obligation amounts lag actual obligations and do not reflect full year totals. Product and Service Codes (AC11-AC17, AC24, AC31-AC33) were used to label research activities.
[12] While obligation data is incomplete as of this paper, Army research and development remains associated with platforms in procurement but reflects additional commercial and noncommercial performers.

Table 5. Small Business Army R&D Obligations, FY2023–2025 (USAspending.gov)

	Fiscal Year 2023		2024		2025		Total OBL.N	Total OBL.$
R&D FUNDING BY RECIPIENT - ARMY AVIATION	OBL.N	OBL.$	OBL.N	OBL.$	OBL.N	OBL.$		
⊞ OTHER THAN SMALL BUSINESS	93	$1,033,154,649	87	$1,281,367,608	12	$9,874,699	192	$2,324,396,956
⊟ SMALL BUSINESS	19	$33,736,481	30	$10,668,808	7	-$8,441	56	$44,396,848
ADVENTIUM ENTERPRISES, LLC	2	$1,365,581	2	-$1,917,650			4	-$552,069
AEROVIRONMENT, INC.	3	-$1,871,023	2	-$4,637			5	-$1,875,660
AIRFOILS INC			1	$0			1	$0
CHEROKEE NATION ARMORED SOLUTIONS, LLC	2	$848,000	8	$1,087,910			10	$1,935,910
DEFENSE SYSTEMS AND SOLUTIONS			1	$0			1	$0
ELECTRA.AERO INC.			2	$1,899,168	1	$0	3	$1,899,168
HFE INTERNATIONAL, LLC	1	$369,682					1	$369,682
KAREM AIRCRAFT, INC.	1	$0					1	$0
MATERIALS ENGINEERING AND TECHNICAL SUPPORT SERVICES CORP.			3	$974,953			3	$974,953
MERCURY MISSION SYSTEMS LLC	1	$0					1	$0
MODERN TECHNOLOGY SOLUTIONS, INC.			2	$3,216,079			2	$3,216,079
PHYSICAL SCIENCES INC.	1	$0	1	$0			2	$0
PIASECKI AIRCRAFT CORP	2	$6,367,345	3	$2,840,393			5	$9,207,738
THORPE SEEOP CORP	1	$0					1	$0
WAVEFRONT RESEARCH, INC			1	$1,999,845			1	$1,999,845
XL SCIENTIFIC LLC			1	$325,000			1	$325,000
XWING, INC.			2	$247,748			2	$247,748
Y-TECH SERVICES, INC.					1	-$8,441	1	-$8,441
YULISTA SUPPORT SERVICES LLC	5	$26,656,896	1	$0	5	$0	11	$26,656,896
Grand Total	112	$1,066,891,130	117	$1,292,036,416	19	$9,866,258	248	$2,368,793,804

The small business segment is smaller; while having different performers, it still exhibits market concentration (for example, Piasecki Aircraft Inc. and Yulista Support Services LLC) but does represent more vendors. Note no small business has annual funding for these PSCs.

Table 6 shows a similar analysis performed using the same data filtered for Army awards coded with NAICS[13] 336411 (Aircraft Manufacturing).

Table 6. NAICS 336411 Army Summary (USAspending.gov)

Army (336411)	Prime	Sub-awardees	Small business sub-awardees
Award FY count (23, 24, 25)	(1, 0, 0)	(22, 117, 0)	(0, 11, 0)
count in dataset	6	128	11
2023 ($M)	$2,273.000	$412.120	
2024 ($M)		$637.500	$25.540
2025 ($M)			

The award FY count row in each column shows the number of awardees in FYs 2023, 2024, and 2025. Table 6 shows award funding for a single prime (Bell Textron, Inc.) in FY 2023.[14] Sub-awardees in FY2024 included firms from all four groups, and 11 small businesses received funding awards for mostly commercial (vendor group) work in 2024.

Tables 3 through 6 show a few of the challenges program offices and firms meet delivering required capabilities with episodic funding. Walter (2019) found that DoD requirements and funding processes collectively push "suppliers toward *homogeneity*, making future *transitions more difficult* and creating a thermostatic pattern of innovation.[15]. In other words, the DIB is exposed to this innovation pattern. When faced with an urgent need for innovation, the DoD will create a demand signal in the defense market. The structural and behavioral barriers described above incentivize incremental evolution or novel adaptation of existing systems and capabilities.

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[13] NAICS: North American Industry Classification System.

[14] Prime manufacturers are "airframe manufacturers" following Holley's categorization.

[15] A thermostatic pattern is when a process responds to achieve a set objective (like a temperature – cooling when above and heating when below the setpoint). Also referred to as a demand signal.

If this is true, then increased supplier *diversity* should make transition *easier* and *change the pattern of innovation.* The prior tables imply that this diversity will likely not come from the dominant market firms. There is evidence that in the DIB, a supplier will cannibalize profitable product lines – for example, AH-64 REMAN is cannibalizing new AH-64 sales providing marginal market diversification (see Table 1). In the defense market, such a strategy may protect market incumbents and affect pricing strategies for both products (De Giovanni & Ramani, 2018).

The DoD cites small businesses as a source of new DIB entrants and innovation (OUSD[A&S], 2022). Small business innovative research (SBIR) awards are an imperfect measure of entry into the DIB. Rovito (2025) showed that small business success (effectively, becoming a profitable business) is related to annual revenue, the number of SBIR Phase I and Phase II awards and total SBIR investments. Phase II awards follow a Phase I award and are an indicator of DoD interest; average awards in a 3-year epoch are used to de-noise data and show general population trends. Figure 5 shows SBIR Phase I and Phase II unique and 3-year average award counts for FY2015 to FY2025.

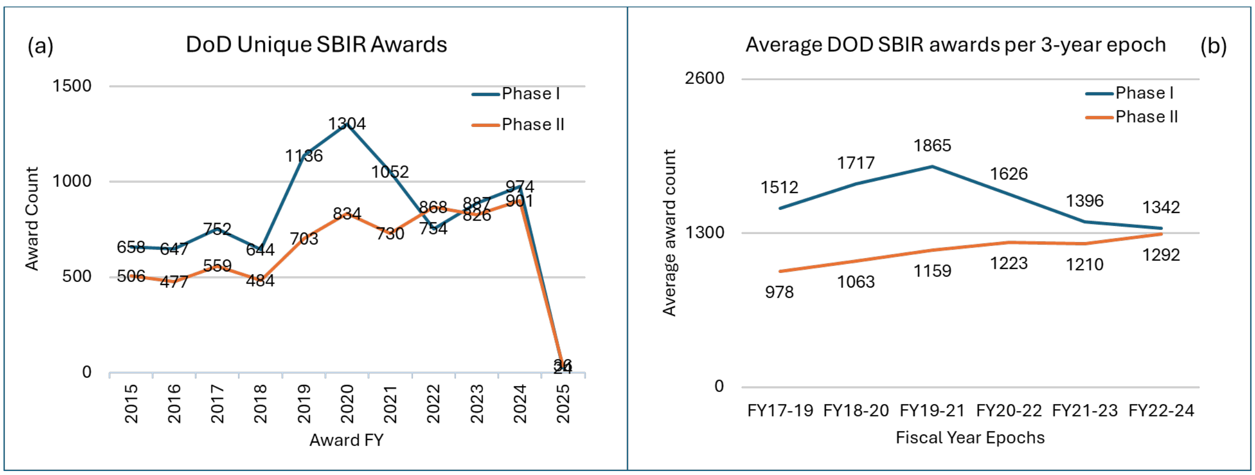

Figure 5. DoD SBIR Awards FY2015–2025 (SBIR.gov)

Figure 5a shows the general trends of unique (meaning differing firms) SBIR awards. The peak in 2020 was related to Covid-19, and the drop in 2025 is due to a continuing resolution. Figure 5b takes a 3-year average of awards and focuses on FY2017 to FY2024. These are all reported DoD SBIR awards; aviation-related awards would be a subset of this population.

Many small businesses receive multiple awards per year (Bresler & Bresler, 2020). From FY2015 to FY2025, 4,632 unique small businesses received one or more SBIR awards. Table 7 summarizes SBIR awards by fiscal year for all DoD.

Table 7. SBIR Award Summary FY2015–2025 (SBIR.gov)

DOD.SBIR.FY	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Phase I											
Total FY awards	1132	1213	1451	1173	1912	2065	1617	1197	1373	1455	26
Unique firm award count	658	647	752	644	1136	1304	1052	754	887	974	24
No award to firm	3974	3985	3880	3988	3496	3328	3580	3878	3745	3658	4608
% SB with award	14.2%	14.0%	16.2%	13.9%	24.5%	28.2%	22.7%	16.3%	19.1%	21.0%	0.5%
% SB without award	85.8%	86.0%	83.8%	86.1%	75.5%	71.8%	77.3%	83.7%	80.9%	79.0%	99.5%
Phase II											
Total FY awards	790	739	983	780	1172	1238	1068	1363	1200	1313	37
Unique firm award count	506	477	559	484	703	834	730	868	826	901	36
No award to firm	2872	2901	2819	2894	2675	2544	2648	2510	2552	2477	3342
% SB with award	15.0%	14.1%	16.5%	14.3%	20.8%	24.7%	21.6%	25.7%	24.5%	26.7%	1.1%
% SB without award	85.0%	85.9%	83.5%	85.7%	79.2%	75.3%	78.4%	74.3%	75.5%	73.3%	98.9%

Table 7 shows that about one in five (yellow highlight) small firms in the dataset received an SBIR Phase I or Phase II award in any year. The table also shows that some firms had multiple awards in a year (consistent with Bresler and Bresler). These two results show that firms need either a *second* product market or aggressive *business developmen*t to stay in business and be an active (government-funded) member of the DIB.

Time is the great enemy – it is a measure of the constant drain of resources and of missed opportunities. There is a time from starting a company to your first sale. When working with the government, time from solicitation to first payment can run to months, increasing firm debt. Small firms often must borrow to continue operations. Small firms often fail as revenues fall short of that needed to sustain operations.

Pitch days are a commercial-type process for rapidly screening offerors; offers are made quickly, in hours not months. An early pitch day trial was the U.S. Army Combat Capabilities Development Command's Ground Vehicle Materials Flash-to-Bang (GVM F2B) Pitch Day in July 2019, which invited National Advanced Mobility Consortium members to propose innovative research to an existing other transaction agreement (TACOM, 2019). This pilot, while focused on trying an innovative acquisition process, established key attributes: a target population, use of a rapid acquisition instrument, and focused solicitation and award. The Air Force ran several pitch days over the past 7 years, including a small business set-aside two-step Commercial Solutions Opening solicitation and award for base operations and support innovative projects (673d Air Base Wing, 2022). DARPA recently ran a pitch day "pilot" to learn how to accelerate time from solicitation to award.[16]

The DARPA AI Biotechnology Pitch Day was sponsored by DARPA's Biological Technology Office and focused on technologies at the "intersection of artificial intelligence and biotechnology" (DARPA-BTO, 2024).[17] Figure 6 summarizes the overall activity schedule.

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[16] See https://www.darpa.mil/news/2024/same-day-awards.

[17] See DARPA-SCA-24-01 for the original and updated solicitation.

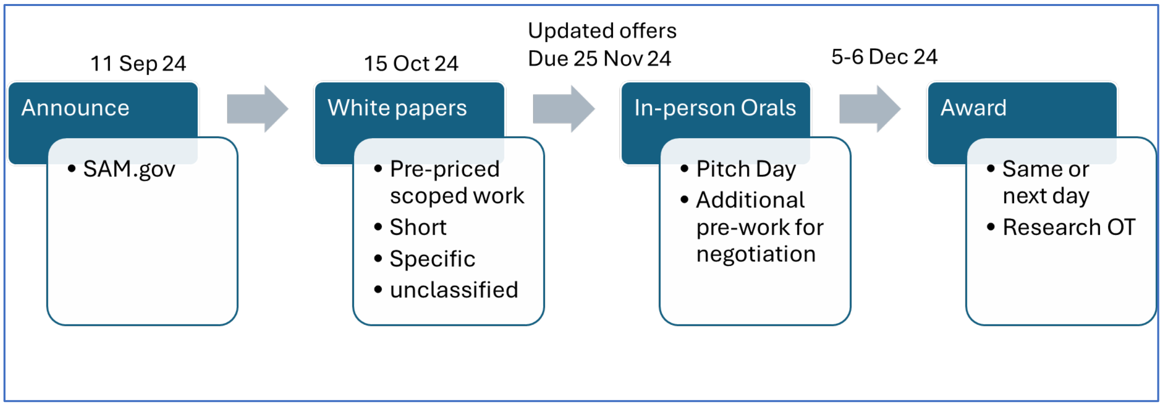

Figure 6. Pitch Day Summary
(DARPA-SCA-24-01)

Pitch Day was structured to minimize time from proposal to award by focusing on funding research within this intersection. It featured other transactions for research awards with limited durations (less than 6 months), limited funding levels (less than $300,000), and without specific follow-on acquisitions. All proposed efforts were unclassified, with three pre-negotiated objectives and award levels (DARPA-BTO, 2024). Specific proposal formats in a three-stage process reduced the administrative burden on proposers and focused the evaluation and award team on *pitch day execution*. Seventy-seven proposers were invited to attend Pitch Day, and 42 awards were made, with nearly 70% being first-time performers (DARPA, 2024).

Generating early revenues is critical to performer viability. This is a fundamental challenge with small business DIB entry – earning enough revenue to continue operations. There are alternatives to sales, such as debt, dilutive capital (venture funding) or selling assets (such as intellectual property).

DARPA recently enhanced its small business mentoring processes by creating the Commercial Strategy Office (CSO) to protect emergent DARPA-funded technologies from adversarial capital (foreign acquisition) and assist small performer firms with the development and execution of viable business plans (DARPA-CSO, 2025). CSO includes:

- The Embedded Entrepreneur Initiative (EEI), which embeds a successful entrepreneur (“commercialization expert”) within performer teams to help build and execute go-to-market strategies;
- Commercial Accelerators, which provide firms access to commercial expertise, ecosystems, and investor networks;
- Tiger Teams, which help firms create high impact solutions to DoD and commercial problems; and
- Venture Horizons, which connects top-tier private investors with DARPA program managers and performers increasing the impact of DARPA programs (DARPA-CSO, 2025).

These work collectively to mature small business investments into successful and sustainable firms. Differing from the Office of Strategic Capital (Austin, 2025), the DARPA CSO seeks to pair *private* investment capital with performers to accelerate breakthrough technologies to market while *protecting early investment and entry* into the defense market.

Conclusions and Future Work

The Department has multiple programs to sustain and improve the productive capacity of the DIB. These programs are complementary, serve specific performer segments and offer differing value propositions to the DoD.

Defense market entry and innovation are dominated by structural and behavioral barriers. However, small firms are likely new market entrants but require support to grow from small technical performers into profitable members of the DIB. Revenue growth is key to profits and growth. Two approaches addressing time to earned revenue and guided growth to commercialization were presented. Future work should include additional efforts focused on reducing barriers to and increasing incentives for small firm market entry and innovation.

Disclaimer

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SUMMIT PANEL 4. STRATEGIC INTEGRATION: AI METRICS, SOFTWARE PATHWAYS, AND SYSTEM SUSTAINMENT

Thursday, May 8, 2025	
1100 – 1215 PT 1300 – 1415 CT 1400 – 1515 ET	**Chair: Joseph Pack, Development Test and Evaluation as a Continuum (dTEaaC) Champion, OUSD(R&E) Developmental Test, Evaluation, and Assessment** **Discussant: Arwen DeCostanza (Ph.D.), Program Manager, Catalyst-Pathfinder Program DEVCOM, Army Research Laboratory** ***Synergizing the Software Acquisition Pathway (SWP) With the Unified Architecture Framework (UAF) For Operationalization*** Colin Dempsey, Senior Model Based Engineering Project Manager, Carnegie Mellon University's Software Engineering Institute ***Improving System Sustainment Through an Integrated Modeling Schema Coupled with Effective Execution of the Lifecycle Sustainment Plan*** Joseph M. Bradley, Visiting Research Engineer, University of Maryland ***Scaling the use of Publicly Available Information across the US Government*** Nick Tran, Decision Analyst, MITRE Corporation

Joseph Pack—is a 16-year mission engineer and architect with a focus on digital engineering and transformation. He received his Bachelors of Science in Aerospace Engineering from NC State University in 2009, a professional certification from the Federal Enterprise Architecture Certification (FEAC) Institute in 2011, and a Master's of Science in Systems Engineering concentrating in Architecture-Based Systems Integration from George Mason University in 2017.

Throughout his career, Mr. Pack has focused on closing the knowledge gap between warfighters and technical communities through pioneering mission engineering processes and concepts. In this capacity, Joseph spent time at sea aboard four different naval vessels, executed 12 live wargames, supporting numerous real-world contingency operations, and brought engineering capabilities directly into the planning, execution, and capabilities assessments spaces of joint warfighters. His efforts trailblazing mission engineering practice, education, and formalization resulted in receipt of a Meritorious Civilian Service Award in 2021. Mr. Pack is currently leveraging his experiences within mission engineering to advocate for greater adoption of digital practices, techniques, and tools with an emphasis on pragmatic considerations of the digital adopter. As Digital Engineering lead for the NAVSEA Warfare Centers HQ, he developed a DE framework to facilitate practical implementation of DE at the enterprise level and reformed organization of warfare center DE initiatives to focus heavily on how engineering is executed on a daily basis. He is currently supporting OUSD(R&E)DTE&A as the lead for development Test and Evaluation as a Continuum (dTEaaC) where Mr. Pack continues working towards 'innovating on methods of transitioning innovation' into the hands of today's engineering communities.

Arwen DeCostanza (Ph.D.)—is the Program Manager of the Army Futures Command (AFC) Catalyst Pathfinder and Accelerating FORCE Programs. Through her leadership, the Army is creating close working relationships between Soldiers, universities, small businesses, and government researchers to collaborative develop better and faster solutions to real problems. She is focused on building scalable methodologies for understanding Soldier needs, incorporating Soldier feedback early in solution development, and accelerating emerging technologies from academia/small business that meet critical Army needs into the hands of warfighters.

Prior to taking on her current role. Dr. DeCostanza was a Branch Chief in the U.S. Army Combat Capability Development Command's Army Research Laboratory, Human Research and Engineering Directorate. Before joining ARL in 2014, Dr. DeCostanza spent over 8 years with the U.S. Army Research Institute conducting research focused on selection, assessment, and organizational performance. Dr. DeCostanza received her Ph.D. in Industrial and Organizational Psychology from The George Washington University in 2008.

Synergizing the Software Acquisition Pathway (SWP) with the Unified Architecture Framework (UAF) for Operationalization

Colin Dempsey—is a Senior Model-Based Engineering Project Manager for the Assuring Cyber-Physical Systems division and Model-Based Engineering team at Carnegie Mellon University's Software Engineering Institute (CMU SEI). He holds an MSE in Systems Engineering from Johns Hopkins University. His area of expertise and research focus on the practical application of model-based systems engineering (MBSE) methodologies to facilitate the design, development, and analysis of software-intensive systems for the Department of Defense (DoD). Prior to joining CMU SEI, he was a systems engineering professional in DoD industry leading efforts in MBSE, Product Line Engineering (PLE), and Digital Engineering transformation. [cdempsey@sei.cmu.edu]

Jérôme Hugues—is a Principal Architecture Researcher at the Carnegie Mellon University Software Engineering Institute for the Assuring Cyber-Physical Systems team. He holds a Habilitation à Diriger les Recherches (HDR, 2017), a PhD (2005), and an engineering degree (2002) from Telecom ParisTech. His research concentrates on software architecture to support the design of complex software-based real-time and embedded systems, and the programming languages and artifacts that support them. Prior to joining the CMU SEI, he was a professor at the Department of Engineering of Complex Systems of the Institute for Space and Aeronautics Engineering (ISAE). [jjhugues@sei.cmu.edu]

Abstract

This study analyzes the activities and statutory and regulatory documentation required for the Department of Defense (DoD) Adaptive Acquisition Framework (AAF) Software Acquisition Pathway (SWP) Planning and Execution phases to identify a mapping of Unified Architecture Framework (UAF) model views.

UAF, an enterprise architecture modeling language standard from the Object Management Group®, provides a comprehensive set of views and structured semantics for identifying capability needs, developing enterprise strategies, developing roadmaps, defining architectures, and analyzing value that is prescribed for the SWP.

The study decomposes the Planning and Execution phases of the SWP into a set of 25 scenarios for the use of descriptive and analytical enterprise architecture models in the embedded software sub-path. The mapped views and scenarios establish a basis for performing the prescribed activities of the SWP using a model-based systems engineering (MBSE) approach. The views also provide a deeper understanding of the structured information required as part of the pathways and the interfaces between enterprise activities.

From an operationalization perspective, DoD stakeholders executing the SWP, using the results of this study, will be equipped to transform a primarily document-based method to fully traceable and analyzable models in accordance with DoD Instruction 5000.97 Digital Engineering.

Introduction

Effective model-based systems engineering (MBSE) to support acquisition objectives requires structure and ontology for capturing and transforming information into useful digital assets. Targeted guidance on the use of MBSE as part of the Department of Defense (DoD) Adaptive Acquisition Framework (AAF) Software Acquisition Pathway (SWP) for embedded software systems is needed to inform a consistent technical approach and enable information models to be value-add and more fully integrated into the software development process.

To conduct the research, the Software Engineering Institute (SEI) is performing a review of the enterprise processes defined in the SWP detailed in DoD Instruction (DODI) 5000.87 (Office of the Under Secretary of Defense for Acquisition and Sustainment [OUSD(A&S)], 2020), whereby the SEI is breaking down the activities and output information of the SWP to a set of scenarios for the use of UAF and aligning model views, defined in the UAF Domain Meta Model (DMM) v1.2 specification, that satisfy the needs of the scenario (Object Management Group® [OMG], 2022a). Then, inspired by the Enterprise Architecture (EA) Guide for UAF (OMG, 2022b), the mapped views are operationalized into process activities for the software pathway, guiding the development of models and how model information is used throughout the life cycle of the pathway. This paper is a summary of the research that is being performed; it will be subsequently followed by a more comprehensive technical report that contains a full mapping of the scenarios to the Unified Architecture Framework (UAF) and associated guidance.

The expected research results are foundational blocks for the application of MBSE, specifically use of UAF, in the activities of programs using the SWP. The study identifies the rationale for the mapped views, determines the statutory and regulatory compliance the views provide, and examines the benefits that models provide as part of embedded software acquisition.

This research paper was developed as part of the MBSynergy project sponsored by the Office of the Under Secretary of Defense for Research and Engineering (OUSD[R&E]) and conducted by the Carnegie Mellon University (CMU) Software Engineering Institute (SEI). Through the MBSynergy project, the SEI seeks to equip the DoD with methods and tools to model MBSE processes to evaluate the value they deliver to an organization and to analyze them from a budget, schedule, risks, or personnel resource perspective.

This paper describes the key concepts of the UAF and the SWP as part of the DoD AAF, reviews an example of mapping UAF views to a scenario for MBSE use as part of the SWP, and details SEI's MBSynergy project efforts to provide a better process for analyzing MBSE needs for an enterprise and uncovering its value.

The Problem Space

DODI 5000.97 Digital Engineering, effective December 21, 2023, established that programs initiated after the effective date will incorporate digital engineering capabilities as part of the acquisition strategy (OUSD[R&E], 2023). As part of this digital engineering capability, the instruction articulates that programs need to "move the primary means of communicating system information from documents to digital models and their underlying data. Digital models become ubiquitous and central to how engineering activities are performed" (OUSD[R&E], 2023). This instruction cemented a growing transition that was initiated in the DoD Digital Engineering Strategy published in 2018 (DoD, 2018) and adopted by the DoD military departments. In a 2022 memo from the Department of the Air Force, it states that "the [DAF] strategic vision promotes digitally enabled processes and replaces the linear, document-centric approach of today with a dynamic, model centric approach" (Hunter & Cavelli, 2022). Similar visions were established for other branches in the 2020 United States Navy and Marine Corps Digital Systems Engineering Transformation Strategy (United States Navy and Marine Corps, 2020) and the Army Directive 2024-03 for Army Digital Engineering (Department of the Army, 2024). The policies, strategies, and directives have made it clear that the benefits of MBSE are understood and have been accepted by the DoD enterprise. A model-centric approach is critical to a digital engineering strategy because it structures information in a digital format that can be better leveraged for data-driven decisions in a digital ecosystem.

The DODI 5000.97 (OUSD[R&E], 2023) and digital engineering strategies from each branch are the driving force for this transition, but how is this being accomplished? The primary solution for programs to adopt is a MBSE approach which leverages semantic languages for transforming enterprise and system information, previously formatted as static documents, into a formalized set of models which can be viewed and analyzed using digital tools. MBSE is a key component of establishing a digital thread from concept development to certification and delivery of software, and this digital thread is what enables the dynamic decision-making capabilities that acquisition programs strive towards.

MBSE has been a transformative concept for many organizations aiming to achieve the vision of digital engineering, but it is not without its complexities and drawbacks. A recent study that collected and coded over 2,900 claims on MBSE concluded “the most negative attributes were: Approach Understandability, Acceptability, Familiarity, and Approach Complexity” (Campo et al., 2022). Knowing which languages, tools, and skills required to implement an MBSE can be challenging, but beyond that, collaborating with others on the approach is difficult, as well, because the context between groups can be vastly different. Driving consistency in MBSE is a challenge; different solutions and processes have been developed by different branches and individual program offices that have resulted in stovepipe solutions and disparate methods of implementation.

In this paper, the SEI delivers a consistent approach to map SWP activities to UAF. Our contribution is a uniform, UAF-based, approach to assist the DoD in implementing the pathway, while preparing for MBSE activities. Our contribution is two-fold. First, we review the SWP to identify canonical scenarios to be executed. Then, we show how to leverage UAF to perform. To support our contribution, we have developed a UAF profile resource to better describe and exercise these scenarios for analysis. This aligns with the DoD vision for Digital Engineering to use a model from acquisition to development, test, and evaluation.

The proposed scenarios define what is to be executed: an activity model that defines the goals and objectives of the enterprise, the stakeholders involved with expected competencies, models to be created, and measures associated with desired quality attributes. A program may refine these scenarios to execute SWP with confidence. In other words, we turned the complexity of the SWP guidance documents into a set of models that acts as guidelines.

Unified Architecture Framework

The Unified Architecture Framework (UAF) is a standard and specification published by the Object Management Group (OMG) that provides a structured language and rules for describing enterprise architectures (OMG, 2022a). UAF evolved from previous enterprise architecture standards in the forms of the U.S. Department of Defense Architecture Framework (DoDAF) (DoD, 2010), the U.K.'s Ministry of Defence Architecture Framework (MoDAF™) (Ministry of Defence [MOD], 2012), OMG’s Unified Profile for DoDAF/MODAF (UPDM™) (MOD, 2012), and the North Atlantic Treaty Organization's (NATO) Architecture Framework (NAF) (NATO, 2018), with the intent of providing a comprehensive and widely applicable standard for modeling enterprise architectures.

UAF, along with the Systems Modeling Language (SysML), which the UAF modeling language is extended from, has become the standard specification for MBSE approaches for the DoD. The UAF specification is organized into a Domain Meta Model (DMM) which defines the view specification, the UAF Modeling Language (ML) which defines the implementation of the DMM, and a set of appendices that provide guidance on the use of UAF, including the Enterprise Architecture Guide for UAF.

The UAF DMM Version 1.2 defines 89 model views that are organized by a set of viewpoints and aspects (OMG, 2022a). Viewpoints refer to concerns of the stakeholder such as operational or security considerations. Aspects refer to types of model constructs that stakeholders are viewing such as states, processes, or parameters. The UAF DMM defines the elements and relationship that are required to satisfy the full set of view specifications.

Figure 1 is a depiction of the 89 model views that comprise the UAF DMM. The views cover large breadth of what is required in an enterprise architecture, from capability definition to operational scenarios, project structure, data models, standards traceability, etc., which aligns well with the information needs of the SWP enterprise.

UAF	Motivation Mv	Taxonomy Tx	Structure Sr	Connectivity Cn	Processes Pr	States St	Sequences Sq	Information[c] If	Parameters[d] Pm	Constraints Ct	Roadmap Rm	Traceability Tr
Architecture Management[a] Am	Architecture Principles Am-Mv	Architecture Extensions Am-Tx[e]	Architecture Views Am-Sr	Architecture References Am-Cn	Architecture Development Method Am-Pr	Architecture Status Am-St		Dictionary Am-If	Architecture Parameters Am-Pm	Architecture Constraints Am-Ct	Architecture Roadmap Am-Rm	Architecture Traceability Am-Tr
Summary & Overview Sm-Ov												
Strategic St	Strategic Motivation St-Mv	Strategic Taxonomy St-Tx	Strategic Structure St-Sr	Strategic Connectivity St-Cn	Strategic Processes St-Pr	Strategic States St-St		Strategic Information St-If	Environment En-Pm and Measurements Me-Pm and Risks Rk-Pm	Strategic Constraints St-Ct	Strategic Deployment, St-Rm-D Strategic Phasing St-Rm-P	Strategic Traceability St-Tr
Operational Op	Requirements Rq-Mv	Operational Taxonomy Op-Tx	Operational Structure Op-Sr	Operational Connectivity Op-Cn	Operational Processes Op-Pr	Operational States Op-St	Operational Sequences Op-Sq	Operational Information Op-If		Operational Constraints Op-Ct		Operational Traceability Op-Tr
Services Sv		Services Taxonomy Sv-Tx	Services Structure Sv-Sr	Services Connectivity Sv-Cn	Services Processes Sv-Pr	Services States Sv-St	Services Sequences Sv-Sq			Services Constraints Sv-Ct	Services Roadmap Sv-Rm	Services Traceability Sv-Tr
Personnel Ps		Personnel Taxonomy Ps-Tx	Personnel Structure Ps-Sr	Personnel Connectivity Ps-Cn	Personnel Processes Ps-Pr	Personnel States Ps-St	Personnel Sequences Ps-Sq	Resources Information Rs-If		Competence, Drivers, Performance Ps-Ct	Personnel Availability Ps-Rm-A Personnel Evolution PS-Rm-E Personnel Forecast Ps-Rm-F	Personnel Traceability Ps-Tr
Resources Rs		Resources Taxonomy Rs-Tx	Resources Structure Rs-Sr	Resources Connectivity Rs-Cn	Resources Processes Rs-Pr	Resources States Rs-St	Resources Sequences Rs-Sq			Resources Constraints Rs-Ct	Resources evolution, Resources forecast Rs-Rm	Resources Traceability Rs-Tr
Security Sc	Security Controls Sc-Mv	Security Taxonomy Sc-Tx	Security Structure Sc-Sr	Security Connectivity Sc-Cn	Security Processes Sc-Pr					Security Constraints Sc-Ct		Security Traceability Sc-Tr
Projects Pj		Project Taxonomy Pj-Tx	Project Structure Pj-Sr	Project Connectivity Pj-Cn	Project Processes Pj-Pr						Project Roadmap Pj-Rm	Project Traceability Pj-Tr
Standards Sd		Standards Taxonomy Sd-Tx	Standards Structure Sd-Sr								Standards Roadmap Sd-Rm	Standards Traceability Sd-Tr
Actual Resources Ar			Actual Resources Structure, Ar-Sr	Actual Resources Connectivity, Ar-Cn	Simulation[b]					Parametric Execution/ Evaluation[b]		

Figure 1: UAF View Matrix (OMG, 2022a).

It can be noted that the set of 89 view specifications for UAF and the required elements and relations that should be implemented as part of them can be overwhelming for new users of the specification. This is where the Enterprise Architecture Guide for UAF plays an important role in providing a workflow for architects and model developers for defining an enterprise architecture model in accordance with the specifications. The Enterprise Architecture Guide for UAF is excellent as a general approach and process for creating enterprise models; however, the general process may not always fit the context, or the activities needed for a specific pathway. We claim a targeted guide for the various adaptive acquisition pathways delivers value to DoD model architects and practitioners and this study explores that guidance for the SWP.

Software Acquisition Pathway

The Software Acquisition Pathway (SWP) is part of the AAF that was established in the FY20 National Defense Authorization Act (NDAA) Section 800 and is further defined in DoD Instruction 5000.87 Operation of the Software Acquisition (OUSD[A&S], 2020). The purpose of the SWP is to provide software intensive development programs with a streamlined path for developing and delivering software capability, emphasizing the use of modern software development methods and tools for delivering capability rapidly. As of the time of this paper, there are currently 86 programs utilizing the SWP across all major branches of the DoD and associated services and the utilization of this pathway is increasing in importance. A March 6, 2025, memo titled *Directing Modern Software Acquisition to Maximize Lethality* and signed by the secretary of defense directs the DoD to adopt the SWP as the preferred pathway for all software development programs (DoD, 2025).

The SWP life cycle is separated into two primary phases, planning and execution, each containing a set of enduring tasks that all participants in the SWP implement. The planning phase contains activities for defining capability needs, developing strategies, developing roadmaps and backlogs, establishing development infrastructure, and designing architecture details that will feed into the execution phase. The execution phase contains activities to develop, test, deliver, and assess the value of the software, all the while actively engaging with users to ensure needs are understood and being met.

Figure 2 is an overview of the SWP life cycle and phases that is provided by the Defense Acquisition University (DAU) knowledge base site for the SWP. The DAU site provides valuable details for SWP participants that include descriptions for each of the activities, guidance for the accomplishment of the activities, and templates for documents that will be generated as part of the activity (DAU, n.d.).

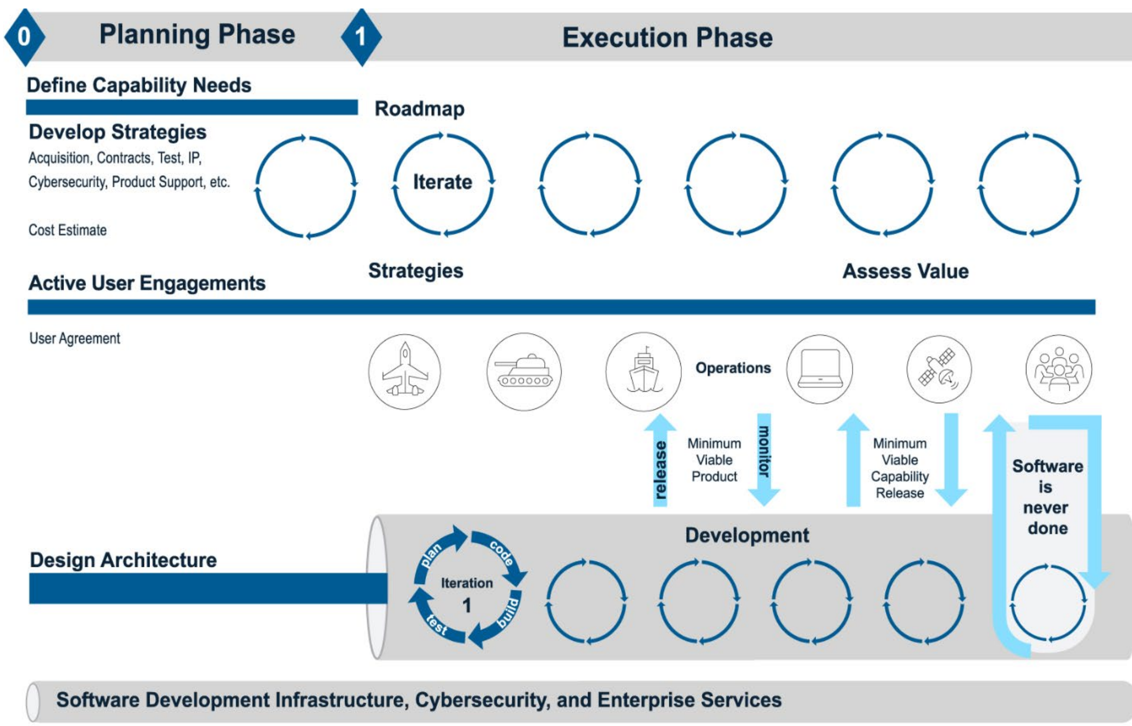


Figure 2: Life Cycle View of Software Acquisition (DAU, n.d.).

The SWP supports several types of software projects as part of the pathway, each with tailored considerations. The types are software applications, embedded software, and Defense Business Systems (DBS). The focus of this study is on the embedded software, which is defined in DODI 5000.87 as “software embedded in weapon systems and other military-unique hardware systems” (OUSD[A&S], 2020). Embedded software supporting weapon systems requires additional rigor and analysis to support certifications for system safety, cybersecurity, and operational use, which is a driving force for the use of MBSE techniques as part of other pathways.

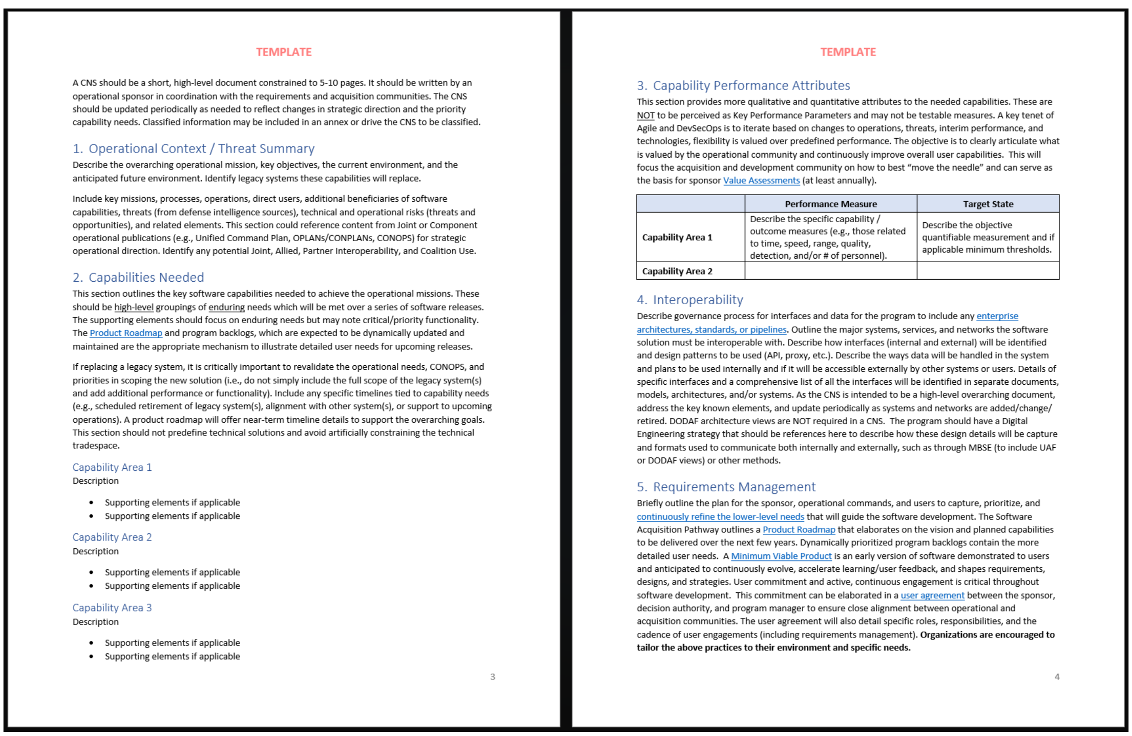
MBSE is not specifically highlighted as an example of “modern tools and techniques” in the policy or guidance information for use on the pathway, except for eight DoDAF views required if the project meets a joint equities threshold for generating a Software Initial Capabilities Document (SW-ICD) (OUSD[A&S], 2020). While not a focus, MBSE techniques can and should be utilized for enterprise and system architecture development. This study intends to inform DoD stakeholders that MBSE can be an effective tool for embedded software programs if performed in a thoughtful, value-driven, and efficient manner.

Required Statutory and Regulatory Documentation

One of the objectives of the pathway is to balance agility with engineering rigor and focus more on the software being developed rather than extensive documentation. To this end, programs using the pathway are not considered major defense acquisition programs and are not subject to the Joint Capabilities Integration and Development System (JCIDS) requirements. While this reduces layers of review and approval processes, as well as the amount of information needed to comply, the SWP must still adhere to a minimal set of statutory and regulatory information as required by law and policy.

The DAU SWP site provides a list of the required information to be compiled to by either the planning or execution phase. In total, there are 34 identified documents or collections of information required with varying applicability based on attributes of the program. This includes artifacts such as a Capability Needs Statement (CNS), User Agreement, Acquisition Strategy, Cybersecurity Plan, System Architecture, Product Roadmap, and Value Assessments to name a few.

To facilitate this formation of documentation, the DAU SWP site provides a collection of templates that SWP program offices and contractors can utilize. For contractor deliverables, it should be noted that Data Item Descriptions (DIDs) requiring specific formats for this information are not prescribed and that SWP programs are encouraged to reduce excessive contract data requirements list (CDRL) deliverables to deliver information in the most efficient way possible. Figure 3 is the template provided for the CNS document that would be developed by the program office.



TEMPLATE

A CNS should be a short, high-level document constrained to 5-10 pages. It should be written by an operational sponsor in coordination with the requirements and acquisition communities. The CNS should be updated periodically as needed to reflect changes in strategic direction and the priority capability needs. Classified information may be included in an annex or drive the CNS to be classified.

1. Operational Context / Threat Summary

Describe the overarching operational mission, key objectives, the current environment, and the anticipated future environment. Identify legacy systems these capabilities will replace.

Include key missions, processes, operations, direct users, additional beneficiaries of software capabilities, threats (from defense intelligence sources), technical and operational risks (threats and opportunities), and related elements. This section could reference content from Joint or Component operational publications (e.g., Unified Command Plan, OPLANs/CONPLANs, CONOPS) for strategic operational direction. Identify any potential Joint, Allied, Partner Interoperability, and Coalition Use.

2. Capabilities Needed

This section outlines the key software capabilities needed to achieve the operational missions. These should be high-level groupings of enduring needs which will be met over a series of software releases. The supporting elements should focus on enduring needs but may note critical/priority functionality. The Product Roadmap and program backlogs, which are expected to be dynamically updated and maintained are the appropriate mechanism to illustrate detailed user needs for upcoming releases.

If replacing a legacy system, it is critically important to revalidate the operational needs, CONOPS, and priorities in scoping the new solution (i.e., do not simply include the full scope of the legacy system(s) and add additional performance or functionality). Include any specific timelines tied to capability needs (e.g., scheduled retirement of legacy system(s), alignment with other system(s), or support to upcoming operations). A product roadmap will offer near-term timeline details to support the overarching goals. This section should not predefine technical solutions and avoid artificially constraining the technical tradespace.

Capability Area 1

Description

- Supporting elements if applicable
- Supporting elements if applicable

Capability Area 2

Description

- Supporting elements if applicable
- Supporting elements if applicable

Capability Area 3

Description

- Supporting elements if applicable
- Supporting elements if applicable

3

TEMPLATE

3. Capability Performance Attributes

This section provides more qualitative and quantitative attributes to the needed capabilities. These are NOT to be perceived as Key Performance Parameters and may not be testable measures. A key tenet of Agile and DevSecOps is to iterate based on changes to operations, threats, interim performance, and technologies, flexibility is valued over predefined performance. The objective is to clearly articulate what is valued by the operational community and continuously improve overall user capabilities. This will focus the acquisition and development community on how to best "move the needle" and can serve as the basis for sponsor Value Assessments (at least annually).

	Performance Measure	Target State
Capability Area 1	Describe the specific capability / outcome measures (e.g., those related to time, speed, range, quality, detection, and/or # of personnel).	Describe the objective quantifiable measurement and if applicable minimum thresholds.
Capability Area 2		

4. Interoperability

Describe governance process for interfaces and data for the program to include any enterprise architectures, standards, or pipelines. Outline the major systems, services, and networks the software solution must be interoperable with. Describe how interfaces (internal and external) will be identified and design patterns to be used (API, proxy, etc.). Describe the ways data will be handled in the system and plans to be used internally and if it will be accessible externally by other systems or users. Details of specific interfaces and a comprehensive list of all the interfaces will be identified in separate documents, models, architectures, and/or systems. As the CNS is intended to be a high-level overarching document, address the key known elements, and update periodically as systems and networks are added/change/retired. DODAF architecture views are NOT required in a CNS. The program should have a Digital Engineering strategy that should be references here to describe how these design details will be capture and formats used to communicate both internally and externally, such as through MBSE (to include UAF or DODAF views) or other methods.

5. Requirements Management

Briefly outline the plan for the sponsor, operational commands, and users to capture, prioritize, and continuously refine the lower-level needs that will guide the software development. The Software Acquisition Pathway outlines a Product Roadmap that elaborates on the vision and planned capabilities to be delivered over the next few years. Dynamically prioritized program backlogs contain the more detailed user needs. A Minimum Viable Product is an early version of software demonstrated to users and anticipated to continuously evolve, accelerate learning/user feedback, and shapes requirements, designs, and strategies. User commitment and active, continuous engagement is critical throughout software development. This commitment can be elaborated in a user agreement between the sponsor, decision authority, and program manager to ensure close alignment between operational and acquisition communities. The user agreement will also detail specific roles, responsibilities, and the cadence of user engagements (including requirements management). **Organizations are encouraged to tailor the above practices to their environment and specific needs.**

4

Figure 3: DAU CNS Document Template (DAU, n.d.).

The CNS template is a Microsoft Word file with the outline of information required for decision-makers of the pathway to approve. The CNS template is useful as pointed guide for capturing information in a localized, static instance. However, if programs wanted to use this information as a driving thread throughout the life cycle of the program, this format would lack the structure and format to do so efficiently. This is where MBSE provides a key advantage.

Required statutory and regulatory information developed as an output of the SWP benefits from transforming from primarily document-based, to model-based. We claim a model-based approach allows for enhanced analysis, decision-making, and collaboration between stakeholders. The use of models as part of the pathway for embedded software systems is key for reducing the documentation burden and developing continuous assurance of software in a rapid development environment.

UAF provides a structured ontology for enterprise architecture definition that can assist in satisfying the goals and objectives of the SWP, assuming the structured views can be effectively mapped to activities and information requirements as part of the pathway. Our study answers the latter in the following sections.

Basis for Mapping SWP Activities to Scenarios

As mentioned in the introduction, this study is being conducted as part of the MBSynergy project sponsored by the OUSD(R&E). The primary objective of the MBSynergy project is to provide DoD stakeholders with the tools and analysis mechanisms to uncover the true value of MBSE techniques within their context. MBSynergy is basing the tools and analysis mechanisms on CMU SEI's Architecture Tradeoff Analysis Method (ATAM), which is a technique for understanding how architectural styles influence the quality attributes of architecture behavior. While typically this technique is applied toward software system architecture, the ATAM principles apply toward analyzing enterprise architectures as well.

MBSynergy has designed a process for using scenario-based analysis for eliciting MBSE value in enterprise activities. This process utilizes a model-based approach to elicit scenarios, capture enterprise goals and objectives aligned to quality attributes, understand the model-based processes and flow of information, and define the measures that will verify that the goals will be achieved. The output is a UAF model defining the scenarios of the enterprise that can be analyzed and used as a reference for the enterprise going forward. This process can be utilized by acquisition programs in the following ways:

- to define an MBSE strategy, define which models to create, and propose relevant model quality metrics;
- to understand the interfaces of MBSE processes and the flow of information between activities, as well as why it is relevant to certain stakeholders;
- to evaluate MBSE process efficiency via simulation, and propose improvements; and
- to ensure scenarios are correctly mapped to acquisition strategies and requirements.

A key element the MBSynergy project is the definition of scenarios for the enterprise architecture as it relates to the use of MBSE. The scenarios focus the context of the use of MBSE to a specific activity the enterprise architecture is expected to perform and allows the exploration of the quality attributes that MBSE helps promote as a feature of the enterprise. The technical report that first introduces this approach, "A Principled Approach to Elicit Digital Thread Specification from User Stories," defines scenarios as an "input/output process within an environment, stakeholders with specific skills [to] achieve a business goal when a stimulus (trigger) is met, producing a response and generating outputs from inputs with measured quality attributes" (Hugues et al., 2025). With scenarios structuring the inputs, outputs, process activities, stakeholders, and measurable elements related to quality attributes, we can conduct scenario-based analysis. In the ATAM technical report, scenario-based analysis is used to "not only to determine if the architecture meets a functional requirement, but also for further understanding of the system's architectural approaches and the ways in which these approaches meet the quality requirements such as performance, availability, modifiability, and so forth" (Kazman et al., 2020). From this analysis, the value and purpose of MBSE can be better articulated and measured in terms of the benefits that it provides in certain scenarios.

The foundation of scenario-based analysis for MBSE being established, the SEI focused on applying this approach toward the SWP, aided by a model resource we developed for the Cameo Enterprise Architecture tool. Figure 4 shows a view of the MBSynergy scenario profile that has been developed. The figure shows the UAF elements and relationships that are created as part of MBSynergy scenario development.

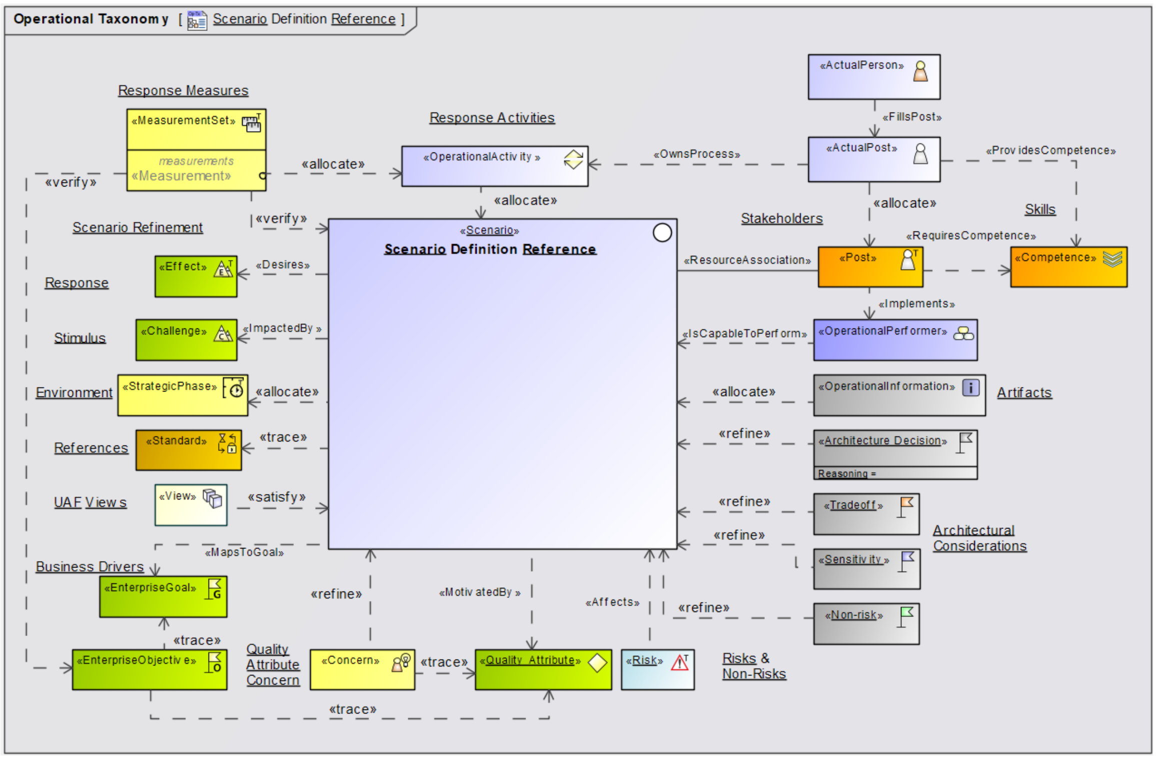


Figure 4: MBSynergy Scenario Profile

The MBSynergy Scenario Profile minimally extends the UAF profile to overlay MBSynergy scenario syntax and context for model developers to leverage for scenario definition. MBSynergy scenarios reference and re-purpose definitions first articulated for scenarios in the ATAM technique used for analyzing software architectures.

This resource was used to capture the 25 scenarios identified for the SWP which will be discussed and exampled in the subsequent sections.

Software Acquisition Pathway Scenarios

For the SWP, scenarios for the use of MBSE were identified by reviewing the activities described in DODI 5000.87 (OUSD[A&S], 2020) and the guidance on the DAU SWP guidance website (DAU, n.d.), in combination with the information requirements that are defined. For each phase, planning and execution, the activities were assessed for the need for having structured information produced or analysis conducted, thus indicating the applicability of model use.

Our assessment produced an initial set of 25 scenarios that capture the major areas of SWP activities that can benefit from being performed using model-based techniques. The scenarios were grouped by the top-level enduring tasks, a term defined by UAF as a common “undertaking recognized by an enterprise as being essential to achieving its goals” (OMG, 2022a).

The enduring tasks identified for the SWP include Define Capability Needs, Develop Strategy, Design Architecture, Plan Roadmap, Engage Active Users, Develop & Test, and Assess Value. It was important to align model-based engineering scenarios to drive home how models provide value to the critical aspects of the software pathway that are common to all. The number of scenarios could continue to expand as different considerations are uncovered as part of the scenario analysis and the operationalization of these scenarios. A high number of scenarios were identified during the planning phase of the SWP, where much of the requirement analysis and design activities are primarily associated. This might be expected considering that typical systems engineering practices aspire to bring much of the design and analysis of software as early in the life-cycle processes as possible to reduce risk.

An example of a scenario is Enterprise Services Definition. The guidance on the DAU SWP describes that programs should define a strategy for managing and leveraging “technical services such as cloud infrastructure, software development pipeline platforms, common containers, virtual machines, monitoring tools, and test automation tools” (DAU, n.d.). One might imagine how invariably useful it would be to have a digital model that defines the enterprise services elements, roles and responsibilities of personnel, service processes related to them, and how these elements interact. The model would be beneficial for a program to design their enterprise fully and continue to manage throughout the various life cycle of the SWP, as well as potentially leverage other enterprise service designs created by other programs. This is just one example of applying a model-based engineering approach to an aspect of the pathway.

Figure 5 shows the collection of scenarios that SEI has identified for the software pathway, grouped by the software pathway phase and enduring tasks.

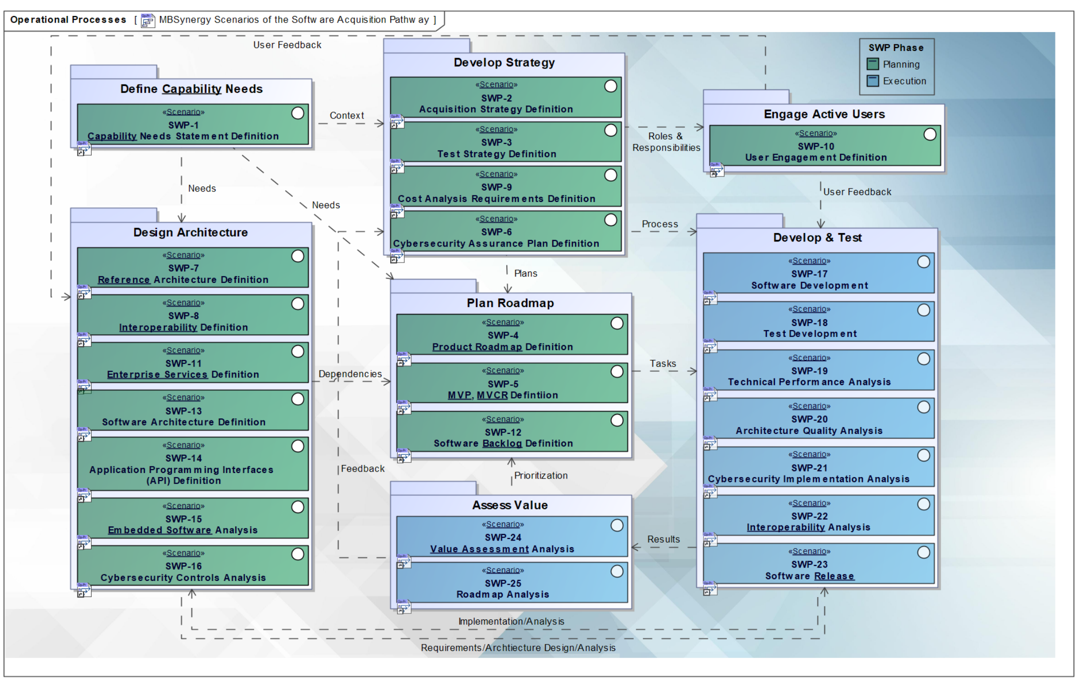


Figure 4: Model View of MBSynergy SWP Scenarios

As shown in Figure 5, the SEI has developed an UAF model that captures detail on the SWP scenarios and maps to the UAF 1.2 DMM. This model synergizes information in the UAF

DMM specification and the SWP guidance to form operationalization guidance and a platform for continued analysis of the value of MBSE applied to the SWP.

Figure 6 is a table developed in the model that shows the mapping of each scenario to the required statutory or regulatory information. The expectation is that some or all of the structured model information produced as part of the scenario satisfies the requirement of the pathway regulations. By mapping the structured information to the scenarios, the flow of information across the life cycle can be analyzed and the rationale for traceability from scenario to scenario can be established. Additionally, since the structured information is contained in the model, it would be feasible to create automated processes for collecting and producing this information in whatever format is most efficient for review and approval.

#	Id	Name	Aligned Documentation	Source	Applicability
1	SWP-1	Capability Needs Statement Definition	OI164 Capability Needs Statement OI171 Clinger Cohen Act (CCA) Compliance OI183 Software Initial Capabilities Document (SW-ICD)	DODI 5000.87 Clinger-Cohen Act (CCA)	Regulatory Statutory
2	SWP-2	Acquisition Strategy Definition	OI158 Acquisition Strategy OI168 Intellectual Property Strategy OI163 Product Support Strategy OI160 Business Case Analysis OI171 Clinger Cohen Act (CCA) Compliance OI169 Periodic updates to strategies	10 USC 2431a DODI 5000.87 Clinger-Cohen Act (CCA)	Statutory for major programs (> ACAT II) Regulatory Statutory
3	SWP-3	Test Strategy Definition	OI150 Test Strategy OI169 Periodic updates to strategies	DODI 5000.87 DODI 5000.96	Regulatory;Programs on DOT&E Oversight list may require a TEMP. Regulatory
4	SWP-4	Product Roadmap Definition	OI161 Initial Product Roadmap OI153 Product Roadmap OI154 Program Backlog	DODI 5000.82, Subtitle III of Title 40 DODI 5000.87	Statutory Regulatory
5	SWP-5	MVP, MVCR Defintiion	OI161 Initial Product Roadmap OI154 Program Backlog	DODI 5000.82, Subtitle III of Title 40 DODI 5000.87	Statutory Regulatory
6	SWP-6	Cybersecurity Assurance Plan Definition	OI156 Cybersecurity Plan OI171 Clinger Cohen Act (CCA) Compliance OI169 Periodic updates to strategies	40 USC 11313 DODI 5000.87 Clinger-Cohen Act (CCA)	Statutory for Mission Critical and Mission Essential IT programs Statutory Regulatory
7	SWP-7	Reference Architecture Definition	OI162 Information Support Plan OI167 Bandwidth Requirements Review OI171 Clinger Cohen Act (CCA) Compliance OI157 System Architecture	DODI 8330.01 §1047, P.L. 110-417 DODI 5000.87 Clinger-Cohen Act (CCA)	Regulatory Statutory for programs > ACAT II; Regulatory for Others Statutory
8	SWP-8	Interoperability Definition	OI157 System Architecture OI167 Bandwidth Requirements Review	DODI 5000.87 §1047, P.L. 110-417	Regulatory Statutory for programs > ACAT II; Regulatory for Others

Figure 5: MBSynergy SWP Scenarios Aligned to Required Documentation

The model is a library or reference architecture for stakeholders of the SWP to use for understanding the mechanisms to efficiently use UAF for structuring information and performing analysis. Each scenario is analyzed for its set of activities, stakeholders' roles, UAF views consumed/produced, quality attributes, enterprise architecture considerations, measures, and risks/non-risks. As a whole, the collection of scenarios defines a MBSE strategy and model development plan for SWP practitioners.

Mapping Scenarios to UAF Views

The mapping of the UAF views to the SWP scenarios was a relatively straightforward process after aggregating the definitions in the UAF DMM 1.2 specification and the information requirements of the SWP. The fact that this was a straightforward process speaks to the applicability of UAF as a framework to satisfy and structure information needs, transforming a document-based approach to a model-based one.

To illustrate the mapping process, we will walk through the operational process flow for the CNS Definition scenario for the SWP. The CNS Definition is a high-level overview of operational context, capability needs, performance measures, and user needs processes. A draft CNS is required to enter into the planning phase of the SWP, and it is expected to be refined and formally approved prior to entering the execution phase.

The template document for the CNS, shown in Figure 3 in a previous section, identifies five areas that should be articulated, including operational context, capabilities needed, performance attributes, interoperability considerations, and an overview of how requirements will be managed in the project. In the scenario, these five areas were transformed into operational activity actions where each action produced a set of UAF views. The UAF view specifications were compared to the text description of the information requested in the template and assessed for alignment. The objective was to select a minimal set of views that could satisfy the collection of information needed and not inundate model architects and developers with too many view specifications to consider.

Figure 7 shows the operational workflow diagram for the CNS definition scenario that is detailed in the model. This is a similar layout and approach to the one described and demonstrated in the Enterprise Architecture Guide for UAF.

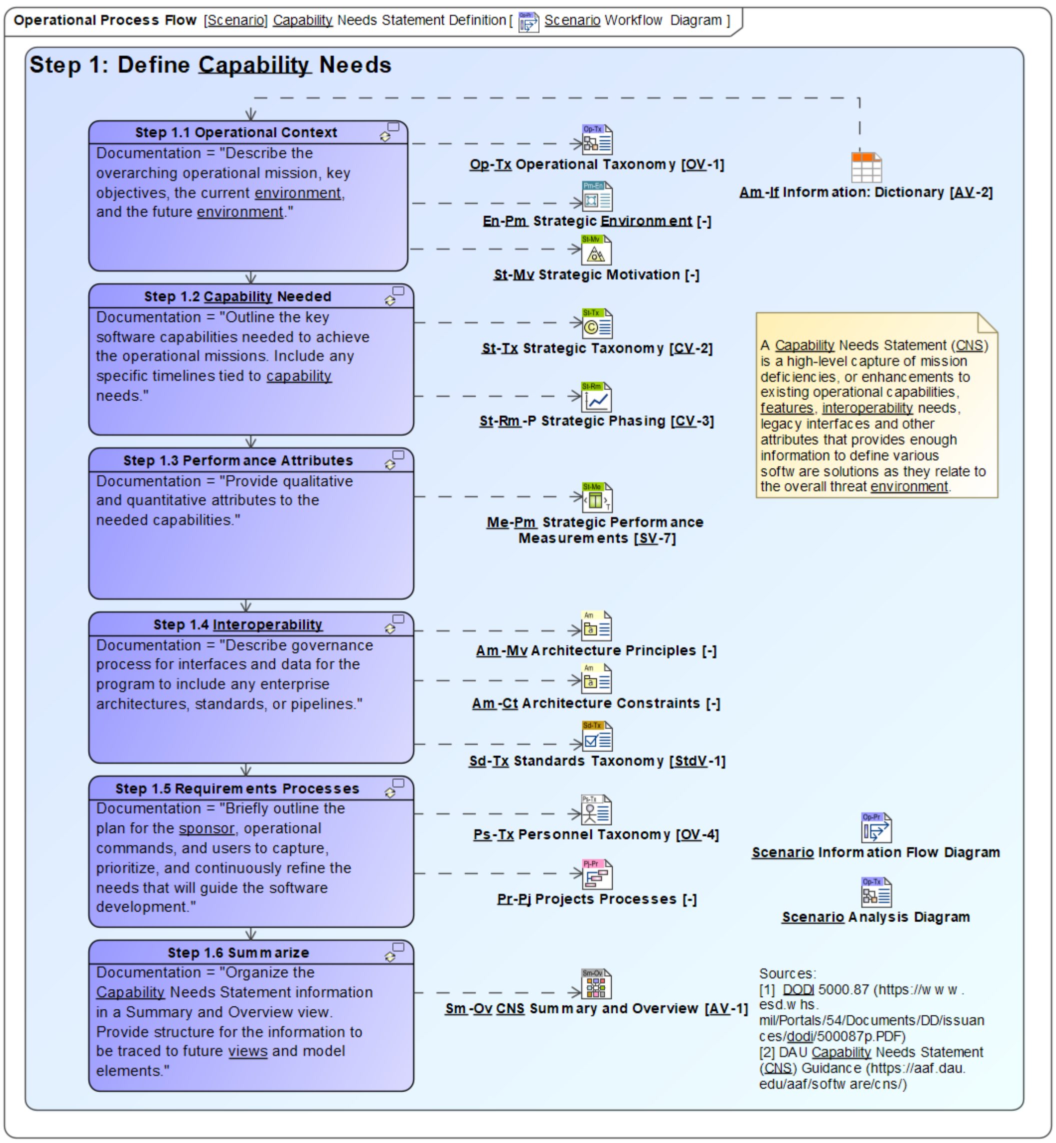


Figure 6: Model View of CNS Scenario

The operational activity actions are intended to be further refined by individual programs into sub-activity process flows identifying the specific roles and responsibilities for project personnel in the process. The UAF view diagrams shown in the figure are intended to be developed as example views that provide an understanding of what and how elements should be modeled. Driving consistency and understandability is a major concern for model use across all SWP users.

Table 1 provides additional commentary for how the UAF view aligns to the "SWP CNS definition" scenario. The UAF Views column contains the abbreviated view name, the full name, and, in closed brackets, the mapping to DoDAF views if available.

Table 1: "Capability Needs Statement" Aligned to UAF Views

Scenario Steps	UAF Views	Rationale for UAF View
1.1 Operational Context	Op-Tx Operational Taxonomy [OV-1]	Op-Tx captures the operational context and problem space, providing the necessary understanding for capability needs.
	En-Pm Strategic Environment [-]	En-Pm captures the current and future environment space of the operational concept, including identification of threats and risks. The view shows the elements and relationships that are involved in defining the environments applicable to capability.
	St-Mv Strategic Motivation [-]	St-Mv captures the key goals and objectives, threat drivers, and opportunities introduced by the software capabilities. The view defines the desired outcomes, goals, and objectives that are motivated by the drivers, and the opportunities that enable the goals and objectives.
1.2 Capability Needs	St-Tx Strategic Taxonomy [CV-2]	St-Tx captures an enumerated and hierarchical list of capabilities with relationships to supporting elements. The view captures the priorities of the capabilities for planning purposes.
	St-Rm-P Strategic Phasing [CV-3]	St-Rm-P captures the strategic timeline details to identify when capabilities are planned for users.
1.3 Performance Attributes	Me-Pm Strategic Performance Measurements [SV-7]	Me-Pm captures a list of strategic qualitative and quantitative attributes as pertaining to the listed capabilities. The view shows the measurable properties expressed in amounts of a unit of measure that can be associated with any element in the architecture.
1.4 Interoperability	Am-Mv Architecture Principles [-]	Am-Mv captures high-level architecture concepts and identifies the systems, networks, and services the software must be interoperable with. The view identifies relevant architectural principles and other guidelines to

Scenario Steps	UAF Views	Rationale for UAF View
		be used in architecture development and evaluation.
	Am-Ct Architecture Constraints [-]	Am-Ct captures interface and data constraints, assumptions, and governance processes to follow. The view depicts and analyzes assumptions, constraints, rules, policies, and guidance that are applicable to aspects of the architecture.
	Sd-Tx Standards Taxonomy [StdV-1]	Sd-Tx captures a list of relevant and/or required technical, operational, and business standards, guidance, and policies applicable to the architecture.
1.5 Requirements Processes	Ps-Tx Personnel Taxonomy [OV-4]	Ps-Tx captures the relevant stakeholders for the project context that participate in user needs processes.
	Pr-Pj Projects Processes [-]	Pr-Pj captures the set of activities that the enterprise will use for refining user needs as part of the software development process. The view describes the activities that are normally conducted during projects to support capabilities.
1.6 Summarize	Sm-Ov CNS Summary and Overview [AV-1]	Sm-Ov captures the set of information views in the previous steps for the CNS. The view allows for quick reference and comparison among projects.

The model views capturing these foundational elements of the CNS will be traceable throughout the planning and execution phase as part of design, development, and value assessments. The model enhances the ability to establish traceability between information early in the life cycle, both within a scenario and from one scenario to another, informing and refining the information that is developed later in the progression.

The process described above for mapping the views was repeated for each of the scenarios. Figure 8 is a snapshot of a portion of the SWP scenario to UAF view matrix diagram that is maintained in the model.

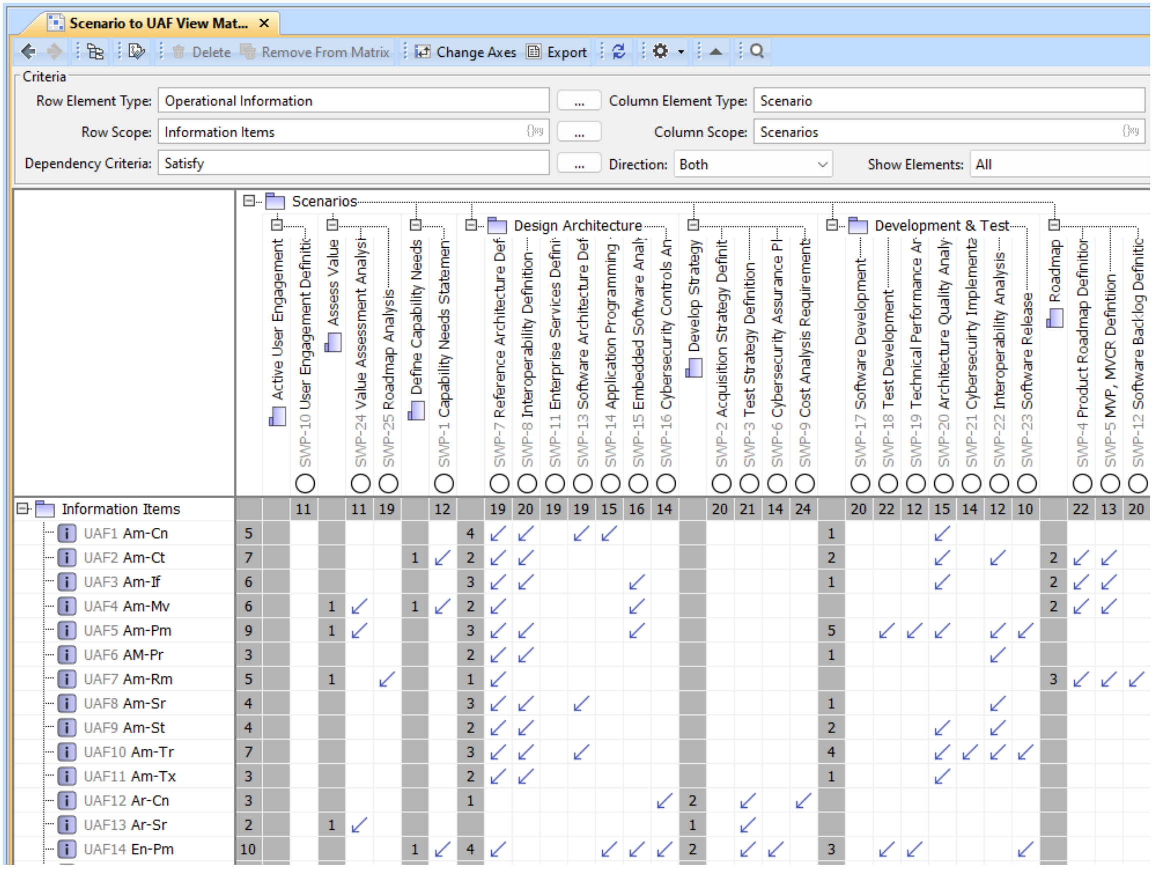


Figure 7: SWP Scenario to UAF View Matrix

This exercise found that many of the views were applicable to multiple scenarios, indicating how the information is used, refined, and matured across the life cycle of the SWP. This information flow, who uses it, and how it gets used is an aspect we explore as part of the detailed analysis we plan to perform for each scenario. Figure 9 shows a scenario connectivity diagram showing the flow of information that transfers from the Capability Need Statement Definition scenario to other scenarios to consume or refine.

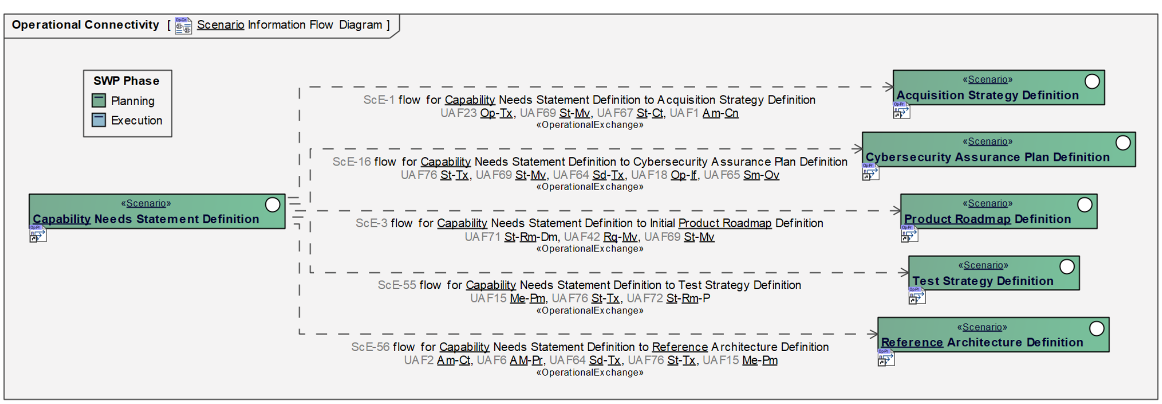


Figure 8: Scenario Connectivity Diagram - UAF Information Flow Analysis

The analysis of MBSE process interfaces assists in risk reduction of the enterprise by pinpointing where critical information is developed and transitioned. Risk reduction actions can be more precisely allocated to scenarios where the impact is greatest and ensure that high-quality information is established for the enterprise, leading to higher confidence and assurance.

Conclusion

The research presented in this paper is part of the foundational blocks for a consistent application of MBSE in DoD programs using the SWP, specifically with the use of UAF. The paper identified 25 scenarios for the operationalization of UAF as part of the SWP Planning and Execution phases for an embedded software sub-path and discussed the alignment of those scenarios to the information requirements of the pathway. To demonstrate the alignment, the paper discussed the UAF views that aligned to the development of a CNS with rationale for not only the satisfaction of the information needs, but also the value of capturing the information as part of an enterprise architecture model. The paper then introduced SEI's MBSynergy approach to analyzing scenarios and detailed how the analysis informs the value proposition of models within the context of the software pathway.

The full mapping of UAF views to SWP scenarios lays the groundwork for the operationalization of MBSE as part of the pathway. With the understanding of how regulatory and statutory information can be captured in UAF, stakeholders of the pathway can build common processes, policy, automation, and training to reduce the burden of model development and fully realize the benefits that MBSE can provide.

For SWP programs, this study and related artifacts aim to be resource for achieving a part of their digital engineering strategy, providing the ability to:

- structure and aggregate life-cycle information in a well-organized model, moving away from document-based information, to support communication and better understand interfaces between information needs
- generate robust traceability in life-cycle artifacts to support the concept of digital threads
- provide a foundation for analysis to occur early in the SWP, enabling more informed decision-making and higher levels of assurance for the desired quality attributes of the enterprise and the software capability being developed
- align with policy (DODI 5000.97) and digital engineering directives from each of the DoD military departments

Next Steps

The SEI plans to develop a technical report capturing the full breadth of content related to the scenarios developed for the SWP. This includes the full mapping of the software pathway scenarios to the UAF view, rationale for the view mapping, and high-level process and information flows from scenario to scenario. The technical report will be supplemented by a UAF model that can be made available to DoD stakeholders and the SWP community for reference and contribution. The SEI plans to continue to build out the scenarios for the software pathway and analyze the enterprise architecture within the scenario context, resulting in a set of quality attribute considerations and a value proposition for each scenario.

The SEI is interested in collaborating with active programs of the SWP to conduct additional studies and workshops relating to the use of MBSE during the pathway activities. Specifically, the SEI is interested in pilot projects to demonstrate the use of the UAF views and to explore the required resources needed to fully operationalize the approach.

The study informs future research into the use of models as part of the SWP, including how models can be continuously developed and monitored alongside software to inform value assessments and increase software assurance, how artificial intelligence (AI) agents and large language models (LLMs) can be utilized to automate aspects of model development and analysis, and how UAF model data can be effectively incorporated into software factory decision pipelines.

Legal Markings

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Improving System Sustainment Through an Integrated Modeling Schema Coupled With Effective Execution of the Life Cycle Sustainment Plan

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Abstract

Title 10 § 4324 tasks the Product Support Manager (PSM) to "(B) ensure the life cycle sustainment plan is informed by appropriate predictive analysis and modeling tools that can improve material availability and reliability, increase operational availability rates, and reduce operation and sustainment costs." Advances in modeling and simulation offer the opportunity for PSMs to bring new approaches to long-standing challenges, particularly using AI and machine learning models. This paper examines how one PSM has used a series of traditional and AI-based models to develop predictive analytics that can advise the platform life cycle with the expectation of improved Operational Availability (Ao) and Material Availability (Am).

There are many challenges, including: (1) most models are built to suit the particular user community, without any intention of connecting the model to others, (2) each model is often built with a set of algorithms that are custom adapted to the problem set, giving rise to composability questions, and (3) many models are built to different time scales, or even independent of any time representation.

Life cycle sustainment of submarines, particularly during service life extension, has been met with challenges that have led to inefficient use of time and personnel resources. While maintenance availabilities include various service, planned, corrective and alteration jobs that maintain or increase readiness of the Navy's deterrent fleet, these facilities encounter cost and schedule overruns caused by constraining factors including personnel, equipment, facilities, supplies, material, weather, or other uncontrollable factors. The COLUMBIA Submarine Program has developed several models to assist in decision making. We describe two models, one a discrete event simulation of the approved and alternate life cycles and the other a manpower forecasting model for the repair facilities and how these models have led to new insights in improvements that will improve Ao and Am.

We also describe a future state where currently disconnected models are integrated together, allowing decision makers insights to see the complete loop from a 3D product model used to design, build, and sustain the platform to the end user applications.

Introduction

We have previously reported on the application of governance to the sustainment effort on COLUMBIA (Baker et al., 2019). In this work, we described the Complex Governance System, its alignment with the nine directed responsibilities of the PSM, and how it could fill in the governance gaps from the Product Support Manager's Guidebook. We also discussed the application of several governance meta-functions to the program situation. One meta-function (Learning and Transformation M4*) was touched upon lightly but presaged our work in modeling and simulation. Currently, an explicit gap exists in the Title 10 responsibilities; we note that

> *The Learning and Transformation (M4*) meta-function, although not emphasized in the Title 10 responsibilities, is a critical element for governance. Learning facilitates the evolution of product support but also involves transformation of the DoD components if their business processes do not satisfy program requirements, or if their way of doing business comes at the cost of viability of another organization or a set of organizations (M4*). Governance through M4* implies continual adaptation and design of the underlying system and business processes through fundamental double-order learning to improve future execution.* (Baker et al., 2019, pp. 13–14)

The continued exploration of Learning and Transformation leads to several questions complemented by the governance perspective of having a model of the current system and potential future systems:

- How can a Product Support Manager (PSM) take advantage of the rapid advances in modeling and simulation to develop an integrated, through life cycle ecosystem of models and simulations to develop otherwise hard to find improvements that lead to cost sensible improvements in Fleet Availability and Operational Availability?
- What considerations might a PSM evaluate as the ecosystem is developed from a collection of siloed simulation instances?
- Can the learnings from this effort be applied to other current or future acquisition programs?

In this paper, we look at how one program is using modeling and simulation to improve the key parameters of A_o, A_m and C/DA specified in DODI 3110.05, first from an individual model perspective, then combining the models into an ecosystem. We begin with an introductory section that lays the foundation of the legal and regulatory basis for the work, describes our evolving concept of an ecosystem, and discusses the fundamental science of the models and simulation. We then transition to a methodology section describing the technical approaches taken in the computational models. A discussion of some of the insights learned and results from our work to date follows, along with some conclusions. We wrap up with a discussion of future work on our vision of expanding the modeling boundaries across the organizational ecosystem and some of the challenges we are sure to confront.

Background

Product Support Management Guidance in USC Title 10 and DoD/USN Supporting Instructions

The Product Support Manager (PSM) is a position designated in law to deliver and implement product support strategies for covered systems. This position is required to develop and maintain the life cycle sustainment plan, approved by the milestone B decision authority. The life cycle decision plan has eight significant elements. The PSM also has nine specific responsibilities, including "(B) ensure the life cycle sustainment plan is informed by appropriate predictive analysis and modeling tools that can improve material availability and reliability, increase operational availability rates, and reduce operation and sustainment costs" (NDAA, , 2021). This section is relatively new and represents the evolving understanding of the tools available to the PSM and the growing responsibilities. For instance, Public Law 111-84 of 2009, which introduced the Product Support Manager (Chapple & Faire) called out only five responsibilities for the PSM, none of which specified requirements for modeling and simulation. The responsibility to conduct modeling and simulation arrived in public law in Section 2337 (renumbered from 805) in the National Defense Authorization Act for Fiscal Year 2013, which began the explicit enumeration of requirements for the PSM to "use appropriate predictive analysis and modeling tools that can improve material availability and reliability, increase operational availability rates, and reduce operation and sustainment costs" (NDAA, 2013).

While Congress was providing legislative direction, OSD and the services were providing regulatory direction for PSMs to execute the law. Department of Defense Instruction 3110.05 has had several iterations, with the latest issuance in April 2024. It specifies three "superordinate metrics that will allow decision makers at all levels across the DoD enterprise to assess the effectiveness and efficiency of weapon system sustainment using a standard structure and consistently applied methodology." An additional nine metrics are specified in 3110.05. While the instruction specifies several characteristics and methods of calculation, it makes no comment on models or simulations (DoD, 2024b).

From a Navy perspective, a new Memorandum was signed out in 2024 that similarly focuses on key measures like Operational Availability (A_o) and Material Availability (A_m). Following the DODI format, instructions are provided to calculate specific measures and reporting intervals (OPNAV letter, 2024).

The COLUMBIA PSM had been working on various models and simulations, to be discussed in detail later, but the recognition had grown that the thread of the guidance combined with rapid advances in modeling and simulation offered the opportunity to begin connecting these models in an ecosystem embedded within the larger Project Blue ecosystem.

Application of "Ecosystems" as a Pervasive Lens

The rise of industry 4.0 and digital solutions has identified a new complexity, in that many of the technologies are interrelated and themselves complex, with few providers able to provide the complete suite with the requisite speed and flexibility. Benitez et al. (2020) had noted that

> *Before the advent of Industry 4.0, technology providers had mostly worked in a dyadic relationship for the development of their solutions in the supply chain (Marodin et al., 2017, 2018), while technology implementation was based on the exchange of units (Lusch and Vargo, 2014). This means that each actor contributed with specific technology modules to the supply chain, which were developed independently from other technology parts and based mainly on transaction as a mechanism of exchange.*

The PSM and his staff set out to create an ecosystem centered around delivery of sustainment to COLUMBIA, all within the scope of the PSM guidebook direction to employ Product Support Integrators (PSI) to facilitate the product support strategy through formal arrangements (e.g., Memorandums of Understanding/Agreement, formal contracts, teaming agreements) with designated Product Support Providers (PSP). The formal arrangements document mutual agreements for the scope of PS and resources provided and constrained in each individual arrangement.

We retain the earlier definition of governance as "occurring within a "meta-system" responsible for design, execution, and evolution of those meta-system functions ("meta-functions") necessary to provide communication, control, coordination, and integration for the complex system (Keating & Bradley, 2015)" (Baker, 2019). This paper addresses the specific need to develop models of the system, both current and desired future, and how COLUMBIA has developed and used models to meet the statutory and regulatory guidance, as well as intended path for a system of models covering the physical span from design through operations and the temporal span of the entire class lifetime.

Modeling Perspectives

This section discusses the current modeling approaches for the life cycle and repair facility manpower. The PSM has explored earlier modeling techniques, not reported here, as part of an exploration of "the art of the possible." The remainder of this section discusses each approach, software choices made and some detail on how each model was designed and implemented.

Discrete Event Simulation (DES)

Discrete Event Simulation (DES) models evaluate operation of a system or System of Systems (SoS) as sequential discrete time periods where each time period is distinguishable by a marked change that is clearly identifiable. In DES, abstract system models use a continuous but bounded time base where only a finite number of relevant events occur. These events cause state changes within the system which are then evaluated within the model to determine the effects on the overall system. In DES models, events occur at a discrete point in time that signifies a change to a system's status. Between two successive status changes, the system remains static. DES is a method that steps through time, skipping static periods where no changes occur (Griendling & Mavris, 2011). In continuous simulations, a system is allowed to change continuously over time (Banks et al., 2004). In DES, however, models are designed to specifically deal with discrete changes through either time-triggered or event-triggered activities whose stochastic output can be used for making decisions. Any continuous time period can be discretized into discrete time periods using cut points. DES evaluates a continuous time period by analyzing and quantizing attributes within discrete time segments before recombining them into a single result that spans the original continuous time period. DES results quantify results for the discrete time periods analyzed within the model. Thus, any continuous time period under examination must be discretized.

Discretization segregates data into discrete units. It replaces an infinite sequence into finite-dimensional problems that can each be solved individually through mathematics before being recombined to represent the solution in the original infinite sequence. Discretization methods produce data whose values can be counted (Yang et al., 2010). The discretization process establishes discrete data values that exist in intervals across a continuous range (Liu et al., 2002). Continuous results can be achieved by examining smaller and simpler results in discrete-time processes (Jacod & Protter, 2012). Partitioning a continuous time segment using cut points is a simple way to discretize any continuous time period. Any continuous time segment can be separated into "k" partitions using k-1 cut points. The process consists first of determining the number of discrete intervals (i.e., partitions) followed by demarcating the boundaries of the intervals (Kotsiantis & Kanellopoulos, 2006). There is no theoretical limit to the granularity of discretization. Mathematically, discretization methods are approximations, but as granularity of the discretization becomes smaller and smaller, the approximation becomes closer to the actual solution of the original infinite sequence (Stetter, 1973). However, there is a practical limit that is determined by the period of observation or the ability to measure or record values associated with discrete time values or cut points. A continuous range can be discretized by using cut points to dissect the range into partitions or intervals. Phases, modes and states have been defined as clearly distinct and different partitions of an operation and a system's functional operations (Wasson, 2014). Although a lack of a standardized taxonomy has resulted in much conjecture and confusion as to the distinction between phases, modes and states (Olver & Ryan 2014), they present an appropriate method for segmenting a life cycle into discrete periods that can be examined through DES.

Phases, modes and states of operation are integral to defining a system even though the distinction between modes and states may be relatively arbitrary (Wasson 2014, 2016). A submarine's life cycle is a continuous period from conception to disposal. A ship's Life Cycle Model (LCM) is the assemblage of unambiguous and specific phases, modes and states and the assigned product baseline. There is not much difference between modes and states, but it is primarily how a user defines modes and states in the context in which it is being used (Wasson, 2016). Any DES must be discretized. DES, as used in the COLUMBIA Submarine Program, requires discretizing each submarine's continuous life cycle into discrete periods that can be quantized. Modeling a submarine using DES requires segmenting the life cycle into discrete time periods. Decomposing a submarine's life cycle into phases, modes and states provides the cut points in the LCM and discretizes a submarine's life cycle.

Each submarine's life cycle is a sequence of phases: Research and Development (R & D), design and construction (including delivery), Operations and Sustainment (O & S) and disposal. DES within COLUMBIA's IPS is primarily concerned with the O & S phase which begins with the submarine's delivery and ends with decommissioning. Decommissioning is the event signaling the transition from the O & S phase to disposal phase. The O & S phase is comprised of alternating modes of operations and sustainment (Lemerande, 2020, p. 8). The operations mode decomposes further into various states, each defined by a configuration of constituent systems and equipment that must meet pre-defined criteria to be considered in the operational mode. A Functional Profile (FP) segregates a mission into periods for specific functions to be performed rather than performing all functions simultaneously. FPs includes all events performed during a mission (USN, 2002). States can correlate to mission segments and be paired with specific equipment and specific configurations assigned to mission segments as unique periods to be assessed (Wasson 2014, 2016; Esary & Ziehms, 1975; Burdick et al., 1977). The sustainment mode is comprised of any period where the submarine is undergoing intermediate or depot level maintenance. A submarine's LCM is the assemblage of specific phases, modes and states. Phases, modes and states provide the cut points for discretizing an SSBN's life cycle. The SSBN fleet life cycle is an agglomeration of the life cycles of the constituent submarines. The COLUMBIA Class LCM consolidates all the phases, modes and states of the SSBN fleet into a single model. DES is a state-driven model that uses probabilistic characteristics for submarines' O & S Phase's modes and states to evaluate and assess scenarios and quantify outcomes across all submarines included in SSBN force data models.

Naval Sea System Command (NAVSEASYSCOM) initiated Model Based Product Support (MBPS) as a digital transformation program to consolidate and update Integrated Product Support (IPS) activities across the fleet. A core aspect of MBPS is the Navy Common Readiness Model (NCRM) that will provide "predicted, optimized and sustainable readiness" for ships and submarines. Systecon's Opus Suite is the chosen software for producing NCRMs in MBPS (NAVSEASYSCOM, 2022). SIMLOX, one of three software programs within Opus Suite, is DES software that has the ability to illustrate how outcomes vary over time, taking into account changing operational demands as well as changing resource availability, maintenance operations and logistics transportation operations. "SIMLOX is an event driven simulation tool that enables detailed analyses of how technical system's performance vary over time given different operational and logistics support scenarios" (Systecon, 2021, p. 17). Systecon developed SIMLOX to evaluate scenarios through simulations to help users understand the implications of various logistics and support conditions on the identified operational requirements. COLUMBIA's PSM became an early adopter of Opus Suite and has been developing SSBN models in SIMLOX to drive improved IPS in the COLUMBIA Submarine Program.

Artificial Intelligence and Machine Learning

AI and ML-driven approaches have the potential to significantly improve fleet management by increasing availability and operational performance. One area of improvement involves adequately sizing the workforce required to perform necessary maintenance. This occurs at both the facility and trade levels. Workforce sizing exercises have been performed in similar circumstances. Turan et al. (2021) provided a case study involving the Royal Australian Navy that combined system dynamics simulations with the use of a sorting genetic algorithm to generate plausible workforce planning scenarios, which are then passed to further simulation models for evaluation. Witteman et al. (2021) applied time-constrained variable-sized bin packing approaches to calculate workforce requirements under optimal operational maintenance conditions for an entire aircraft fleet owned by a European airline. Potential modifications to these workforce sizing algorithms can include the incorporation of models for resignations, retirements, recruitments, promotions, and even annual leave (Akyurt et al., 2022).

While workforce sizing is an appropriate technique to summarize the requirements across an entire facility, complex systems require analysis at the trade level to ensure that all aspects of maintenance can be covered by the workforce. Applying skillsets to the individual workers creates a variation of the Multi-Skilled Resource Constrained Project Scheduling Problem (MS-RCPSP), which attempts to optimize work schedules while considering worker skillset (namely, each worker can only work on tasks for which they are skilled) and material availability constraints. MS-RCPSP has been frequently tackled across a variety of industries using techniques such as parallel scheduling schemas (Almeida et al., 2016), genetic programming (Lin et al., 2020; Zhu et al., 2021; Snauwaert & Vanhoucke, 2023), binary integer programming (Zhang et al., 2023), mixed integer linear programming (Snauwaert & Vanhoucke, 2023), Benders decomposition (Balouka & Cohen, 2019), and variable neighborhood searching (Chakrabortty, 2020).

MS-RCPSP has been proven to be an NP-hard problem (Blazewicz et al., 1983). The consequence of this finding is that known methods are incapable of producing a solution to the MS-RCPSP problem in polynomial time, meaning that the computation required to produce the optimal solution scales at least exponentially as the inputs become more complex. Submarine maintenance requires hundreds of workers tackling hundreds, if not thousands, of jobs during any maintenance period. Even under idealized conditions, the scope of the submarine maintenance environment renders existing MS-RCPSP techniques computationally impractical. Techniques that attempt to simulate operational conditions, such as the stochasticity induced by Isah and Kim (2021) or the mid-project job delay forecasting by Awada et al. (2020), improve the realism of the modeling and simulation process but exacerbate the computational complexity of the problem. As a result, entities have asked whether other numerical, data science, artificial intelligence, or machine learning techniques can achieve results faster while appropriately considering the operational conditions (Washko, 2019).

Another area where AI and ML can improve maintenance facility performance involves prediction of unplanned work, which is known to contribute significantly to maintenance delays. The Government Accountability Office (GAO, 2020) notes that unplanned maintenance causes a 36% underestimation of workforce size, directly leading to over 4,000 days of maintenance delays in the aircraft carrier and submarine fleets during Fiscal Years (FYs) 2015–2019. This number accounts for 47% of all delays across the nuclear-powered fleet during that time span (GAO, 2019). Unplanned work generally arises after maintenance begins and can result from equipment breakdowns, inspection and/or test failures, discovery during maintenance of other parts, or other reasons. As a result, unplanned work is difficult to project. Data science efforts can identify patterns in unplanned work and attempt to apply the results to other machinery, allowing synthetic work packages to be developed for equipment that does not yet have maintenance history.

Methodology

In this section, we detail the two specific models that were developed for the life cycle model and the repair facility manning.

Discrete Event Simulation

DES in the COLUMBIA Submarine Program uses SIMLOX to demonstrate how simulation outcomes vary over time with varying inputs, resources and constraints. SIMLOX is designed to account for operational demands, maintenance requirements, resource availability and transport schedules to produce results that characterize operational and maintenance demands. SIMLOX models simulate mission scenarios according to predefined operational profiles while considering maintenance and support and the consequences resulting from logistics constraints and on operations throughout the scenario. Data related to maintenance schedules and resources, operational schedules/profiles and maintenance strategy are loaded into SIMLOX templates to produce a Database Model (DM). Each SIMLOX DM is generated by importing curated data tables from a Predictive Data Model (PDM) directly into SIMLOX using Open Database Connectivity (ODBC) functionality inherent in Opus Suite.

The PDM creates conditions and curates data needed to conduct DES in SIMLOX. The PDM was developed within the Navy Marine Corps Intranet (NMCI) using common applications available in the USN's Information Technology (IT) infrastructure. It is a development environment that collates submarine LCM and pertinent product support information into the requisite tables for importation into SIMLOX. The PDM developed for SSBNs uses MS Excel and MS Access to create, condition and curate data tables that comprise a comprehensive data model. Synthetic data was created and conditioned in MS Excel and curated in MS Access before importation into designated SIMLOX data tables for processing in a DES. The PDM's data architecture is a collection of data tables that allows flexibility in the composition of individual submarines and their life cycle phases, modes and states and the necessary product support environment (i.e., model entities and resources). The PDM is modularly constructed to allow for incremental improvements to increase model fidelity and usefulness. The PDM's output is curated data collated into tables that exactly match SIMLOX tables. Curated data tables in the PDM are imported directly into SIMLOX via ODBC. Data integrity is maintained between MS Excel, MS Access and SIMLOX to ensure data quality remains intact throughout the model. The PDM's continued development and improvements remain unclassified while using synthetic data. However, the PDM is portable to the USN's classified network to allow classified modeling when actual fleet data will be used. Using a standardized PDM allows separate DMs to be developed independently before being assimilated into a single model and run as a consolidated simulation with multiple ships. Moreover, the standardized PDM allows any quantity of modes and states to be included in a single DM. The PDM can be applied to any submarine within the fleet. Every submarine can use the same PDM to develop its own model specific to that ship. A standardized PDM ensures any DES will be executed in the same way.

PDM data tables are characterized as either common across the scenario or specific to a product (model entity). Common tables apply universally across the entire model and do not change based on submarine schedules. They consist primarily of logistics, product and organizational support resources that apply universally throughout the model. Common data tables often apply across multiple scenarios because they establish the product support environment for ships and ship operations within models. Tables specific to individual ships consist primarily of each ship's LCM data. Ship specific tables share a common structure, but the data contained within each row of data is unique. Tables in a SIMLOX DM consist of columns and rows. Each column is defined by a specific name and header and, in some cases, default values (Systecon, 2021, p. 83). Every row is a separate record in the database. In each DM, each row is either uniquely associated with an individual ship (i.e., ship specific data), or it is common and applies across the entire fleet. The order of joining is inconsequential since each row represents an individual record. Any rows common across the fleet will be duplicated and therefore must be removed, while rows specific to an individual ship are unique. Combining data tables from separate DMs is simply consolidating rows of data from individual DMs into common data tables and removing duplicate rows. SIMLOX's table structure supports piecemeal development; separate DMs can independently run individual ships' simulations separately. However, to simulate all ships in the same integrated fleet simulation, the data tables from separate database models must be combined into a consolidated DM. Individual ship DMs combined into a single model yields an Integrated Fleet DM (IFDM). Running an IFDM in SIMLOX as a DES produces results for individual ships within the confines of the product support structure and within constraints of the fleet's shared resources. SIMLOX results contain data stored as tables and graphical renderings in one common file.

SIMLOX can produce a DES for any number of submarines within a product support structure defined by the modeler. SIMLOX is scalable and can be used to evaluate any quantity of SSBNs in any configuration for all phases, modes and states. SIMLOX, as an "off the shelf" product, has some limitations but is an adequate modeling environment. Furthermore, SIMLOX is approved to be installed on Navy classified networks. SIMLOX allows for spiral development in successive models to continually improve and increase model fidelity. Features available within SIMLOX support different levels of fidelity, depending on a given model's construct. The most basic model requires specific data tables to be populated, while more complicated models must include additional tables. Once the minimum tables are populated and a basic simulation can be executed, additional features within SIMLOX can be included to add fidelity to DES results. DES in SIMLOX can be continually improved and updated with new functionality. Systecon has continually improved Opus Suite functionality with multiple releases throughout the past several years.

Artificial Intelligence/Machine Learning

Due to the overall taxpayer investment and strategic importance of the COLUMBIA class, it is important to ensure that the submarines last throughout the entire planned life cycle. The best way to achieve this standard prior to ship delivery is to thoroughly plan for maintenance throughout the ship's life cycle. Artificial intelligence and machine learning methodologies can assist with this planning by learning from historical maintenance data and providing insights on the requirements needed to sustain COLUMBIA ships. This is important because the sensitivity and hiring requirements imposed by national defense work limit the amount by which the workforce can be scaled at any one time. Furthermore, there may be changes in the structure of the workforce, particularly the number of employees skilled in different trades, due to the incorporation of new technologies onto the COLUMBIA class.

The artificial intelligence and machine learning aspect of this project addresses five key questions:

1. What sized workforce is required to perform the maintenance necessary to ensure that the COLUMBIA fleet fulfills its national security obligations?
2. Given the calculated workforce size in Question 1, what distribution of skillsets is needed to ensure the COLUMBIA fleet fulfills its national security obligations?
3. Given the results of Questions 1 and 2, what is the probability that a provided work package gets completed within a provided timeframe?
4. Can work packages be generated synthetically to improve the confidence in Answer 2?
5. How can the tools developed to analyze Questions 1–4 be efficiently packaged for use by maintenance planners?

Several assumptions regarding working conditions were made in the modeling process. It is assumed that staffing levels remain consistent throughout the period of work, meaning that daily staffing levels do not change drastically at any point during the simulated life cycle. Machinery is assumed to be of sufficient quality and quantity to avoid causing bottlenecks in the work process. Future jobs are assumed to be completed as scheduled, meaning that no individual job is deferred to future maintenance periods. Due to the nature of the data and normal operating conditions, the model inherently accounts for a base level of deferral which is assumed to be consistent over the life cycle. Maintenance periods that require use of drydock facilities are assumed to be conducted entirely in the drydock. Finally, the modeling process assumes that work at the two facilities happens independently, meaning that jobs and workers remain at their original facility and that boats do not switch homeports during their life cycle. This final assumption allows for the development of separate models for each maintenance facility, which makes sense given that the two TRF facilities operate under slightly different philosophies. A system of models (comprising of predictive modules) is proposed to address the above five key questions:

A Resource Per Day – Schedule Confidence (RPD-SC) module was developed to determine the overall workforce size. The first iteration of the RPD-SC module is trained using a corpus of all completed jobs conducted on 207 maintenance activities across all OHIO class submarines from 2010–2021. These activities include 34 docking and 77 pierside (non-docking) maintenance activities for Bangor and 19 docking and 71 pierside (non-docking) maintenance activities for Kings Bay. Daily charge data, including the number of man-hours spent on each job, is captured daily at each maintenance facility. These data were aggregated across the entire facility, then subdivided separately by maintenance activity and calendar day. Similarly sized maintenance activities were grouped together, and their daily charges were normalized to produce a generic work profile for that "type" of maintenance activity. When provided with maintenance dates and a projected scope (in man-hours), the RPD-SC module calculates the required resource expenditure needed for each day in the maintenance period to stay on track to complete the project in time. This process can be applied over each maintenance activity for each boat at a facility to produce a plot of the overall staffing needed at the maintenance facility. This plot provides the guidance needed for facility leadership to determine the required workforce size, thereby answering the first question.

The charge data that powers the RPD-SC module also bins the jobs by Work Center (WC). Hence, the second iteration of the RPD-SC module was to perform a similar analysis at a more granular level for each WC. These work centers are typically broken down by trade. For example, work center 38C conducts repairs requiring machining while work center 72A performs rigging operations. The process for generating work profiles is conducted at each of the WCs with sufficient work for analysis. This step is significant during WC analysis as some work centers only perform their work at specific times during a maintenance period. For example, 72A's work, which mostly involves the removal and replacement of equipment to improve access to other parts of the submarine, is largely conducted at the beginning and end of activities, while 38C's work is performed consistently throughout the maintenance activity. A similar plot to the overall facility plot is generated as output of the RPD-SC WC iteration, which provides the guidance needed for facility leadership to determine the number of workers at each WC and answer the second question.

Work center analysis revealed that oftentimes work is not linearly related to the estimates at the beginning of a maintenance activity. A third iteration of the RPD-SC model addresses this issue at both the facility and WC levels by incorporating a heuristic-based, non-linear model approach. Data sets are broken into three regions using the Jenks natural break algorithm (Jenks, 1967). Linear analysis is conducted in the two outer regions to provide better fits on outlier data and provide reasonable extrapolations of the work estimates. In the interior region, a gradient boosting decision tree algorithm (Friedman, 2001) is used to fit on the data. The results of each of the trees are calculated then aggregated to produce a non-linear fit in the central region. The result is a fit that better adheres to the non-outlier data while minimizing the number of degrees of freedom.

The RPD-SC module can produce raw work estimates, but when used alone, it cannot determine the likelihood that a maintenance activity is completed on time. The Resource Probability of On-Time Completion (RPC) module fills this void. RPC takes the start date, projected maintenance activity length (in days), estimated scope of maintenance, facility-wide staffing levels, and a derived value for the amount of work conducted at the facility (called load measure) as inputs. Load measure is derived from aggregated historical performance metrics gathered from the observed data. This measure is similar to the work profiles generated in RPD-SC, but it applies across the whole facility rather than for an individual maintenance activity. The underlying technology of RPC is a Gaussian Process Classification model that is trained using the aforementioned observed maintenance data and outputs a probability that a maintenance activity completes within a provided activity length, answering the third question posed. It should be noted that the RPC module only uses historical maintenance activities in its training set, so the outputs will only be accurate for new activities that somewhat resemble those in the training set.

The previously mentioned modules are each trained using observed maintenance records, but the available data may not be sufficient to ensure that the models run at peak efficiency. A synthetic data generation routine was developed to combat this issue by simulating realistic staffing/planning data using advanced machine learning techniques. The routine starts by clustering all available job data at the work center level to identify distinct job types. A job list is created for each maintenance activity, which consists of a list of job counts by cluster. A conditional variational autoencoder (CVAE) learns patterns from the job list training data and generates new synthetic job lists based on specified characteristics.

This synthetic data is instrumental in filling gaps in the existing datasets, such as projecting job distributions for maintenance activities that are not similar to those currently observed. Synthetic data allows for analysis and prediction of job compositions across different scenarios, correlates job types with input maintenance activity characteristics, and helps anticipate staffing needs more accurately. Additionally, the model can simulate future maintenance activities by leveraging shared jobs, enabling better understanding of what COLUMBIA maintenance activities will look like, particularly under newly developed circumstances foreign to existing ship maintenance plans. These simulated work packages address the fourth question posed at the opening of this section.

The RPD-SC, nonlinear RPD-SC, RPC, and synthetic work generation modules combine to produce a powerful tool suite capable of predicting maintenance needs across the entire 60+ year life cycle of the COLUMBIA class. The final package takes a nominal life cycle schedule as an input. Facility-level workloads used in the RPC module are calculated using the provided start and end dates for the maintenance activities. The RPD-SC module uses the provided maintenance scopes and profiles each activity based on the activity length and the learned workload profiles. These RPD-SC results are graphically depicted on a visualization dashboard for each activity, as well as aggregated over the entire facility to show the entire projected workload on a given date. Additionally, the scopes and dates feed into the RPC model, which estimates the probability of a successful maintenance activity. These outputs allow maintenance planners to set target rules such as a nominal workforce size, which allows for further calculations such as overtime rate during busy periods, white space during slower periods, and workforce optimization through re-assigning work on docked ships (Tse & Viswanath, 2005). The above-mentioned modeling and dashboard will allow planners to envision 'what-if' scenarios at both TRFs and adjust maintenance availabilities to over the entire life cycle of the fleet. This overall package solves the final question posed at the opening of this section.

Discussion

Each of the models provided insights to assist the PSM. The discrete event model highlighted several risks within the approved life cycle and offered alternative life cycles for consideration to reduce or eliminate those risks. The AI/ML model is an earlier model but has offered insights the ability to develop synthetic work packages for a class not yet delivered. Some specific results are discussed in the following paragraphs.

The first OHIO class SSBNs transferred into service in the early 1980s. The USN has more than 40 years of historical technical and logistics data for OHIO class SSBNs. The VIRGINIA class submarine program has about 20 years since the first of its class entered service. Although much of COLUMBIA's design incorporates legacy systems from OHIO and VIRGINIA class submarines, a portion of the new SSBNs will be new technology for which there is limited technical and logistics data for parts other than data estimated by the ship designer. Moreover, 12 COLUMBIA class SSBNs will deliver the same Sea Based Strategic Deterrence (SBSD) mission currently provided by 14 OHIO class SSBNs. O & S for COLUMBIA will necessarily be different to OHIO in order to deliver SBSD with two fewer submarines. DES provides the ability to model COLUMBIA's configuration baselines, life cycle schedules and O & S profiles as well as wider USN logistics support and TRFs' facilities and resources to forecast effects integral to IPS.

Success thus far using SIMLOX has demonstrated the usefulness of DES to IPS for the COLUMBIA Submarine Program. SSBN operations and sustainment are different to other Navy ships. SSBNs operate a "two crew" concept with each submarine routinely scheduled strategic deterrent patrols followed by in-port refit periods at a TRF. SIMLOX uses discretized life cycle schedules to simulate individual submarines' modes and states for an entire class of submarines within the same simulation. Both TRFs play the primary role in sustaining SSBNs; they will provide the majority of all in-service sustainment and husbandry for COLUMBIA class SSBNs. Within SIMLOX, the TRFs are key resources within the DES that support evaluation of submarines across their life cycles. Stochastic forecasting predicts submarines' operational successes during specific modes and states based on each submarine's configuration, technical parts data, expected failures and repair capabilities within the product support network. SIMLOX also generates parts' demands based on simulated operations and sustainment activities, to include adequacy of OBRP allocations from simulated parts failures and subsequent onboard repairs conducted Ships Force personnel, to forecast demand rates for parts. DES results have also produced availability calculations based on simulated operations and sustainment activities.

Artificial Intelligence – Machine Learning

Early analysis focused on applying reinforcement learning (RL) techniques to optimize maintenance schedules, but several shortcomings were discovered. RL is ideal for cases where jobs must be performed in a certain order, but the existing datasets do not capture this information. RL also works best when job lists for a maintenance period are known, but in many cases, these lists are fluid until the maintenance period is underway. This results in a model that is myopic in nature and incapable of producing long-term predictions. The compute time required to run RL models makes application of RL models difficult in an operational environment. This is particularly true when determining the compounding effects of deferring work to future maintenance periods since the unplanned work added to future job lists cannot be finalized until the boat performs its patrol. Finally, RL algorithms usually produce an autonomous guidance for conducting maintenance periods, which may be met with distrust and operational resistance by people familiar with conducting live maintenance.

Considering these shortcomings, the AI efforts shifted focus to traditional statistical learning approaches. The result was a suite of models that are less complex, capable of viewing long-term effects of short-term solutions, and powerful enough to provide meaningful results. Early model development directly predicted daily charged hours, but it proved difficult due to many unknowns, including the total ongoing work at the facility, how these charged hours were distributed, and other factors that might impact the workforce, such as extreme weather and extraneous conditions such as the Covid-19 pandemic. This prompted the development of models trained at the refit level on completed jobs. The workforce prediction models are trained using completed work as input and total charged hours as output. These models determine the resources required to complete a scoped work package. The trained models do not directly make daily predictions. Instead, profiles outlining the distribution of work over a maintenance activity are generated by computing statistics on historical data. By combining maintenance activity level predictions and profiles, daily workforce predictions are obtained. A requirement for this method is an understanding of how conditions affect the workforce on a daily scale. However, this model excels at making long-term predictions for the required workforce and understanding long-term trends in workforce demand.

Iterative model development practices allowed for the creation of more complex models that maintained long-term outlooks and retained predictive capability over the RL approaches. These models include the non-linear and machine learning-based approaches outlined in the Methodology section. By applying these approaches, the mean absolute errors of prediction were reduced by more than 5% for the non-linear approach when predicting resource expenditures at the western maintenance facility. Model run time does not increase significantly despite the additional complexity. Furthermore, the non-linear model was designed to give reasonable predictions in regions without data, for example, activities with very small or large work packages. This package was named Maintenance Availability and Resource Prediction (MARP) for brevity.

Model Integrations and Results

DES modeling efforts described above produce common data useful in multiple modeling environments. A standardized output file has been generated for use in cooperative modeling activities. The PDM output file contains the following data fields: submarine unique identifier (i.e., hull number), unique maintenance availability identifier, scheduled start date, scheduled completion date, planned duration and estimated scope of work in RDs. For maintenance periods where a portion of the production work will be conducted in a dry dock, planned durations of time in dry dock as well as scheduled dates for docking and undocking operations are also included. The output file is a simple MS Excel worksheet with data separated by columns with common header names. These curated data sets are common between modeling environments; they provide the source data for both the DES and the AI/ML models and any other models that could potentially be developed in the future.

Model integrations between the DES (SIMLOX) and the AI-based MARP model are carried out by passing in the output schedule of the SIMLOX model as input (in the form of a spreadsheet as described above) to the MARP model. The input schedule includes a contiguous sequence of COLUMBIA maintenance availabilities over the lifespan of the fleet (2030–2080), the scope of work, and the type of availability. The MARP model then processes the input schedule and computes resources needed and a probability of on-time completion for each maintenance availability.

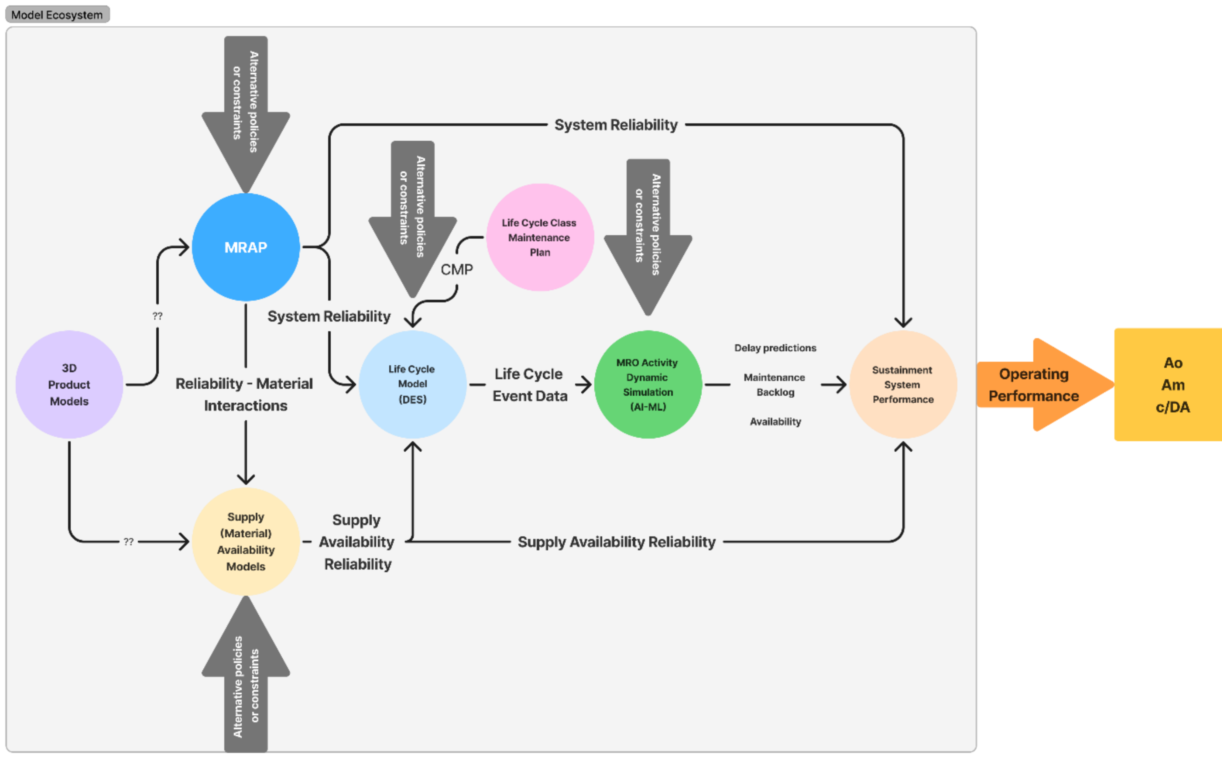
Conclusions

The work to date has demonstrated the viability of our intended path to develop an interconnected ecosystem of models, including 3D product models, reliability models, supply models, and class maintenance plans, to enhance decision-making and operational efficiency. The model offers an improved ability to optimize workforce sizing and predict maintenance needs, considering factors such as resignations, retirements, recruitments, and promotions to ensure an adequate workforce. Initial efforts to use reinforcement learning illustrated the limitations in a high noise environment, enabling the decision to more traditional statistical learning approaches augmented by newer algorithms. Since the new class of submarine has not been completed, the use of synthetic data generation routines will allow for credible simulations of realistic staffing and planning, enabling better analysis and prediction of job compositions and staffing needs. Iterative model development led to the creation of non-linear and machine learning-based models, which improved long-term predictions and reduced prediction errors.

Future Research

Future work is progressing at two levels; the first is the individual model level. Future work on the AI/ML modeling side includes further enhancing and validating the RPD-SC models at a granular work center level. Future work also aims to use job level information as input. Current models use the sum of estimated man-hours across jobs to make a prediction. Using trends at the job level would provide more accurate predictions. For example, some jobs may tend to require more expended man-hours than originally estimated. Another avenue to explore is incorporating job and workload assignment practices at the facilities. This allows for flexibility in how work is distributed overtime and does not use a static profile. Using this approach, a facility could predict workload while minimizing overtime, for example.

Due to the success of the development of the first two models and the demonstrated ability to interconnect brining other models together is underway. An initial exploration of other elements of the ecosystem has been explored. Contained within our ecosystem are at least the following models and simulations: 1) the builder’s 3D product model used to design, build, and sustain the platform; 2) an intermediary viewer that permits rapid access to the 3D model data in a lightweight, easily transportable model; 3) the reliability models, primarily developed by warfare centers for the Hull, Mechanical and Electrical (HME) and combat systems; 4) the supply models populated by the construction data packages from the builder and government organizations held by both NAVSUP and DLA; and 5) the class maintenance plan. Other models and simulations exist but are ignored for this level of abstraction. A generic pictorial is offered in Figure 1.



Build an integrated model ecosystem spanning from the 3D product model to operational models to report, predict and improve $\mathbf{A_o}$, $\mathbf{A_m}$ and C/DA

Figure 1. Abstracted Model Ecosystem

The future work will focus on developing the ecosystem. Several challenges are already understood and will require research and development. Three challenges will be discussed as part of future work. Those challenges are 1) composability, 2) verification and validation, and 3) governance of the ecosystem as an enterprise. Davis and Tolk (2007) assert that

> Strict plug-in/plug-out is unlikely to be valid for models, except in special cases, because of substantive subtleties about the component models and the assumptions that underlie them. It is much more feasible to design models in a fashion that will allow subsequent composition in short amounts of time—e.g., hours or weeks, rather than months or years.

Many of the models in our ecosystem are complex, well-developed products. However, the interaction with the other models is in a nascent stage. This highlights the problem of composability, which Davis and Tolk (2007) define as “Composability refers to the ability to select and assemble components in various combinations to satisfy specific user requirements meaningfully (NRC 2006)" (p. 860). Additional research is necessary to identify, clarify and resolve composability issues.

Related to the composability challenge is the concept of Validation, Verification and Accreditation of both the individual models and the entire ecosystem of models. Each of the individual models has a VV&A path adjudicated by the product owner (PM or equivalent). However, the ecosystem as a whole has not developed a VV&A plan. Research (Salado, 2015, 2023) offers suggestions to supplement to DODI 500.61 and MIL STD 3022 guidance.

The final challenge discussed in this paper is the topic of ecosystem (and model) governance. Several of the models are not program exclusive and are themselves evolving in conjunction with their environments. Technical advances like the advent of cloud hosting and a microservice architecture collide with monolithic models not designed as Cloud Native Applications. Whether cloud hosted or not, cyber security concerns must be integrated into the development path. Several of the model product owners have mature charters; others are nascent. The earlier reflection on the impact of Industry 4.0 creating a need for multiple participating organizations rather than a single source all create a complex system (or system of systems for those inclined). A governance system is also evolving to enable "control, communication, coordination, and integration of a complex system" (Keating & Bradley, 2015).

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Scaling the use of Publicly Available Information Across the U.S. Government

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Abstract

The U.S. Government (USG) requires ever-increasing access to publicly and commercially available information (P/CAI) to enable the full breadth of national security, public policy, and economic objectives. Scalable and fiscally efficient access to the complex and dynamic P/CAI ecosystem is difficult across USG but remains essential to strengthen situational awareness and enable strategic decision making across a wide range of missions. This paper first assesses the challenges with acquiring and using P/CAI across the USG at scale. It then recommends centralized, shared solutions that could be employed to minimize duplicative data purchases, promote data integration and development of advanced analytics, and manage risks associated with sharing information across authorities (e.g., Titles 10, 15, 28, 31, 34, and 50 entities). Research questions focus on opportunities for enterprise coordination to centralize the collective buying power of the USG through adaptable acquisition and technical approaches that support scalability and automation, while addressing legal risks among different USG agencies in a relatively novel problem space. P/CAI is valuable to national security missions, and scalable data acquisition, data harnessing, and compliance considerations are necessary to unleash it for the USG. By leveraging centralized shared services, the USG can enhance its ability to use P/CAI effectively.

Problem Statement

The U.S. Government (USG) faces continued challenges to coordinate the acquisition and analysis of publicly and commercially available information (P/CAI), consisting of data that is freely available to the public (PAI) and data that is purchasable from commercial vendors (CAI) (Office of the Director of National Intelligence [ODNI] Senior Advisory Group, 2022).

Today, it often pursues disconnected efforts within or across agencies, while missing opportunities to leverage economies of scale, according to a MITRE survey of existing literature (DoD, 2023b; U.S. Department of State, 2024; U.S. Intelligence Community 2024). This results in multiple contracts for the same P/CAI source, sometimes within the same agency, and increases costs due to duplicative development efforts to integrate and analyze the information. A recent study completed by the RAND Corporation for U.S. Army Cyber Command revealed that the lack of enterprise-level acquisition efficiencies presents a challenge in acquiring P/CAI and creates barriers to collaboration with industry, as well as uneven development across organizations (Marcelino, 2024). In addition, the study found that multiple organizations across echelons do not know whether each of their data needs is already being met in other parts of the U.S. Army (Marcelino, 2024). This highlights the need to standardize a coherent acquisition and access approach that leverages economies of scale and brings transparency to P/CAI portfolios for interoperable use.

The Department of Defense (DoD) acknowledges these concerns, which are discussed in DoD Directive 3115.18 *DoD Access to and Use of PAI*. This directive states that the DoD will share capabilities and data across DoD components to reduce duplication and increase integration for lower costs and increased efficiencies (Office of the Under Secretary of Defense for Policy, 2020). The Intelligence Community (IC) also addresses these issues in the *2024–2026 Open Source Intelligence Strategy*, which states the need to coordinate the acquisition of open-source data to avoid redundancy and expand data sharing, as appropriate, to enable missions and ensure the most efficient use of IC resources (Intelligence Community, 2024). It also states the need to align and manage open-source collection efforts across the IC to enhance the speed and awareness of collection while avoiding duplication of effort (ODNI, 2024). While agencies like Treasury and the Department of Homeland Security (DHS) do have policy and resources to govern P/CAI, there is currently no overarching policy or directive that promotes sharing of P/CAI acquisitions across the DoD, the IC, and other civilian agencies (ODNI, 2022).

Recent Requests for Information on P/CAI capabilities issued through the USG's procurement portal, the System for Award Management, indicate ongoing investigation into P/CAI solutions and information sharing, but are overshadowed by the extensive challenges USG agencies face in assessing the growing number of data vendors (DoD, 2023b). Many vendors offer similar data as third-party resellers or aggregators, making it impractical to evaluate all options (ODNI, 2024). Once acquired, the sheer volume of data can overwhelm USG end users, especially those reliant on manual analysis, leading to the underutilization of data that is procured. Lastly, the varying authorities and policies among USG agencies further complicate P/CAI sharing. Potential legal risks could occur if raw data and analysis derived from P/CAI sources are integrated with data sets managed by USG agencies with mismatched authorities. This presents a challenge for developing an enterprise solution to streamline, scale, and share P/CAI.

As an operator of Federally Funded Research and Development Centers (FFRDCs), MITRE has worked closely with commercial and USG partners to conduct hands-on experimentation in P/CAI management practices to better understand how industry and USG can work together to overcome the challenges discussed above. The resulting research presented in this paper identifies recommendations for challenges associated with data acquisition, integration, and automation from P/CAI sources.

Value of Publicly and Commercially Available Information

Awareness has grown in recent years of the value of P/CAI, also known as OSINT when used for intelligence purposes, in protecting U.S. national security, to the extent that the IC termed it the "the INT (intelligence source) of first resort" in its most recent strategy (Intelligence

Community, 2024). Similarly, the DoD is applying P/CAI in support of its Information and Communications Technology Supply Chain Risk Management capacity to "defend forward" through analysis of potential subversion opportunities (DoD, 2024). The Assistant Secretary of the Bureau of Intelligence and Research at the Department of State noted that "the explosion of OSINT in recent years has transformed how governments and people around the world consume and process information about society and global issues" (Department of State, 2024). P/CAI is expected to grow in the coming years as commercial technologies generate more open-source data.

A simple pathway to getting started with P/CAI is leveraging what already exists in commercial industry and adapting it for government use. Commercial offerings are booming in the era of big data and constant technical innovation, resulting in a vast range of data capabilities and automation opportunities—all of which may be adaptable to the USG depending on mission applicability and engagement options with commercial partners. If awareness of commercial products and USG-commercial partnerships are centralized and made scalable, data and other tech-forward tools can be harnessed and integrated by adapting commercial-off-the-shelf technologies.

P/CAI, also known as "alternative data" in the private sector, is expanding based on recent enhancements in commercial technologies across product development, marketing, investment, and other fields. Data is captured from sources such as credit card transactions, geolocation, social media, shipping trackers, mobile app usage, and product reviews (Bhuta, 2023). Unlike data that is structured from traditional sources, such as surveys, census data, and government records, alternative, or nontraditional, data consists of new attributes and forms of data that are produced by capturing usage of commercial and consumer technologies. Over the next few years, advancements in storage, capture, and analysis technology are expected to match continued growth in data volume and availability, reflecting the growing number of P/CAI data vendors, which have increased by about 29% in the past few years alone (Wilkinson, 2023). Alternative data has become much more accessible since many companies have started to clean, package, and sell information that is generated at various points in the value chain and make it commercially available to guide investment decisions.

Commercial Adaptation Fuels Federal Efficiency

P/CAI that is commercially sold as alternative data products is broadly available in a constantly changing information environment, typically for a price. Commercial providers take on the work-intensive, high-resource steps of data identification and collection, then create their own products with technical innovations in response to user needs. It is vital to understand what data content, delivery mechanisms, and underlying technical formats are available from each provider. This knowledge will identify opportunities to connect organizations and products to each other for useful applications.

In circumstances where available P/CAI capabilities do not match the government's needs, the USG, FFRDCs, and commercial providers can work together to iterate and refine capabilities for mutual benefit. Existing commercial products offer a useful foundation to tailor to novel government requirements or to create new capabilities—bringing together industry technologists and the timeliest government needs for agile, targeted solutions. Commercial products can be adapted quickly in an environment of creative, forward-leaning innovation, especially in partnership with organizations that are integrated with USG mission sets and can translate actionable requirements.

Collaborative experimentation has been established as a successful method to fulfill persistent capability gaps with incubators that exist within and external to government hosted across academia, government, and industry. For example, In-Q-Tel is a not-for-profit organization that breaks down barriers among startups, venture capital organizations, and the USG for commercial success and national security impact. It does so by identifying opportunities for investment in national security areas of interest, including digital intelligence and autonomous systems, resulting in long-term, high-success partnerships (In-Q-Tel, 2025). USG supports innovation organizations such as the Defense Innovation Unit (DIU), Naval X, and AFWERX, which accelerate technology transfer from industry to government, focused on advanced technologies (AFWERX, 2025). MITRE, operating FFRDCs on behalf of the USG, incorporates useful practices from industry and government to create its own "Bridging Innovation" capability which builds trusted community relationships across both academia and industry, then matches and transitions them to government requirements (MITRE Corporation, 2025).

Current State of Publicly and Commercially Available Information Acquisition Across the Federal Government

To assist USG in understanding the growing P/CAI ecosystem, MITRE profiled 84 P/CAI vendors ranging from raw data providers to data brokers. From Fiscal Year 2021 to 2024, 40 out of those 84 vendors received a total of 879 federal contracts from more than 30 USG agencies. Each contract was under $7.5 million (the threshold for streamlined government acquisition of commercial products and services), for an aggregate amount of about $320 million (Department of Treasury, 2025). Of those contracts, only 18% used an indefinite delivery vehicle (IDV; i.e., an enterprise ordering vehicle to include indefinite delivery indefinite quantity contracts, blanket purchase agreements, basic ordering agreements, and federal supply schedules). The remaining awards were definitive contracts (e.g., purchase orders or standalone contracts) or subcontracts to a prime (Department of Treasury, 2025). In comparison, the USG typically obligates 30% to 40% of its aggregate funds through an IDV (HigherGov Docs, 2025).

The high percentage of definitive contracts or subcontracts awarded to these vendors (82%) represents an opportunity for USG agencies to collaborate on P/CAI requirements with common use cases through IDVs. IDVs enable faster awards and access since the pricing, terms, and conditions are pre-negotiated within the IDV itself and flow down to each award issued under the IDV. Cost savings can be achieved through volume-based pricing by aggregating requirements from USG agencies that utilize the IDV, leveraging economies of scale. Lastly, IDVs provide a predictable demand signal to industry by indicating recurring requirements over the span of multiple years, whereas definitive contracts do not, as they are isolated to a single specific requirement.

Total USG Contracts to P/CAI Vendors (FY21–24) ($x \leq$ $7.5 Million) ($n$ = 40 vendors)		
Contract Approach	Number of Awards	Awarded Value
Definitive Contract	599	$217,954,118
Subcontract	136	$40,344,721
Indefinite Delivery Vehicle	144	$59,950,411
Total	879	$318,249,249

Figure 1. Total U.S. Government Contracts to P/CAI Vendors
(U.S. Department of the Treasury, 2025)

Background and Challenges for Enterprise Acquisition, Automation, Analysis, and Compliance

Acquisition Considerations

The hundreds of P/CAI tools and capabilities in the commercial marketplace add further complexity to contracting efforts and potentially escalate acquisition costs due to duplicative purchases of the same products and capabilities (Marcelino, 2024). Establishing an enterprise acquisition strategy that utilizes IDVs for P/CAI would help achieve economies of scale for enterprise data access and sharing. This approach would improve USG purchasing power with industry and advance industry participation with more predictable work and potential long-term engagements that allow for-profit entities the opportunity to make deliberate investments in their capabilities and increase their value to a broad range of potential USG customers.

IDVs can be managed using interagency contracts, where an IDV is established for the purpose of procuring and managing P/CAI with pre-negotiated prices, terms, and conditions. Any USG agencies with P/CAI requirements can then leverage these IDVs to place individual orders for the data type, data access, and engineering support that is needed at the time. Pricing typically depends on the data product/access type (e.g., Application Programming Interface [API], bulk, user interfaces), pre-negotiated terms and conditions of the underlying contract(s), and the scope of how the data is accessed, used, and shared. The approved uses for access and shareability in license terms can also impact pricing and the level of active management required for each contract.

A volume-based pricing model that offers a per unit cost for data licenses/access or a token model can be pre-negotiated with a contract minimum, however, overall pricing is dependent on usage. Volume-based models can include price breaks if a certain volume is achieved, or multiple years of support is approved upfront. While enterprise vehicles may be overly expensive for a single agency to attempt, they are made tenable through the combined purchasing power of all of USG as each agency places individual orders for their current needs against it. No matter the pathway that provides USG with a streamlined ability to procure data, the contracting approach must also consider what type of data product(s) would be most generally valuable and usable. For example, some P/CAI vendors may offer access to platforms that include data dashboards and analytics with limited export capabilities, whereas others may provide pay-by-query models aligned to API or bulk access, which would offer a preset volume and simple method to track costs per user.

While there are several IDV contracting approaches that can be leveraged by various agencies across the USG, the following are well suited for acquiring P/CAI from data vendors as they provide pre-established, streamlined processes for requirements with a consistent demand signal for USG agencies and industry and build awareness of commercial capabilities upfront.

1. Governmentwide Acquisition Contracts (Multi-Award)

   GWACs are suitable for USG agencies with information technology (IT) requirements looking to leverage expertise and resources from prime contractors and lead integrators (i.e., companies that scout the data ecosystem and match vendors to requirements) to research, identify, acquire, and manage P/CAI solutions, including raw data, data management solutions, and commercially driven analysis from multiple vendors. This type of contract is valuable for USG agencies that have limited experience with P/CAI or limited resources to directly engage with and procure from data vendors and can include room for adaptation in the established work scope to “learn as you go.” It enables a more hands-off approach by leveraging prime contractors that have specialization in the P/CAI marketplace and can evaluate commercial products on behalf of government and report back with their findings. When a USG agency has a particular P/CAI requirement, an order can be awarded off this IDV to a prime contractor or lead integrator that has expertise in implementing and managing such a requirement. The prime contractor or lead integrator would be responsible for the general oversight of the P/CAI vendors as subcontractors to them by awarding subcontracts (or sub-awards) (HigherGov Docs, 2025). This is not limited to just P/CAI but can also be used to procure supporting capabilities such as entity resolution and automation solutions, which are described later in this paper.

2. Blanket Purchase Agreements

   This is suitable for USG agencies that have readily available resources and existing expertise with P/CAI. Blanket Purchase Agreements (BPAs) are used to fill anticipated repetitive needs for supplies or services from a published, pre-negotiated pricing catalog provided by the vendors on this IDV (Federal Acquisition Regulation, 2025). This IDV is most appropriate for vendors selling data that is needed by the USG on a continuous and persistent basis. Each order issued under a BPA must be under the simplified acquisition threshold (SAT), which makes this IDV very effective for making rapid awards and mass purchases down to the license, access, or query level (Defense Acquisition University, 2025). Vendors can join a BPA vehicle at any time by offering an overview of their capabilities to its Contracting Officer, who would then evaluate and approve them for inclusion. Because P/CAI is commercial in nature, the SAT would be $7.5 million per order, which increases to $15 million under specific circumstances (Federal Acquisition Regulation, 2025). As this type of IDV allows P/CAI vendors to sell directly to the USG, this enables USG agencies to contract with vendors directly and manage their own usage. With this IDV requiring a more hands-on approach, the USG agency would be responsible for the oversight of vendors as prime contractors and suppliers.

3. Basic Ordering Agreements

   Like BPAs, a substantial number of requirements can be procured under Basic Ordering Agreements (BOAs). BOAs can expedite contracting actions even when services requirements, quantities, and price are unknown at the time, making it a flexible option in uncertain environments. Despite that uncertainty, BOAs provide pricing methodologies that create structure for products and services and reduce procurement lead time. Unlike BPAs, which are more suited to repeatable and tangible items, BOAs are suitable for directly procuring data management capabilities in which pricing would be dependent on the scope of the data to be processed and managed. Though a similar function can be done with a GWAC as previously noted, BOAs would be optimal for USG agencies who are their own lead systems integrator (as opposed to outsourcing it to a contractor through a GWAC or an independent contract; Defense Acquisition University, 2016). Any vendor can join a BOA vehicle at any time.

4. Other Transactions (Consortium)

   This is suitable for USG agencies that need to experiment with new data and test new use cases with industry partners. Other Transactions (OT) do not have barriers associated with federal contracting because they are not subject to Federal Acquisition Regulations and can attract additional companies with innovative capabilities that typically do not do business with the USG. This is applicable to the P/CAI space since many of these vendors work in financial and consumer goods industries with limited exposure to the USG.

In this context, OTs can be used to set up a consortium, which is a community of expertise centered on a certain technology or problem that the government can collaborate with industry to solve through ongoing adaptation (MITRE, 2025). Each consortium is managed by a consortium manager (CM) and can include dozens to hundreds of members (i.e., companies that have offerings deemed of potential value to the USG). The CM researches, identifies, evaluates, and negotiates suitable P/CAI or supporting data management tools from consortium members that can support emerging USG requirements with innovative use cases from readily available or adaptable commercial capabilities. The CM would be responsible for general oversight and ensuring that the vendors meet the requirements, but the USG would be responsible for execution and implementation. However, not every USG agency has OT authorities (MITRE, 2025). Agencies that do not have OT authorities can alternatively leverage an approach that the General Services Administration (GSA) piloted with Commercial Solutions Openings (CSOs) to produce a streamlined acquisition process like that of an OT (GSA, 2020).

Data Access and Products

Many vendors offer access through either APIs or bulk transfer. (For the purposes of this paper, data access via user interface is considered manual analysis and not discussed in this section.) APIs are products offered by commercial vendors for data delivery that provide users with the capability to submit queries in line with their authorities, undergo review regardless of origin, and receive only the results that apply to their specific mission needs. APIs create opportunities for rapid scalability at an enterprise level, continuous integration and delivery, and increased economies of scale (Department of Defense, 2023b). Conversely, bulk data is typically the same raw data that is provided through APIs but delivered as a file on a periodic basis (usually ranging from weekly to quarterly), often offering a larger scope of information in exchange for the storage and processing costs inherent in maintaining such large files. APIs require intentional data collection, which may result in lag times and require additional processing for integration. Receiving a file via bulk data delivery allows for pre-processing (or batch processing) of raw data as opposed to having to process the data on demand.

There are tradeoffs in benefits between these two common delivery mechanisms, with the optimal usage depending on the needs and capabilities of the user. APIs can offer instant access to the full catalog of data available from a provider, with the potential for real-time updates, though users need to know what to look for and collect—requiring more time upfront to curate queries. Bulk data offers access to all data immediately, but as a static file that is updated on a periodic basis when a new file is shared. The ability to pre-process bulk data and host it within system infrastructure, as opposed to the data residing in the vendor's infrastructure, may be a key consideration. However, uploading bulk data sets, which can be as large as several terabytes, may require significant time, processing, and storage resources. Also, if the vendor changes its bulk data format, users must adjust integration methods and storage structure to accommodate the update. Both methods offer access to the same underlying data streams and may not always be offered by every vendor, especially in cases where the data is niche. The optimal collection option for each organization depends on the data management approach, balancing data processing time and requirements for data currency and ease of integration.

Data Conditioning, Integration, and Analysis Considerations

When leveraging a multitude of data sources from P/CAI vendors for analytic insights, it is vital to apply advanced technology to integrate and combine data sources. The value of using P/CAI is limited to a system's ability to ingest vast amounts of data (Černiauskas, 2023). Ideally, the data portfolio at an organization's disposal will be vast, containing several types of data across domains that provide a robust view of a given area of interest. This amount of data can easily become overwhelming without automation solutions, many of which exist across industry and offer immediate efficiencies. A wide range of alternatives offer government spaces and missions the choice of the most bespoke and innovative offerings.

Working across big data becomes manageable by applying automation tools to repeatable tasks that permit subject matter experts to review data across a large portfolio as outputs of automated analytics (WBR Insights & Northern Trust, 2021). With automation, the analysis of a few dozen entities can be optimized to take only days (if not hours), whereas conducting the same analysis manually on the same amount of entities would typically take months, a potentially disastrous amount of time when working in national security, aviation, or healthcare. However, regardless of the availability of enabling commercial offerings, a deep understanding of USG-centric use cases, their system requirements, and underlying workflows in constrained environments must be accounted for in the automation equation for collaboration to be a success.

Once data is made available through the appropriate contracting approach, it must be integrated or connected across the universe of disparate data schemas prior to automation. Both private sector companies and public sector agencies struggle with combining data from differentiated sources and processing raw data from P/CAI vendors into usable formats. For example, one common challenge is entity resolution due to the same piece of information being labeled or stored differently across vendors and data sets. This limits the ability to search across all offerings to find matches without some kind of relationship mapping or integration. Though this may seem simple to address through manual keyword lookups, it becomes impractical when analyzing hundreds, if not thousands, of data attributes at scale. This is further magnified due to the ever-evolving ecosystem of P/CAI that can result, for example, in an entity of interest having changing attributes due to mergers, the creation of subsidiaries, or changes in ownership (Ekster, 2021).

Even after data is integrated, organizations still face technical challenges in the automation of analysis. It is just as, if not more, difficult to codify repeatable steps in analytic workflows that can be automated through a detailed and structured plan (Wilkinson, 2023). Analysts must be able to quantify the “art” of analysis—identifying the patterns, opportunities, and vulnerabilities that have real impact and making them understandable to others to ensure maximum P/CAI value. Commercial partners with technical and automation expertise that can help connect information and identify potentially useful nodes need to be able to communicate with end users and understand requirements—which is especially difficult in classified environments. The IC recognizes the challenge of transforming raw data at scale from a growing volume of available data to produce meaningful analytics and intelligence (ODNI, 2024). It is vital to leverage technology to move beyond data integration into data understanding, visualization, and delivery, at the speed of other nations that are already harnessing the use of AI and ML to limit manual analysis using advanced technologies.

Compliance/Authorities Considerations

Another factor that limits the scalability of P/CAI is that its availability and breadth necessitate strong consideration of privacy and civil liberties frameworks. P/CAI can reveal sensitive and damaging details about individuals, and, without proper controls, it can be misused to cause harm, embarrass, or otherwise inconvenience a U.S. person. Mirroring the growing utilization of P/CAI across government, there is a growing need to refine the policies to governing P/CAI use to ensure American values are maintained. P/CAI concerning U.S. persons (USP) are subject to a set of overlapping federal regulations that provide concurrent, but inconsistent, standards to govern the handling and use of such data (Ford, 2022).

Existing legal frameworks and policies are in place to guide this issue, such as Executive Order (EO) 12333 and the Privacy Act of 1974. Furthermore, individual agencies and communities have their own regulatory frameworks that govern P/CAI, such as the Intelligence Community Policy Framework for Commercially Available Information (ICPM 504-01; Director of National Intelligence, 2025). It is these differentiating frameworks that make it difficult to share P/CAI analysis across USG agencies, let alone among the IC elements. For example, IC guidelines discuss using least intrusive means for collection techniques, which is typically inclusive of P/CAI. However, the DoD's manual that governs intelligence activities (DoD Manual 5240.01) goes further to include collecting no more information than is reasonably necessary, which would apply to P/CAI if it includes U.S. persons' information (USPI) and would then limit the IC's preference of using P/CAI over other sources of information. The rules of volume, proportionality, and sensitivity (VPS) of USPI vary across IC elements. Though some IC elements have established, or are in the process of developing, more detailed VPS guidance, the IC may want to clarify its preference for collection using the least intrusive means to explain data usage rules of openly accessible P/CAI data across different environments (ODNI, 2022).

These differing frameworks increase the complexity of how USG agencies can share P/CAI among themselves, making it difficult to achieve an interagency response where interagency coordination and information sharing is critical. Such policies revolving around the use of P/CAI sources are inefficient, costly, and inadequate for the scope of today's national security challenges. Having more uniform standards for cross-jurisdictional data access, analysis, and dissemination in support of USG objectives would help facilitate mission success. This can be achieved with a data management plan that is supported through an agency-specific approach to data access that collects only the information that aligns to each agency's authorities and needs. None of these frameworks entirely preclude aggregating P/CAI and analyzing it with sophisticated techniques in support of mission objectives. They also do not prevent more subtle and less intrusive methods whereby data is not acquired or stored in bulk by U.S. officials at all, but rather is obtained via preset API queries that only gather the information that is relevant to USG mission requirements, while avoiding access to or storage of unnecessary sensitive information. An agency-specific approach would enable adherence to robust protections for USP and other sensitive classes, while maintaining the ability to access the dynamic, openly available data that is freely used by non-USG agencies, including threat actors.

Recommendations for Enterprise Acquisition, Automation, Analysis, and Compliance

An enterprise acquisition strategy enables a coordinated approach for contracting, data integration and analysis, and authorities alignment to acquire P/CAI. This strategy would assist agencies in identifying the optimal contracting approach for their situation and offer a combined approach across organizations for those identified as having aligned authorities and data needs that can benefit from shared license terms.

An Adaptable Contracting Approach for Agile Data Requirements

As previously mentioned, there are clear advantages to an IDV, or shared contracting vehicle, that can be used by multiple USG agencies with pre-negotiated terms and conditions for P/CAI access and supporting capabilities. Implementing such vehicles reduces the burden of each USG agency needing to set up and negotiate its own contracts to acquire P/CAI, allowing agencies to focus on scoping the data type, access, and level of support needed to meet their current P/CAI requirements.

Each of the previously mentioned contracting approaches has advantages and should be leveraged in different circumstances based on the requirements of the user(s) and to provide maximum flexibility for rapid acquisition and cost savings. This approach is called modular contracting, which is a technique that leverages multiple contracts (typically IDVs) to develop a capability (Federal Acquisition Regulation, 2025). Rather than establishing a single monolithic contract, there could be a centralized acquisition organization with authorities to execute different IDVs that would maintain a portfolio of contracts and enable the ability to scale and evolve a robust data portfolio over time (Defense Acquisition University, 2025). This would provide flexibility to different USG agencies that may have varied P/CAI requirements at any given time, ranging from simply needing to procure API access from a specific P/CAI vendor to needing a turnkey solution that can access many data sources from an integrated solution and quickly search across an entire network of information.

There are examples of USG organizations using a modular contracting approach, with opportunities for increased adoption across the USG. The U.S. Army Digital Capabilities Contracting Center of Excellence is one recent example of an agency that has adopted modular contracting to achieve speed and flexibility with software development (Miller, 2024). DIU also employs a modular approach to provide flexibility with bringing in different vendors to work together to on prototyping efforts (Lopez, 2022). In 2024, the Government Accountability Office (GAO) surveyed programs that used modern software development approaches for their Weapon Systems Annual Assessment and found that 20% of them used modular contracting (GAO, 2024). As an example of specific applications, commercial data management solutions can be acquired through a GWAC or BOA depending on the USG agency’s acquisition strategy, enabling the integration of dozens of government-acquired P/CAI data sources. Conversely, a USG agency may already have an established process to acquire and manage P/CAI but encounter novel data types or have a new requirement the agency must respond to quickly. In this case, an OT consortium could be utilized to experiment with new P/CAI and/or test new data management capabilities by leveraging the collective expertise of the consortium members. On successful completion, the USG agency can apply the lessons learned to its traditional contracting vehicles for implementation and execution. DIU has taken this approach by partnering with GSA to on-ramp solutions to established contracting vehicles (Tuxhorn, 2023).

With an enterprise strategy applied to P/CAI contracting efforts, the examples above could enable the scaling of P/CAI across the USG based on need, with agencies employing the best possible contracting vehicle appropriate for a given scenario. Most agencies can leverage either a central office or their own internal office to deploy this contracting approach, provided there are resources and expertise in agile acquisitions available to them. Organizations like the U.S. Army and DIU would still employ their acquisition strategies but would have the option of using volume-based pricing through a centralized IDV when needed.

Shared Services and Commercial Partnership for Technology Applications of P/CAI

A coordinated approach across the enterprise would also help address the difficult technical challenges of disparate P/CAI data schemas and entity resolution. A model of enterprise data handling and applications presents the potential to save resources by staffing a centralized authority with data engineers that can coordinate and manage data processing and integration solutions as a shared resource for users accessing enterprise data. The team of centralized engineers would benefit from partnership with commercial industry and adaptation of existing solutions that are tested and readily available. These could include capabilities to deploy on sensitive government systems in real-time, handle complex data integration of multiple sources across open architecture frameworks, and harness capabilities for anonymization of sensitive information prior to local storage using homomorphic encryption technologies (IBM, 2023).

While there are benefits that should be considered for centralized data conditioning and integration, there are also advantages of a locally supported data engineering and automation approach, whereby agency-specific end users of data process, integrate, and develop automation within their offices or organizations reflecting their missions. A local approach mitigates the potential of overtaxing existing resources with requirements to store and process all information for all agencies. These tasks can be done at the agency level, with the agency pulling only data that is timely and relevant to mission sets that can be further prioritized at the user level. Additionally, IT system requirements vary across different agencies, making it challenging to have a centralized capability that can support multiple agencies (GAO, 2025). A local approach allows each agency to develop the necessary underlying infrastructure in accordance with the agency's IT requirements while maintaining an open standards architecture to facilitate use, access, sharing, and interoperability across the USG. It also empowers data product owners at the agency level, allowing them to manage their users' data requirements specific to their unique missions. This includes data collection, application development, and custom query creation that is relevant to mission-specific uses. However, as previously described, there are challenges when it comes to processing and integrating P/CAI that all agencies will encounter, regardless of varying IT requirements and unique mission needs. Even if an agency is pursuing local solutions, there are still opportunities for it to take advantage of centralized lessons learned and shared resources, including code repositories, proven ontologies and data dictionaries, and insights on key commercial partners that can assist at all levels.

Shared services and resources, such as centralized knowledge management repositories, would encourage the sharing of algorithms and ontologies among USG agencies using the same data for similar purposes. Shared services would be particularly useful when tackling recurring technical challenges such as data standardization across USG agencies and integrating multiple data sources. Standardization not only enables effective knowledge management and interoperability across USG agencies but also increases their ability to leverage and combine multiple data sources for more streamlined integration and deeper analysis and maximizes the value of P/CAI (Tingley, 2020). Standardization is required for data conditioning since it enables broader discovery, utility, security, and efficacy of data across systems, with existing efforts lacking the scalability to the full USG. The 2019 Federal Data Strategy attempts to achieve data standards within relevant communities of interest across USG through a number of action plans, but requires additional support to continue development (Congressional Research Service, 2024). Digital.gov offers a variety of communities of practice that allow for collaboration and sharing of resources across USG entities who are focused on developing digital experiences, but is voluntary in adoption of its practices (Digital.gov, 2025).

Entity resolution is another technical challenge that can be addressed through shared, commercial services to enable leveraging of multiple data sets by identifying relationships and creating combined solutions. There are commercial companies that have developed entity resolution capabilities which can continuously ingest, normalize, and integrate new data sources with existing data catalogs or provide entity matching analysis across data sources (Bailey, 2024). Centrally sharing knowledge of readily available capabilities, whether they be USG or commercially developed, can pave the way to address common technical challenges and provide immediate value to improving P/CAI analysis. Optimally, centralized shared services for federal P/CAI would offer a catalog or repository of USG and commercial capabilities to maximize the use of P/CAI, including points of contact and real exemplars of success stories that can be adapted across the USG.

In addition to shared services, USG agencies could opt to share findings about their usage of centralized platforms in a common knowledge base. Rather than simply sharing code, organizations could opt to develop system-to-system query capabilities, potentially via APIs. This is a model currently employed by some organizations to avoid duplication in the information being gathered, as many suppliers are of common interest across the USG. Such an approach would avoid recurring costs to a shared contract vehicle collecting the same data for differing missions. Ideally, data collection systems will be created to communicate with one another, which requires deliberate development to facilitate information transfer.

Resourcing is another consideration that will impact data engineering and automation at any level. In environments where resourcing at the agency level is constrained and specialized technical talent is highly competitive, it may be beneficial to leverage existing commercial capabilities for data processing, storage, entity resolution, and other complex technical facets. Though leveraging readily available applications and capabilities would require upfront costs, (e.g., for software licensing and potential integration development with government systems), such immediate investment to jumpstart capabilities would establish long-term value through the increased efficiency of automation. Using readily available capabilities would avoid the cost of custom, potentially duplicative solutions across the USG while freeing up resources that can be prioritized elsewhere. The technical skillsets needed for immediate application or adaptation would also be readily available through an external partner, though only technical teams that are willing to adapt to stricter government non-disclosure requirements should be considered, and transition time to build understanding of USG requirements would still be necessary.

Close partnership between industry and government is also a necessity when automating analysis solutions using commercial tools. Government users understand the mission sets, workflows, and applications required and would need to learn how to translate that to commercial technologists. There are architecture framework vendors who have already partnered and are familiar with government system requirements and offer readily available functionality to onboard different data sources. USG agencies may also require transition time to understand commercial company structures and mindsets, what they do and do not need to know to be useful, as well as agile methodology milestones that help end users both meet requirements and provide feedback throughout development sprints.

Overall, a centralized, shared service created in partnership with commercial industry can standardize P/CAI sources and applications and provide a knowledge management system to potentially reduce development efforts across various agencies. This would accelerate data accessibility, interoperability, and sharing of insights across the USG. Local approaches may still be necessary in minimal, scoped cases depending on IT and mission concerns, but the impacted organizations can still benefit from sharing knowledge and technical resources while they operate with the freedom of application and query development at the end user level. Lastly, similar to how USG agencies have varying IT requirements, they also have varying requirements associated with data compliance and usage authorities, including privacy and civil liberties, which is further discussed in the next section.

Centralizing an Authorities Library for Compliance

A central library of taggable authorities that data users can implement into their local systems in accordance with their agency's governing framework would be pivotal in a model of sharing P/CAI across the USG in support of multiple stakeholders. At the local level, the library would operate by tagging every search across P/CAI sources based on the organization and its underlying authorities for easy compliance checks. Additionally, each agency's system would be assigned authorities based on the agency's governing framework and could be enabled through logical access control systems (National Institute of Standards and Technology, 2020). With this approach, before results from searches are shared, the receiving agency could see the authorities associated with the content and could cross reference them with its own assigned authorities to ensure it can receive and view the data, analysis, or shared technical resources.

Compliance tracking across P/CAI is important because the permissibility of using certain query terms (e.g., U.S. company names) is restricted to those agencies with authorities to search and retrieve those data attributes. Thus, technical controls are necessary for an agency to query and access the intersection of data attributes with U.S. individuals. The centralized library approach would facilitate the following: how, by whom, to what extent, and in what form information from query results can be handled and stored; how and to whom information can be disseminated; and requirements for record-keeping, institutional oversight, and accountability.

Conclusion and Considerations

The value of P/CAI to national security missions and the intention to increase the use of this data has been made clear by directives, policies, and public statements from officials across the IC, the DoD, and civilian agencies. Creating a system of acquisition that scales to meet this demand signal is critical for success, as is the development of systems of systems that can manage cross-cutting data and bring to bear advanced technologies to transform data into actionable information. MITRE's recommendation to institute agile acquisition across the USG through centralized, shared services and a modular contracting approach is designed to meet this need. The recommended operation of a centralized authority that can leverage various contracting approaches (GWAC, BPA, BOA, and OTs) and employ them in parallel on a situation-dependent basis can provide maximum value at the speed of relevance. Localized data processing with centralized shared services is a highly efficient option to enable innovation and tailored solutions at the agency level, while promoting knowledge sharing and reducing duplication across government. System-to-system communication should also be considered by the USG to enable the sharing of critical findings between and across classification levels for government organizations with similar mission objectives.

Key to creating a sustainable system from these recommendations is the need for USG agencies to institute mechanisms that protect them from legal risks related to privacy law and differing authorities. Maintaining a library of current authorities would allow agencies to understand their boundaries when engaging with P/CAI and ensure a robust, speedy process for determining what analysis can be shared and received within its given authority frameworks.

Effectively implementing these recommendations may include consideration of a centralized authority buoyed by interagency working groups and agreements that enable collaboration. In addition, the workforce available to execute the centralized model would benefit from analysis on impact and opportunities for targeted skillset growth.

Managing Agency for Centralized P/CAI Use

Several organizations already provide centralized contracting, including the GSA Office of Information Technology Category, National Institutes of Health Information Technology Acquisition and Assessment Center, National Aeronautics and Space Administration Solutions for Enterprise-Wide Procurement, and DoD Chief Digital and Artificial Intelligence Office's Tradewinds. Additionally, the Department of the Air Force recently established the Advanced Data Consortium, an OT consortium specifically for the procurement and implementation of P/CAI. One or more of these organizations could be tapped to provide broader support to P/CAI acquisition and coordination at scale and/or contribute to the centralization of acquisition, with workforce augmentation based on the recommendations below. Any organization taking ownership over enterprise P/CAI approaches needs to commit to being responsive and accountable to a diverse set of requirements and stakeholders across different title authorities.

Alternatively, a new organization can be assembled with the combined authorities required for modular contracting. It's also necessary to consider that outside of traditional FAR-based IDVs such as GWACs and BPAs, not every agency has the authority to use OTs, however, they can have them bestowed through statute or take advantage of the GSA's approach and use CSOs to procure innovative commercial items in coordination with the centralized authority.

Workforce Expertise

A centralized acquisition authority will need acquisition experts adept in data acquisition through modular contracting, including OT consortiums and collaboration with the private sector. It will also need experienced national security analysts and technical data management experts. Acquisition experts are instrumental in defining scope and identifying the appropriate contracting vehicle for P/CAI requirements based on aligned authorities. Many agencies already have acquisition experts in-house who take on integral tasks, ranging from refining requirements to contracting services (National Institutes of Health, 2021). The GSA utilizes their acquisition experts for scope reviews to ensure requirements are developed correctly and align to the appropriate GSA contract vehicle (GSA, 2025). This acquisition expertise and agility offers USG agencies an example to build on and establish a system to accelerate the adoption of digital and data analytics solutions.

Processing of the varied formats of P/CAI requires technical expertise best suited to data scientists and systems engineers, many of whom are embedded in the commercial sector and accessible through private sector partnerships. While processing and conditioning would optimally take place locally and be supported by commercial expertise, employing some level of technical expertise at the centralized authority would be useful for guiding and maintaining centralized services. Organizations known for excellence in data management and innovative solutions for connecting across networks could provide the necessary technology and expertise to build local solutions and would partner well with government analysts that have hands-on familiarity with agency automation needs and can help to identify opportunities for adaptation. Technical experts are increasingly necessary across industries in a big-data, technology-driven landscape and must have incentives to remain embedded in national security contexts, which could be assisted by USG's willingness to share and adapt to changing environments by leveraging new technologies and centralized approaches.

The centralized acquisition authority may also seize the opportunity to engage Chief Data Officers or other data leaders to help maximize value derived from P/CAI acquisitions by utilizing their awareness of overarching strategies and standards across agencies.

Interagency Collaboration

The recommendations outlined in this paper create an opportunity for USG agencies to partner with one another to increase efficiency, share best practices, and collaborate on many fronts, from technology to policy. There are several mechanisms for interagency collaboration that can be applied, including congressional actions (e.g., specific congressional authority with associated funding), agency directives, and interagency agreements that convene cross-USG agencies with common goals and challenges through a written agreement such as a Memorandum of Understanding (MOU; GAO, 2012). DoD Directive 3115.18 established the foundation for a DoD PAI Advisory Council to improve the effectiveness of P/CAI usage and its integration into wider DoD programs across defense agencies (Office of the Under Secretary of Defense for Policy, 2020). The Intelligence Community Data Co-op is a nascent interagency effort spearheaded by the Office of the Director of National Intelligence with plans to include stakeholders from agencies across IC elements that are seeking civil liberties and privacy best practices to integrate P/CAI data for the entire IC while avoiding duplicative purchases and reducing overall costs (ODNI, 2024). Aside from those community-specific examples, there are interagency collaborative mechanisms that can be utilized based on common goals and objectives, agnostic of community.

EOs or legislative actions could require enactment of the centralized approach and shared services recommended in this paper. In lieu of required action, creating an Interagency Group at the component or program level is an option to kickstart voluntary collaboration. This effort does not necessarily require congressional action or initial funding but rather the time and labor of willing participants, and it can be executed through MOUs (GAO, 2023). This approach would create a forum where participants could identify enabling technologies used by their offices and share code, queries, data standards, automation tools, and analysis with one another. Such a group could also advise the agency managing the P/CAI enterprise contract vehicles to better quantify volume-based acquisition by aggregating demand signals. Lastly, the group would be well-positioned to recommend national-level policy changes aimed at easing restrictions to sharing data and collaborating across authorities and resource types to maximize the use of P/CAI, striking a balance between harnessing the ever-changing data industry and rigorous adherence to existing government privacy and compliance regulations.

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SUMMIT PANEL 5. DRIVING DEFENSE INNOVATION: PARTNERSHIPS, COLLABORATION, & ENTREPRENEURIAL APPROACHES

Thursday, May 8, 2025	
1225 – 1340 PT 1425 – 1540 CT 1525 – 1640 ET	**Chair: Kaitie Penry, Director, Emerging Tech & Innovation, Office of Research & Innovation, Naval Postgraduate School** ***Bridging the "Valley of Death": A DoD/FFRDC Partnership to Accelerate low-TRL, Commercial Space Technology for Military Programs*** Andre Doumitt, Director, Emerging Programs, The Aerospace Corporation ***Collaborating with Universities and Small Business Innovation Research (SBIR) to Address the USMC's Critical Needs*** Lt Col. Gabe E. Mata, 1st Marine Logistics Group ***A Paradigm Shift for how DoD Funds People to Drive Innovation Through Entrepreneurial Science*** Pete Khooshabeh, Regional Lead, Army Research Laboratory

Kaitie Penry—is the inaugural Director of Research Innovation at the Naval Postgraduate School. In this role, she oversees the development of NPS' enterprise innovation process and prototyping portfolio, supporting the Secretary of the Navy's initiative to establish the Naval Innovation Center at NPS.

Penry joined the NPS team in May 2023 from the National Security Innovation Network (NSIN), a program office within the Office of the Under Secretary of Defense for Research & Engineering. At NSIN, Penry was the Bay Area Regional Engagement Principal focused on building relationships with early-stage startups and academia in order to develop novel solutions for national security problem sets. She was also a National Security Fellow at UC Berkeley. Prior to this, she was the NSIN Deputy Education Portfolio Manager focused on design and execution programming.

Penry also worked at Headquarters, Marine Corps for eight years on related strategic areas to include logistics, crowdsourcing/ideation, rapid prototyping, security cooperation, and technology concepts. She earned a master's in foreign policy from American University and a bachelor's degree from the University of California, Davis in International Relations.

Bridging the “Valley of Death”: A DoD/FFRDC Partnership to Accelerate low-TRL, Commercial Space Technology for Military Programs

Andre Doumitt—The Aerospace Corporation

Ben Bycroft—The Aerospace Corporation

Mat Bissonnette—The Aerospace Corporation

Oskari Vakki—The Aerospace Corporation

Ian Stern—The Aerospace Corporation

Tom Heinsheimer—The Aerospace Corporation

Marcus Bracey—AFRL/SpaceWERX

Abstract

The Department of Defense (DoD) has historically been challenged to integrate commercial technology into major acquisition programs, particularly from small businesses and non-traditional defense contractors. Traditional procurement processes, lengthy development timelines, and stringent requirements have often created barriers for innovative companies seeking to contribute to national security efforts. Within the Space Force, these challenges are further amplified by the rapid pace of commercial space advancements, which often outstrip the traditionally slow and complex defense acquisition cycles. As a result, cutting-edge technologies developed by commercial industry remain underutilized, limiting the DoD’s ability to leverage the full potential of the United States (U.S.) innovation ecosystem. To address this gap, a structured and repeatable process is needed to systematically assess, mature, and transition emerging technologies into defense applications. The Technology Readiness Level (TRL) Bootcamp provides a scalable solution designed to accelerate the adoption of commercial space technologies by streamlining technical evaluation and providing mission-driven analysis and targeted testing, thereby increasing the probability that high-potential innovations can be rapidly integrated into operational defense programs.

Introduction

Due to a changing international competitive posture in the space environment, the United States risks losing its position as the preeminent global space power. To maintain that position, it’s imperative that the United States maximizes the total breadth of its innovation and industrial power. Unfortunately, there are numerous obstacles to achieving that vision.

One such challenge is that the U.S. Space Force program managers in charge of major programs such as GPS and MILSATCOM are frequently deluged with commercial tech companies marketing a range of products and services. Due to their breadth and variety, understanding their actual level of technical maturity, and what additional time and resources it will take to achieve program readiness, is often far from clear. Worse, to capture new business, small businesses often represent their technical maturity as higher than it actually is. As a result, such companies are often seen as “risky,” and program managers can be disincentivized from engaging and selecting such companies for Government programs. The results are damaging and include an inability to efficiently leverage innovation from the U.S. industrial base, missed opportunities to leverage commercial investment, a widened opportunity gap for small companies, and reduced international competitiveness for the United States vis-à-vis rival powers.

Research into methods for transitioning non-traditional, commercial space technology into U.S. Space Force programs resulted in the establishment of a pilot project dubbed "TRL Bootcamp," initiated in March 2024 (Air Force Research Laboratory [AFRL], 2024). The TRL Bootcamp, sponsored by SpaceWERX in partnership with The Aerospace Corporation, began as a program to guide promising technologies through the "Valley of Death," the challenging transition phase that small businesses often face between receiving initial funding through Small Business Innovation Research (SBIR) or Small Business Technology Transfer (STTR) contract awards and achieving full product readiness or commercialization. The pilot TRL Bootcamp was designed to support SpaceWERX's (2022) Orbital Prime program, which concentrated on developing technology for in-space servicing, assembly, and manufacturing (ISAM) and dynamic space operations (DSO).

To achieve the desired outcomes, the TRL Bootcamp provides a framework to rapidly accelerate the TRL of selected technologies. The approach calls for an initial rigorous maturity assessment of a given technology within a mission concept of operations (CONOPS). Next, the program provides specific analyses and testing designed to quickly mature the technology on a path to transitioning into a program of record. This is followed by a public/private partnership wherein Government and national lab assets are leveraged to actually perform the recommended testing, after which the technology is given its new maturity rating. The authors postulate that establishing a system that rigorously assesses technical maturity against a target mission CONOPS, paired with providing access to laboratory test equipment at Government and national labs, is an achievable and scalable method for better leveraging the innovation and industrial strength of the U.S. commercial sector and can result in more efficient exploitation of the U.S. industrial base for military effectiveness and international competition.

The Challenge of Transitioning Commercial Space Technology to Military Applications a Changing Military and Economic Competitive Environment

Impact on Military Competitiveness

Today, space is critical to virtually all aspects of our society. From military operations to civilian applications and economic drivers like banking and finance, space is a critical link to the functioning of our civilization. It has also become an Achilles heel. Failure to robustly integrate commercial technology into the space domain creates substantial economic and strategic risk, making our nation vulnerable to competitors and adversaries alike. Threats to space assets are now very real and include direct ascent anti-satellite missiles as well as co-orbital attacks and non-physical attacks such as cyber-attacks, jamming and blinding satellites with lasers. A report from the Center for Strategic and International Studies (2024) notes that *"China's first ASAT launch in 2007, then its geosynchronous ASAT launch in 2013, prove that China is perfecting kill shots."* It goes on to point out that Russia resumed its ASAT testing in 2021 after a decades-long pause, giving the world a highly bellicose demonstration just before invading Ukraine. These examples, including India's successful ASAT test in 2019, prove that the space domain is no longer beyond the reach of war. The international techno-economic environment has also changed from what was a superpower face-off between the United States and the Soviet Union to now 77 countries around the world with space programs, including 16 countries with launch capability (Space Insider, 2023).

Consequently, a robust, whole-of-nation approach that combines commercial and Government space capabilities may be our best approach to addressing an increasingly dangerous space domain and new economic competitors here on Earth. To that point, a report by the National Security Space Association (2022) strongly urges that immediate attention be given to "*more effectively leveraging the commercial space sector's investments, technology, know-how, goods, and services to enhance defense and intelligence space activities.*" Other authors emphasize the same point, including U.S. Space Command (2024), which notes, "*Commercial capabilities and services support Government, civil, and commercial space architectures in peacetime and potentially provide additional capacity to meet military requirements in crisis and conflict.*" Finally, the RAND Corporation (2023a) points out that "*Commercial space services can provide additional capacity and resilience to existing space capabilities or provide new ones.*" The report goes on to cite potentially impactful commercial contributions to space-based Positioning, Navigation, and Timing (PNT) signal strength and accuracy, SATCOM throughput latency, coverage and jam resistance, and how a variety of services from multiple commercial providers brings resiliency through dissimilar vulnerabilities.

The Commercial Funding Hockey Stick

Research by Bryce Space indicates that in the 10 years from 2000–2009 there was $2 billion of private capital invested into space technology, for an average of $200 million/year (Bryce Tech, 2019, p. 14). By contrast, for the period 2009 through 2024, research from Space Capital (2024) shows equity investment reached a cumulative $338.7 billion, or $2.1 billion/year, a 1,000% average annual increase over the previous period (p. 19). This is tremendous growth and precisely the investment the Government would like to leverage for its space programs.

Startup Mortality & the "*Valley of De-Orbits*"

Startups are exciting, but they experience high mortality as they struggle to bridge the gap between product development and market traction. Despite dramatic private sector investment in space technology, research by the Bureau of Labor Statistics (BLS, n.d.) indicates nearly half of all startups fail by year five. There are many reasons for this, which go beyond the scope of this paper, but research indicates that lack of product-market fit (see Figure 1) may be the single largest factor in startup failure, at 34% in one study (Failory, n.d.). For space startups, who need to capture both Government and commercial contracts for survival, the failure rates are likely higher, but aren't tracked separately by the BLS. The Government space sector presents significant barriers to entry. These include long, complex procurement processes; funding gaps between R&D and full scale deployment; lack of clear transition pathways; high cost of Government-specific compliance and security requirements; challenges competing against large, established prime contractors; and critical risk aversion in DoD acquisition (GAO, 2022; Congressional Research Service, 2023). Any single factor, and certainly all of them together, present significant entry barriers to DoD programs for small companies. The barriers can create a kind of "Valley of De-orbits" that limits how much commercial technology investment can be transitioned into Government space programs, and by extension, the extent to which the United States can leverage its full industrial base for military and commercial competitiveness on the world stage.

This paper focuses primarily on one particular entry barrier to the DoD acquisition: risk aversion. This approach will break down aspects of risk aversion and propose a path forward. Ultimately, the goal is to accelerate the transition of small business space technology into Government programs.

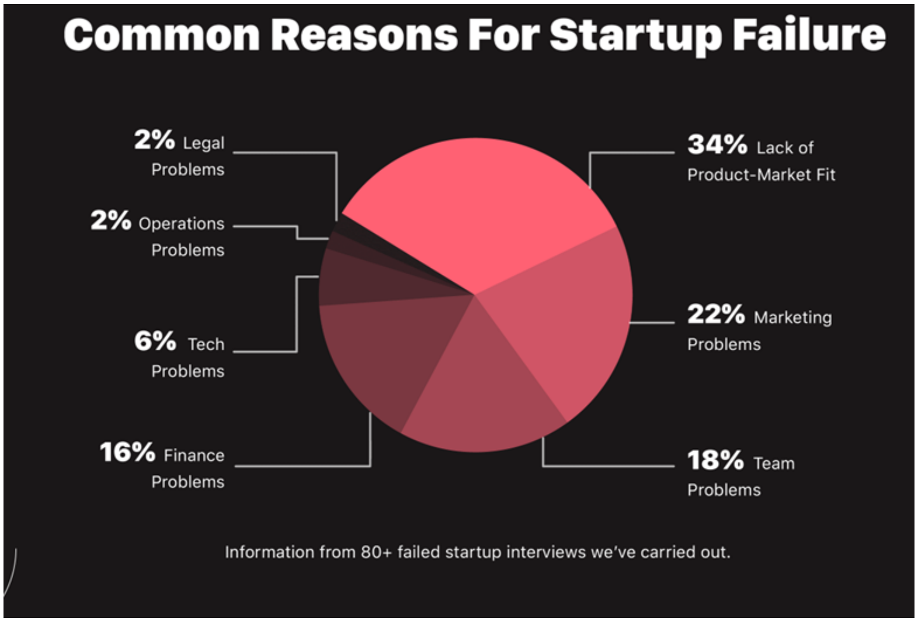

Figure 1. Common Reasons for Startup Failure

Risk Aversion in DoD Acquisition - Technical & Business

In its 2024 report entitled *Aligning Incentives to Drive Faster Tech Adoption*, the Defense Innovation Board writes "*the Department of Defense … has a systemic aversion to risk and a lack of urgency that has led to a culture of sustaining the status quo. This environment is characterized by a preference for familiar solutions and partnerships, often at the expense of exploring potentially superior, albeit riskier, new technologies*" (p. 10). The core of this is simple: people do what works. This means working with large defense contractors who have largely proven their ability to deliver on large, complex government programs. The incentive structure for government program managers strongly reinforces this, since pay and promotions are built around delivering large programs on cost and schedule. In this context, ideas like "innovation," "startups," and "emerging technology" sound like a *threat* to cost and schedule.

Risk aversion can comprise aversion to both technical and business risk. For technical risk, program managers worry—consciously or unconsciously—about three kinds of technical risk: the maturity of the technology being proposed (is it baked, and will it work as advertised), will it successfully integrate into my technical environment (will it work for *me*), and will it scale (will it work *across* my programs and networks). That said, if the technical maturity is deemed to be too low or simply isn't clear, integration and scaling won't be considered.

The second risk is business: If a program manager is comfortable with the technical risks, the idea that a startup has at least a 50% chance of being out of business after 5 years can be an obstacle. Program managers focus on cost and schedule, and large, established brands don't bring the existential risk common to small businesses. Big companies have established supply chains, existing regulatory compliance, proposal teams, a history of delivering, and are not likely to suddenly go out of business. Given their size and integration into the defense ecosystem, large defense primes likely have numerous personal relationships with the government customer as well, further cozying the dynamic.

This is the context facing many government program managers, many of whom are excited by the wave of innovation washing over the space industry but struggle to reconcile that with the systems and incentives governing their programs and careers. In this environment, another obstacle is simply "data overload," where program managers are overwhelmed by a flood of commercial companies, all clamoring for attention and loudly attesting that their solution is the perfect fit for whatever program is on offer, but nearly universally lacking business and technical validation. This entire issue, including technical and business risk, is neatly encapsulated in the phrase "*Nobody ever got fired for buying from IBM,*" which you will occasionally still hear and is at the root of the risk aversion preventing the full exploitation of commercial innovation.

Limited Opportunities to Demonstrate Operational Capability

There's an old adage in the space community that says "*you can't fly in space until you've flown in space.*" This tongue-in-cheek point means that space systems only gain full confidence after they've attained space heritage. At the same time, there's a recognition that there are insufficient opportunities for emerging technologies to perform demonstrations, testing and integration to access space, especially when it comes to working with DoD systems and architectures. This is essentially a barrier to entry, as most government programs have extensive testing and certification requirements before integration is permitted onto the system,[1] and small businesses are unlikely to be able to self-fund the flight test and certification costs.

Thus, despite the recent proliferation of various Government "innovation" programs designed to nurture innovation, testing and demonstration options remain few. As noted in a recent RAND publication, "*Most Defense Innovation Organizations do not have the funding required to sponsor larger-scale live-fire exercises themselves; they can, however, advocate to include specific technologies or products in a live exercise run by an operational component*" (The RAND Corporation, 2023, p. 51). We are starting to see exactly this emerge, with the recent addition of several SpaceWERX portfolio companies participating in the INDOPACOM Northern Edge exercise focused on demonstrating alternative PNT. In this context, below we will discuss our emphasis on Concept of Operations (CONOPS) in the context of TRL assessment, and touch on some emerging approaches to emulating mission environments that begin to address the lack of demonstrations, testing and integration opportunities on DoD systems.

ITRL Bootcamp: A Systematic Approach to Accelerating Technology Transition

In the prior section, we discussed three kinds of technical risk, maturity, integration and scaling, which limit acquisition of innovative technology. In practice, we don't really consider integration and scaling if there is no confidence in *current* technical maturity or its ability to grow on a predictable timeline. This is the core priority we address with the program called "TRL Bootcamp." This program was designed to help bridge the 'valley of death' by providing a structured, mission-driven framework for technology maturation and transition. The TRL Bootcamp process will be introduced below, followed by an overview of the program as executed to date.

The TRL Bootcamp Process

Step 1: Onboarding Technology Readiness Assessment

A core tenet of TRL Bootcamp is to evaluate and support the acceleration of a technology's readiness in the context of CONOPS relevant to USSF mission needs. Approaching the evaluation of these technologies in this way helps identify mismatches between the development path for a company and the intended mission needs driving requests for proposals and development in time to adjust and refine. Independent evaluation of TRL is performed following the NASA (n.d.) *Technology Readiness Assessment Best Practices Guide*,

[1] As an example, Space Force Instruction 13-604 providing *Guidance and Procedures on System Acceptance Throughout the Space Force* (U.S. Space Force, 2023)

which goes far beyond the high level TRL bullet points or 'thermometer graphic' which most new entrants to space technologies encounter when prompted to self-assess TRL. These best practices detail the fidelity to which core technology elements have been demonstrated, analyzed, and/or tested as well as the degree to which system integration, mission requirements, and environments are understood and verified in order to meet each TRL level. An independent evaluation performed by trained assessors avoids the challenges of self-reported TRL by ensuring adherence to the detailed guidance for TRL definitions rather than flexible interpretation of high level TRL summaries. This problem was highlighted when studying the technologies being developed under the Orbital Prime program where 40% of TRL self-assessments were at least two or more levels higher than when evaluated by an independent, trained assessor. This process also ensures that the CONOPS tied to the TRL is a match for USSF mission needs and is at a level of maturity matching the technology's development which ranges from a generic class of missions at early TRLs up to a specific mission at higher TRLs.

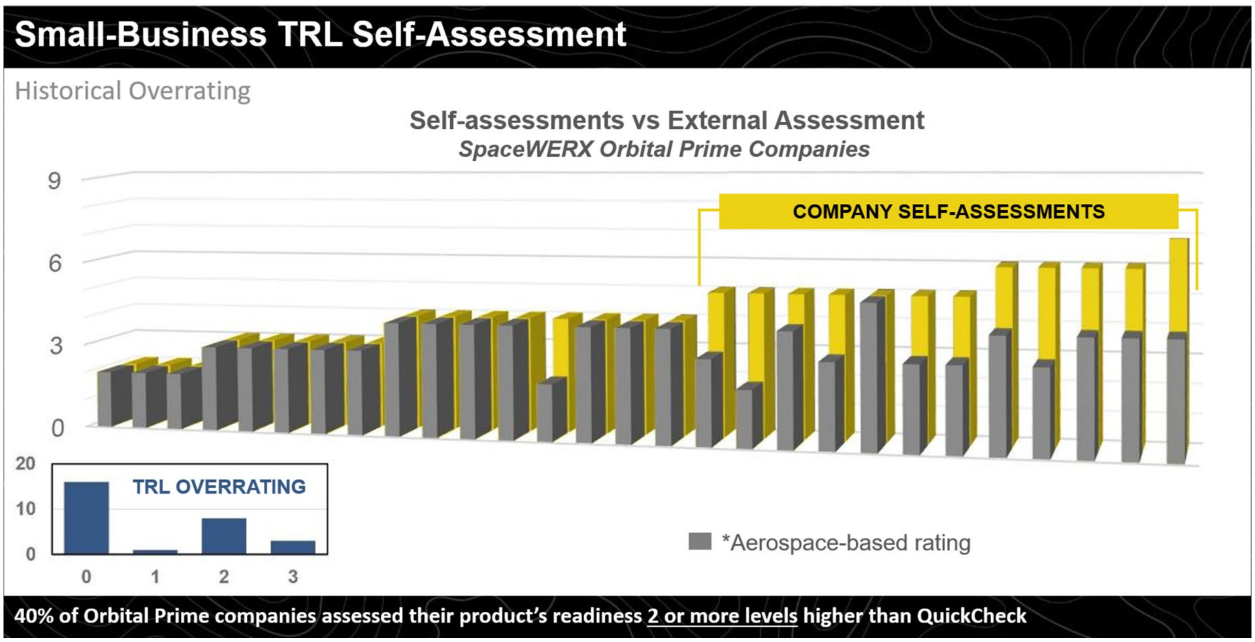

Figure 2. Small Business TRL Self-Assessment

The primary goal for this TRL assessment is to identify the gaps in CONOPS maturity, performance or function demonstrations, and fidelity of analysis or a test preventing a technology from reaching the next TRL. These gaps are used to recommend prioritized efforts to companies in the TRL Bootcamp and to identify complementary support from subject matter experts, modeling and simulation capabilities, and test facilities accessible through the program. The assessment also allows early identification of integration challenges and potentially mismatched environment expectations which are common among new entrants to space technologies.

Step 2: Tailored Support Engagement and Recommendations

Companies taking part in TRL Bootcamp span the full breadth of non-traditional defense contractors, ranging from lean teams of deep experts with novel technology to businesses positioning themselves to become a new era of prime integrators and growing a full complement of staff and skill sets. Similarly, these companies may be staffed by engineers who have flown countless technologies in space or teams looking to apply their expertise from other domains and approaching the challenges of transitioning technologies to space for the first time. In this phase of the program, the gaps identified by TRL evaluation are used to form TRL-raising recommendations tailored to the company's staff and facilities. Where gaps exist which require external support, public-private partnerships are coordinated and leveraged to offer paths to analysis, modeling and simulation, and test capabilities which may otherwise be out of reach for a small business or unknown to a non-traditional defense contractor.

The program connects small businesses with Government and national laboratories and attempts to streamline access to critical subject matter expertise, capabilities, and testing facilities. Identifying and, when able, providing this access allows companies to more efficiently use Government contracts to mature their technologies by bolstering their core competencies with support to fill critical gaps to the next TRL. This approach encourages not only a focus on efforts truly necessary to prepare a technology for transition, but provides pathways to reach these goals without extending existing staff beyond their expertise or levying expectations of the breadth of skill sets and facilities of a prime contractor onto a small business. With priority gaps to the next TRL and external support to complement a small business's competencies, the degree of engagement during the subsequent laboratory phase of TRL Bootcamp is tailored to match the needs.

Step 3: TRL Bootcamp Laboratory Phase

Given priority TRL gaps and the recommendations and support identified in the prior steps, engagement during the Laboratory Phase of TRL Bootcamp falls into several categories. For companies with technologies in early formulation or CONOPS refinement phases (TRL 1-3), or conversely who have good coverage of capabilities needed to close gaps, TRL Bootcamp may engage in an advisory "phone a friend" capacity. Companies may request consultation with experts with space domain and/or targeted technical expertise but perform analysis and test using their own resources. In cases of technologies further in development (TRL 3-4) with gaps that fall outside the capabilities of a small business, TRL Bootcamp works to provide support in these areas for analysis, integration with modeling or simulation capabilities, or targeted hardware testing to verify individual parameters of performance, function, or build. For more mature technologies (TRL 4-6), TRL Bootcamp attempts to provide advanced integrated test opportunities by pairing companies with testbeds and proving grounds meant to mimic relevant environments or operational scenarios for a technology. These opportunities are intended to demonstrate not only individual properties of a technology, but its ability to integrate with a system and perform its function in simulated or emulated operational contexts. Technologies preparing for integration with specific missions and flight (TRL 7-9) are more likely to have facilities related to the mission Systems they will integrate with for testing. In these cases, TRL Bootcamp may engage in advisory support to provide recommendations to effectively utilize these test opportunities or aid in analysis and recommendations based on results.

Step 4: Offboarding Technology Readiness Assessment

Upon completion of the TRL Bootcamp, a revised TRL assessment is performed to include progress made by the company and provided by external support as part of the program. This revised TRL assessment is provided to companies not only to identify progress made during the program but to identify the new priority gaps to achieve the next TRL. Companies may then leverage this offboarding assessment to prioritize their future development of their technology, as well as approaching future funding or transition opportunities with an independent evaluation of their TRL.

Preliminary Outcomes From the TRL Bootcamp Pilot

TRL Bootcamp Program Execution

TRL Bootcamp is a program funded by the U.S. Space Force's SpaceWERX program office. In its current format, companies are eligible after having been awarded a SBIR or STTR Phase II contract and been selected by a combination of SpaceWERX and its partner USSF program office for the topic in development. For the initial TRL Bootcamp program, a 9-month pilot was launched in March 2024 with companies from Orbital Prime, a space technology investment program which sought to accelerate transition of technologies for In-Space Servicing, Assembly, and Manufacturing (ISAM) as well as Active Debris Remediation (ADR). Orbital Prime started with 120 Phase I STTR awards and progressed to 50 SBIR/STTR Phase II awards as follow-on efforts. Seven companies from the subsequent Phase II cohort of performers entered the inaugural TRL Bootcamp and brought technologies ranging from individual payload mechanisms meant for ISAM and ADR applications up to entire in-space infrastructure concepts, each with novel elements and a determined team looking to make an impact on USSF's mission needs. As noted in a concurrent Air Force Research Lab press release, "TRL Bootcamp … gives SpaceWERX partners access to Aerospace Corporation's 100,000 square-foot laboratory and subject matter experts. Aerospace Corporation operates the only federally funded research and development center committed exclusively to the space enterprise. This collaboration will allow companies to test and mature their technologies in a state-of-the-art lab" (AFRL, 2024). For the Orbital Prime's TRL Bootcamp, companies were paired with subject matter experts and lab capabilities from The Aerospace Corporation's Collaborative & Autonomous Vehicle Ecosystem (CAVE) lab. This facility and its staff provide capabilities to integrate and assess ISAM and more broadly Autonomy technologies simulated operational scenarios. The laboratory allows for hybrid hardware-, software-, and simulation-in-the-loop testing including testbeds purpose-built for operational scenarios such as autonomous spacecraft docking and servicing. The TRL Bootcamp team is currently engaged with SpaceWERX's Tactically Responsive Space (TacRS) cohort, with a wider range of technologies in the TacRS portfolio TRL Bootcamp is engaging subject matter expertise and laboratory facilities with additional national laboratories including partners from AFRL's Space Vehicles Directorate (AFRL/RV) with facilities tailored to not only the TacRS mission space but specific needs for closing TRL gaps within the cohort.

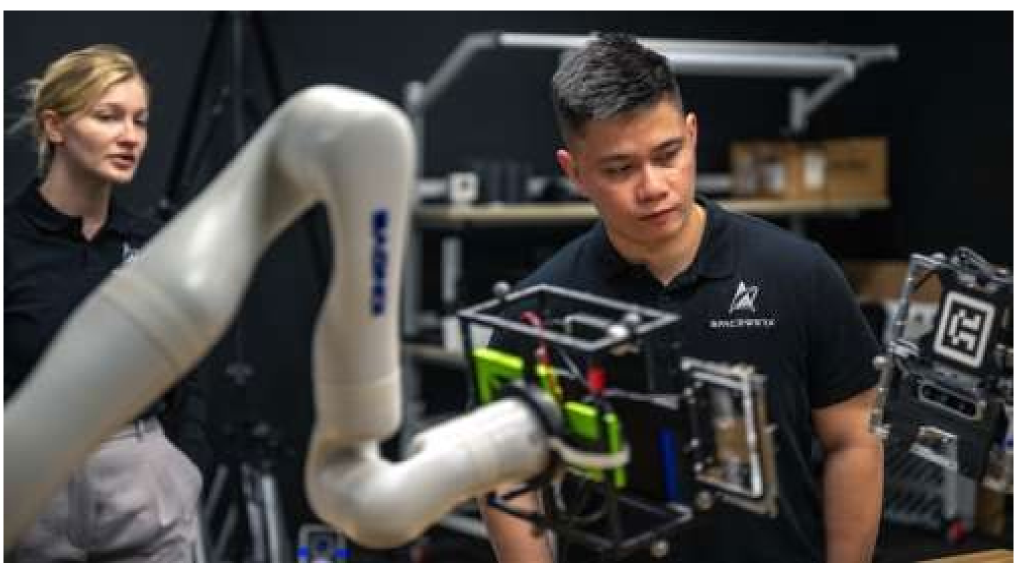

Figure 3. ***SpaceWERX Team at Aerospace Collaborative and Autonomous Vehicles Ecosystem (CAVE) Lab***

Early Indicators of Success

As of this writing, the program has been running less than 1 year, so results are still forthcoming. Nevertheless, early indicators suggest that "the discipline of TRL," including the close relationship to CONOPS, is beginning to have the desired effect. For example, we have seen where greater focus on mission CONOPS impacts company product development, which in turn brings greater alignment between small businesses and mission needs of programs offices within the USSF. The key to that progress is an improved understanding of how a small business's product and capability fits into a larger ecosystem. Also, by making available the precise subject matter experts and specialized test equipment, we believe we've seen faster technology maturation via targeted testing and analysis than otherwise would have been the case had the company been required to independently identify and schedule those services, or certainly acquire and create them internally. We have seen cohort companies form new partnerships and integrations, with the potential for greater levels of systems integration for customers and end-users. We are beginning to implement programs that access classified information to better inform commercial product development, in partnership with other Government labs like the Air Force Research Laboratory. We are starting to see the "brand" of TRL Bootcamp beginning to confer added credibility among the Government program managers we are interacting with when it comes to their perception of companies within a given TRL Bootcamp cohort. Lastly, lower TRL technology companies, technology developers at universities may see a "track" to Government program success and target the program accordingly.

These preliminary results are in the context of what in recent years has been a trend toward TRL becoming a kind of marketing banner, to be waved about, with little to no reference to the foundational nine levels and six factors that make up that scale. Through this program, we are working to spread the gospel of "Disciplined TRL" to partners, government agencies and commercial companies, including training and education on how other organizations can perform their own technical assessments following this framework. As one partner noted in a recent news article, *"BMNT works with the Aerospace Corp. to assess companies and their projects. We look at their technology readiness level ... because many of the companies are still research oriented companies*" (Space News, 2024). In short, greater TRL discipline means Government program managers can more accurately evaluate "time to fielding" of emerging technologies, creating greater adoption of innovation from the U.S. industrial base and more effective and efficient Government space programs.

Conclusion and Future Outlook

The TRL Bootcamp has demonstrated a measurable impact on military innovation, particularly in accelerating the maturation of commercial space technologies for the Space Force. Early results indicate significant improvements in identifying and addressing critical gaps in both technology development and capability alignment. Through rapid TRL assessments, the bootcamp provided companies with a structured roadmap to guide testing and validation efforts. These assessments enabled tailored support, including subject matter expert (SME) guidance, integration and testing assistance, and, in some cases, access to advanced modeling and simulation tools to deepen technical analysis. For small businesses lacking the resources, experience, or access to specialized software, this level of support was instrumental in achieving the necessary technical rigor to advance their technologies toward operational readiness.

In addition to technology maturation, a key success of the TRL Bootcamp was its role in helping participating companies refine their work plans and capability scopes to better align with mission needs. Many small and nontraditional businesses enter the defense sector with innovative solutions but lack a clear understanding of how their technologies fit within the broader military space ecosystem. Through direct engagement with defense subject matter experts and partnering program offices within Space Systems Command, companies gained valuable insights into operational requirements and mission priorities. The bootcamp provided detailed guidance on typical CONOPS that should be utilized to shape their technology development and transition strategies. This structured approach enabled companies to better position their solutions to meet identified capability gaps, increasing their potential for successful integration into future Space Force programs. By equipping businesses with the necessary resources and knowledge, the TRL Bootcamp has enhanced the ability of commercial innovators to contribute effectively to national security objectives.

Beyond these immediate successes, the TRL Bootcamp has established a scalable and repeatable framework for broader defense adoption of commercial innovations. Over the initial 9-month period, seven companies from a targeted mission area participated, refining both their technologies and their transition pathways into defense applications. The ongoing expansion of the program includes onboarding future cohorts with varying mission sets, incorporating a range of technologies at varying levels of maturity. By maintaining a structured process while adapting to new mission requirements and stakeholders, the TRL Bootcamp continues to enhance the DoD's ability to integrate cutting-edge commercial capabilities into national security operations. Looking ahead, this methodology has the potential to serve as a model for accelerating technology adoption across the broader defense ecosystem, fostering stronger partnerships between the military and the commercial sector to maintain the United States' competitive edge in space and beyond.

Remaining Challenges and Future Expansion

Finally, this program may serve as a model for how the federal Government can leverage its national labs to accelerate commercial technology development from startups, incubators, accelerators and small businesses. A franchise model could facilitate that adoption and would include a playbook and instructions for how to set up and run such a program for another Government agency or for an international partner Government.

To realize that ambition, it would serve to expand TRL Bootcamp into a joint, cross-domain initiative by incorporating technologies across air, cyber, maritime, land, and space domains. Strengthening partnerships with DoD laboratories, national research centers, and university-affiliated institutions would ensure broader access to technical expertise, specialized facilities, and mission-relevant testing environments. As the program grows, enhancing coordination between military branches and research entities will be critical to ensuring seamless technology transition and interoperability across domains. By building a scalable, DoD-wide model, TRL Bootcamp can drive faster, more efficient technology integration, strengthening the nation's defense innovation ecosystem.

Final Thoughts

This program is still too recent to provide insightful metrics on company success rates and follow-on contracts resulting from this program. Nevertheless, The TRL Bootcamp is showing early signs of success as a transformative approach for accelerating the transition of commercial space technologies into military applications. By integrating rigorous maturity assessments with government lab testing and industry collaboration, the program has provided a structured and repeatable model for identifying, refining, and advancing critical capabilities. The success of the initial cohort highlights the effectiveness of this approach in bridging the gap between innovative small businesses and the complex needs of the defense space ecosystem. As the program expands to new mission sets and technology areas, it will continue to enhance the DoD's ability to rapidly adopt and operationalize emerging commercial innovations. With its scalable framework and mission-driven focus, the TRL Bootcamp represents a critical step toward strengthening national security through increased collaboration between the military and the commercial space sector.

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Collaborating With Universities and Small Business Innovation Research to Address the USMC's Critical Needs

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Abstract

The U.S. Marine Corps (USMC) faces significant challenges in adapting its logistics framework to embrace modern technologies, notably in the integration of Artificial Intelligence (AI) and Machine Learning (ML) into its operational frameworks. The USMC needs holistic AI/ML integration strategies as well as organizations, technologies, and modern doctrines to facilitate AI/ML integration and pace with the state-of-the-art. We show how the USMC's 1st Marine Logistics Group (MLG) work with as technology transition partners in AI/ML applications with academia and industry. The focus is on material readiness and personnel readiness, therefore ensuring sustained future combat power.

The opportunities for such partnership and collaboration between defense, industry and academia would create an environment where not only the USMC acquisition professionals, policymakers, and/or end users can quickly adapt to emerging and relevant technologies, but also innovative ideas and solutions from academia and industries can be rapidly developed into the USMC operational needs. We show SBIR companies can start with small scale innovations and collaborate with the USMC to develop, test, and transit technologies truly useful for the warfighters. The process creates the momentum for SBIR companies and long-term plans to scale up the technology and maintain innovation cutting edges.

We present a couple of case studies. We discuss success stories and lessons learned from these efforts so far, what coordination is required in the future, and what capabilities and challenges USMC and SBIR collaborations present for the operational and acquisition communities.

Keywords: Small Business Innovation Research, SBIR, Marine Logistics Group, Artificial Intelligence, Machine Learning, Automation

Research Problems

The ongoing conflicts in the world vividly demonstrate how unmanned aerial vehicles (UAVs) and AI have revolutionized modern warfare. Furthermore, China's strategic military expansion in the South China Sea includes sophisticated surveillance systems and a rapidly growing naval presence, necessitating an advanced logistical framework to support these remote bases effectively.

The logistical demands of maintaining and operating advanced technological equipment in real-time conflicts are critically important. The conflict emphasizes the necessity for rapid resupply, repair, and maintenance to sustain operational capabilities. The USMC faces significant challenges in adapting its logistics framework to embrace modern technologies, notably in the integration of AI/ML into its operational frameworks as following needs (Mata, 2024):

- Need a holistic strategy: The USMC needs to integrate data science and AI/ML into the Marine Corps' logistical and operational frameworks. There is a critical gap to establish necessary doctrines and strategies to pace with the full utilization of emerging AI/ML technologies to assist decision-making and operational efficiency for the USMC. For example, China has made significant strides in integrating AI/ML into its military capabilities using coherent strategies such as "Military-Civil Fusion." This holistic approach could potentially give China an edge in optimizing the use of AI in military logistics and operations. The United States must prioritize the seamless integration of AI/ML technologies into operational doctrines and logistics frameworks.

- Need to align organizations, technologies, and modern doctrines in a manner that enhances the USMC's capability to conduct posture and deterrence-focused operations (e.g., Global Position Network): It is a necessity for the USMC to align with technological and operational changes, advocating for a complete overhaul of logistical approaches to support modern military operations (Palmer, 1997; Deputy Commandant for Information, 2024).

Different roles in the acquisition community, such as contracting officers, program managers, senior leaders, and engineers can all contribute to the success and agility of the technology transfer. While military organizations such as the 1st MLG may provide critical needs, universities such as the Naval Postgraduate School can provide research and publish papers for innovative ideas, and small business innovation research (SBIR) companies such as Quantum Intelligence and Tagup can provide innovative ideas, implementation, and technology transformation of many innovation ideas.

SBIR is a bottom-up approach to innovation. Scope specifications do provide adequate bridging for industry partners to meet the resource sponsors requirements. The RFP process (e.g., length restrictions, demonstration requirements, contract structure) ensure that awarded SBIR contracts are mission oriented and outcomes-driven to drive competition and innovation opportunities. This process also maximizes utility of the product or system to the end-user and mitigates risk to the DoD.

Innovation with SBIR companies starts with a small scale. The USMC applications can bring momentum for the SBIR companies; however, it is critical for the SBIR companies to have a long-term effort up across the DoD and commercialization plan so the technology can be validated and achieve large-scale results.

The SBIR companies collaborating with DoD organizations such as the 1st MLG in Phase II product development, testing, production, and sustainment can promote innovation while preserving the efficiency and creativity of small teams. It is critical for SBIR companies to engage the end users in the early stage of Phase II. The 1st MLG provides the critical infrastructure, data, needs, and end users' requirements to train AI/ML models and validate the discovered insights.

Case Studies

One of the holistic strategies of the USMC's 1st MLG to integrate AI/ML technologies into the operations is to work as technology transition partners with academia and industry, specifically, the Naval Postgraduate School and small business innovation research companies such as Quantum Intelligence and Tagup, to not only ensure material readiness but also personnel readiness, therefore ensuring sustained combat power for the USMC.

The opportunities for such partnership and collaboration between defense, industry, and academia would create an environment where not only the USMC acquisition professionals, policymakers, and/or end users can quickly learn about emerging and relevant technologies, but also ideas and solutions can be rapidly developed, tested, and transitioned into the USMC operational needs.

A few initiatives are shown will be detailed as the research results:

1. Leveraging Artificial Intelligence to Learn, Optimize, and Wargame (LAILOW) framework by the Naval Postgraduate School: LAILOW was funded by the Office of Naval

Research (ONR) Naval Enterprise Partnership Teaming with Universities for National Excellence (NEPTUNE) program. LAILOW is a framework used for the USMC to machine-learn operation and collaboration patterns from historical data that can be used to predict future needs. The LAILOW framework uses historical data to predict future logistical needs and prepare for unforeseen circumstances through predictive modeling and data analytics. The LAILOW framework is also an optimization framework of logistical operations to maximize efficiency, readiness, and responsiveness by modifying logistical and business decisions and actions within the feasibility constraints. The LAILOW framework can leverage coevolutionary algorithms (Zhao et al., 2021) to explore "what-if" scenarios where logistics challenges that do not exist in the historical data, providing simulations and wargames to discover vulnerability, emerging scenarios that are not seen in the historical databases, and more importantly discover resilient solutions.

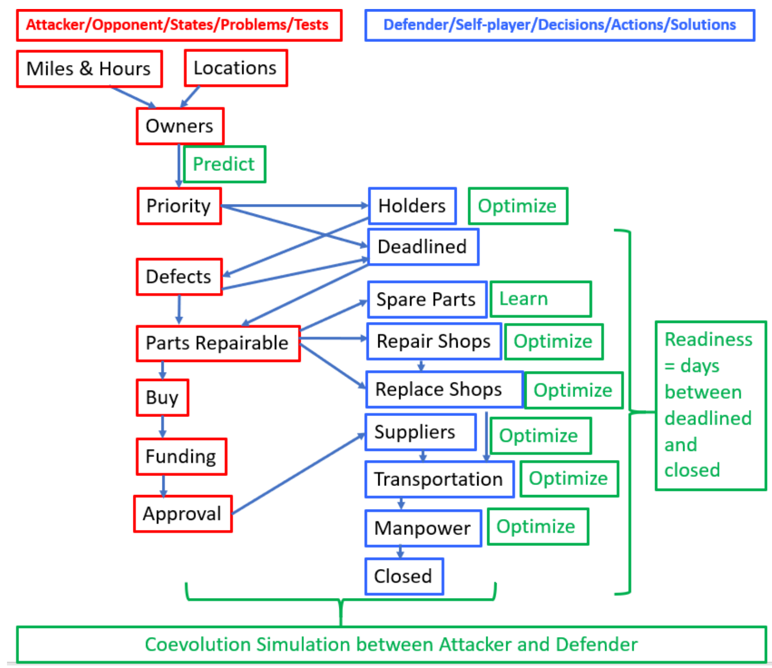

Figure 1. An Example of USMC Logistic Enterprise Equipment Maintenance and Logistics Process Using the LAILOW Framework
(Zhao et al., 2021)

2. Collaborative Learning Agents (CLAs) and risk management framework from Quantum Intelligence, Inc. (Quantum): CLAs were originally developed under a NAVSEA-funded SBIR Phase I/II. Currently, the 1st MLG will work with Quantum to customize the CLA system (Zhao & Zhou, 2019) developed by Quantum to address the USMC's challenges and needs, specifically the needs for the Warfighting Systems & Human Factors Integration (WHI) capabilities of integrating maintenance logistics with human elements for optimal return in minimum time, minimum injury, optimal safety, and minimum cost.

The technology addresses the gap in WHI to integrate AI/ML strategies and models into existing WHI databases and business processes that can significantly enhance the efficiency, effectiveness, adaptability of systems, and quality of tactical decision making.

The result would be a risk management framework with distributed AI agents. In the context of WHI, different end users may not have the rights to share data directly because of sensitive data of human elements such as personal identification information (PII). Quantum's innovative CLAs allow AI/ML models to be fused without the raw data. In addition, the risk management framework would apply data-driven AI/ML to predict future risks based on fused AI/ML models and discover root causes of risks and generate actionable insights in strategic, operational, and tactical levels.

Figure 2 shows an example to demonstrate the CLAs using the data sets of the mishap and incident reports of a marine transportation equipment and related data resources from the I Marine Expeditionary Force (IMEF). The 1st MLG is one of IMEF's organizations.

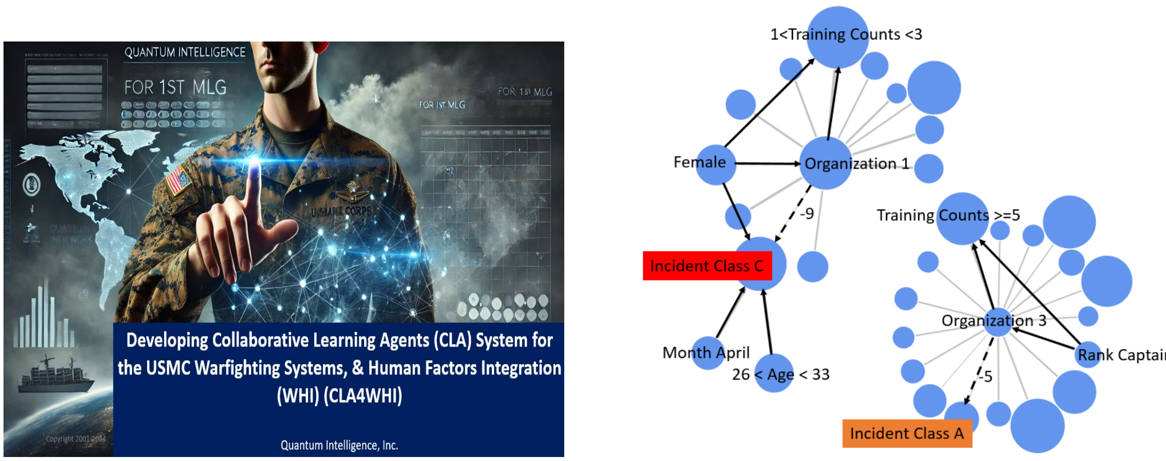

Figure 2. Counterfactual Knowledge Graphs From the Fused Patterns Using Collaborative Learning Agents From Quantum
(Zhao et al., 2025)

3. Manifest for logistics optimization using ML by Tagup Inc.: Tagup offers a commercially available logistics modeling and simulation (M&S) technology capable of improving contested logistics planning and decision-making as measured by total combat readiness. The software is currently deployed in production for the Marine Corps but is relevant to any branch of service, like the Navy, Air Force or Army. Manifest consists of a suite of software applications and service infrastructure that leverage the wealth of historical equipment operations, maintenance and supply data using AI/ML. Commanders and logisticians use Manifest to determine the optimal stocking policies by National Stocking Number (NSN) and location that maximize equipment readiness and combat power given cost, space, and manpower constraints.

Manifest is used to close the gap between dated logistics automated information systems and planning processes. Manifest was initially developed under a NAVAIR-funded SBIR Phase I/II and underwent testing for a subset of Marine Corps Class VII and IX ground equipment, including 880 Light Armored Vehicles (LAVs) and over 8,200 Medium Tactical Vehicle Replacements (MTVRs; Tagup, 2021). Manifest has since been generalized and operationalized for medical equipment and supplies (Class VIII). It is currently used by 1st Medical Logistics Company (1st MEDLOG), supporting their INDOPACOM Area of Responsibility (AOR) via three distinct supply nodes (Camp Pendleton, Marine Rotational Force-Darwin, and the Philippines). Ultimately, Manifest enables logisticians the ability to dynamically adjust their stocking policy/criteria (quarterly) by synchronizing many complex supply decisions and their relationship with time, so the warfighter has what they need, when they need it. The AI/ML models and simulations dynamically inform logisticians on the optimal timing to replenish inventory by location based on lead times from their suppliers, expiration of perishable items, budget, and operating tempo (OPTEMPO).

For example, simulations of Class VIII materiel for 1st MEDLOG are used to quantify the tradeoff between readiness and cost, resulting in a potential increase in readiness and fill rate for a fixed cost, or a reduction in surplus stock without compromising readiness or fill rate. This allows the USMC to effectively wargame/evaluate cause-effect relationships, ensuring the best equipment sets and supplies are available downrange for our operating forces.

Manifest has revolutionized the mobilization planning process by identifying the optimal equipment sets for deployment within seconds—a task that previously required hours or days. It also offers data-driven insights for replenishing medical equipment sets that consider current and incoming inventory to enhance readiness posture. Furthermore, it recommends the optimal inventory stocking policy by location, maximizing readiness, and fill rate while minimizing surplus stock. Using 2 years of historical transaction data (captured in DMLSS), Manifest has reduced operating costs by over 20%, all while maintaining readiness. Additionally, Manifest has right sized intermediate supply points. The same tools could be used to increase readiness by up to 13%; however, the unit decided to address budget cuts first.

More details of Manifest, its applicability to Class VIII, and results can be found in a March 2024 *Marine Corps Gazette* article titled "Machine Learning for Medical Logistics" (Fowler & Polera, 2024) or in a video published by 1st Marine Logistics Group (The 1st MLG, 2024).

Additional information from the original SBIR Phase II on Class VII and IX are available on request. References from users are also available upon request.

Figure 3 shows Manifest in action at 1st MEDLOG (when compared to the status quo). Manifest is used to enable more efficient inventory replenishment and mobilization planning operations, given the inventory on hand, budget available and upcoming planned exercises/deployments. More details on the use of the tools can be found at the following video on 1st MLG's website: https://www.1stmlg.marines.mil/News/Videos/videoid/926019/.

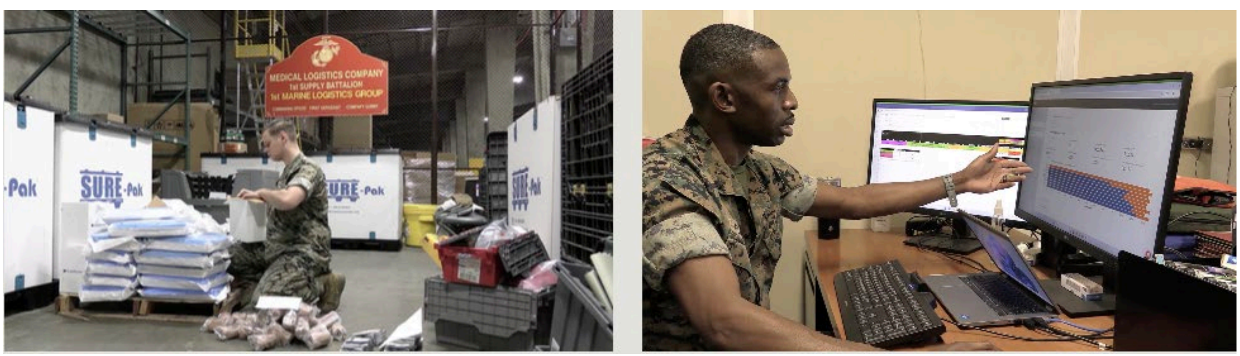

Figure 3. Manifest in Action at 1st MEDLOG

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A Paradigm Shift for How DOD Funds People to Drive Innovation Through Entrepreneurial Science

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Aimee Rose—studied Physical Chemistry at MIT, developing materials for explosive detection. She transitioned the materials to a start-up where she led product development through two acquisitions and an IPO. These products were deployed in Iraq, Afghanistan, and airports nationwide. She received national recognition for these outcomes including the U.S. Army's Greatest Invention Award, TR35 Young Innovator Award, and Humanitarian of the Year from MIT's Technology Review Magazine. Rose then served as founding Chief Technology Officer at Advanced Fabrics of America. She later joined Activate and now serves as Executive Managing Director, supporting each community's leadership, organizational strategy and future expansion.

Thane Campbell—is Founding Dean of The College at Deep Science Ventures that provides a three-year PhD called the Venture Science Doctorate where science companies are built to tackle global challenges. Partnered with more than 30 universities, corporates, and national labs, Deep Science Ventures already has the capacity to train 2,000 Founding PhDs to build the fields and industries of tomorrow. Backed by Shmidt Futures, Innovate UK, Anglo American and Germany's Federal Agency for Breakthroughs—SPRIND, he seeks to train 1,000 moonshot founders, every year. He holds a PhD in AI-powered immunophenotyping completed in collaboration with GlaxoSmithKline.

Abstract

The Department of Defense (DoD) funds approximately $2.7 billion in basic science annually (American Association for the Advancement of Science, 2020) that generates many high impact innovations from graduate students working in university laboratories. However, the traditional academic path does not train these developing scientists on the process of technology transition and transfer (T3). This paper describes current ecosystem bottlenecks and explores lessons learned for DoD T3 from a novel doctoral program driven with a venture science pedagogy (Campbell, 2024) as well as a complementary entrepreneurial research fellowship. Best practices from these programs can inform the DoD's extramural funding arms, e.g., the Army Research Office, Air Force Office of Scientific Research, and Office of Naval Research, etc., how to optimize their academic scientific investments and their student programs to enhance T3 and impact the acquisition workforce.

Background and Problem Statement

In World War II, the United States created its most innovative engines. After the war Vannevar Bush articulated a peacetime mission for accelerated progress, creating the National Science Foundation (NSF) and DARPA. Today that mission is not being communicated to the 50,000 science, technology, engineering, and math (STEM) PhD scholars trained in the United States, every year. If 1% of this talent base was activated to operationalize their research towards the commercial markets, the United States would see an additional 500 high impact science companies formed every year. The DoD funds more than $3 billion of basic research in universities every year (National Center for Science and Engineering Statistics, 2022) and less than 10% of that focuses on multidisciplinary, convergent science, e.g., MURI (DoD, 2024). DARPA deploys an additional amount of nearly $2 billion every year towards fundamental research. These resources are more than sufficient to repeatedly convert 1% of U.S. STEM PhD scholars into the engineers of our nation's next breakthroughs and to lay the foundations for a "moonshot nation" (Bahcall, 2019). Greater mission impact could be delivered if the DoD has efficient mechanisms to harvest talent and breakthroughs from federal basic science investments.

What is preventing DoD from accessing this talent and opportunity? Three key gaps have developed over the past 50 years, creating a chasm between invention and capability. The United States is not training student inventors in the process of commercialization even though they are often the best positioned to lead this work. Meanwhile, industry has superior market knowledge but seeks short term returns rather than long term investments and relies on academia for the next generation of inventions. At the same time, career academics are pursuing novelty, publications, and grant funding and often overlook the market potential of their intellectual property (IP). Furthermore, some of the legacy sectors in the United States have established defenses to block innovation.

STEM PhD programs simply no longer train for the careers that students will eventually pursue. With limited faculty positions available, the percentage of graduates going into industry continues to increase, however, coursework at universities has not evolved to position these graduates to understand and develop technology in the context of market needs. There are some programs addressing this gap. NSF's Innovation Corps (i-Corp) captures technical talent across the university system, introducing customer discovery skills into the front of the talent pipeline, i.e., starting in undergraduate education. Programs like Activate Entrepreneurial Research Fellows (ERF) and Breakthrough Energy Fellows support postdoctoral talent, nucleating startups when they are ready to spin out. NobleReach Foundation is also clearly demonstrating the value of DARPA-inspired talent development. Both the Graduate Intern and Senior Fellows programs at NobleReach Foundation could be served by a PhD training program dedicated to deep tech moonshots.

The ARPA innovation ecosystem is a key source of talent but its reliance on research professors as Program Directors has been criticized by Bill Bonvillian, one of the architects of ARPA-E (Bonvillian, 2021). The key criticism is that while university laboratories supply the scientific workforce, they are not designed to train its entrepreneurs or managers about how to run DARPA programs. Science-based entrepreneurship, unlike that based on software (e.g., "lean start-up methodology"), depends more on forward-looking analyses of sector-scale opportunities than on customer development. Through specialized venture-building environments, hundreds of new tech stars could pour out of labs every year, giving their regions a fairer share of U.S. innovation.

Innovation incentive structures are not aligned across academia and industry. Historically, large corporations provided much of the runway for U.S. innovation. Before 1970, firms like DuPont, Xerox, and AT&T prized basic research, but changing stakeholder composition and increased competition led to drastic R&D cuts (Arora et al., 2019). Since then, the sharpened divide between academia (research) and industry (development) has been slowing the U.S. economy. Despite increases in total spending on higher education R&D (6x; National Center for Science and Engineering Statistics, 2020), trained PhDs (2x), and research publications (7x; Arora et al., 2019), more product innovations now rely on acquiring inventions from universities, and small firms (nearly 50% in the manufacturing sector; Arora et al., 2017). However, market entry is not a priority for university researchers. Industry rewards the commercial utility of inventions, but academia rewards novelty—which is why academics are 23% less likely to file for a patent than industry for the same discovery (Bikard, 2018). This mismatch in incentives blocks market launch.

While conflicting national, industrial, and institutional incentives limit our growth, competitors are gaining a strategic upper hand. As an International Trade Administration official told Congress in a hearing on the Chinese threat to American competitiveness, “China, by controlling America’s revenue stream, also controls America’s ability to earn income and fund R&D” (Nikakhtar, 2020). In the United States, complex established legacy sectors (CELS) operate within well-defended technological, economic, and political paradigms rooted in incentives, price structures, expert communities, political support, university curricula, and career paths built over decades. With these defenses, incumbent firms and their aging technologies “resist any change that threatens their business models” (Weiss & Bonvillian, 2011). These defenses result in hidden market imperfections like network dependence and non-appropriability—wherein customers benefit more than investors—that keep university spin-offs out of CELS. Thus, the training gap and incentives problem upstream, and market imperfections downstream, are major barriers to our innovation system’s productivity and scope.

Manufacturing economies like China and India build innovation into all sectors and have productivity growth rates two to three times that of the United States (Weiss & Bonvillian, 2011). While reshoring manufacturing is necessary to rescue domestic supply chains, it is not sufficient. China is turning its trade deal revenues into innovation and productivity gains which cannot be reshored—through massive investment in state-owned-enterprises, e.g., LinkDoc (Sturman, 2018) and Jinko Solar (JinkoSolar Holding Co., Ltd., 2020). This structure is why the International Trade Administration emphasizes that a “second essential component of a reshoring strategy is incentivizing inward investments in domestic manufacturing and R&D activities” (Nikakhtar, 2020).

The training gap, incentives problem, and market failures must be solved simultaneously. This necessary alignment was a key insight of Nobel Laureate Economist Paul Romer, in his analysis of the National Defense Education Act’s Title V PhD Fellowship which led to the creation of the fields of electrical engineering and chemical engineering (Romer, 2020). Very similar dynamics were in play when ARPA created the first computer science PhD. These programs leveraged a common playbook which led to the modern-day industries of Energy Resilience and AI, yielding trillions of dollars of economic growth.

More unique to the DoD is the acquisition gap. The DoD is distinct in that it funds full stake product development to turn technologies into capabilities that serve the warfighter. However, the path for startups to be part of their solution set has been encumbered by entrenched prime contractors holding needed relationships and contracts for procurements. This system leaves startups with two paths to selling to the military. In the first, a startup would partner with a prime who then captures most of the value of the product. This economic structure often prevents a startup from raising the private capital it needs to realize the full potential of the technology and to drive pricing down. Alternatively, the startup can scale on the commercial market first, then come back to sell to the DoD. This model is served by DIU and has been successful at delivering new capabilities to the DoD. However, either of these paths increases the time it takes to get new solutions to the warfighter. Tighter integration between startups and the DoD stakeholders could help align incentives earlier in their commercialization journey, unlock follow-on funding, and provide a new path to talent and capability acquisition for the DoD.

Examples of Success

New models are needed to attract and capture talent and innovation into the defense industrial base. Fortunately, the best practices have emerged from some notable programs that specifically serve STEM talent, more specifically the Venture Science Doctorate (VSD) and the Activate Entrepreneurial Research Fellowship (ERF). Their design, best practices, and existing programs can be leveraged to meet the goal of harvesting basic science breakthroughs to create a next generation workforce to serve warfighter needs.

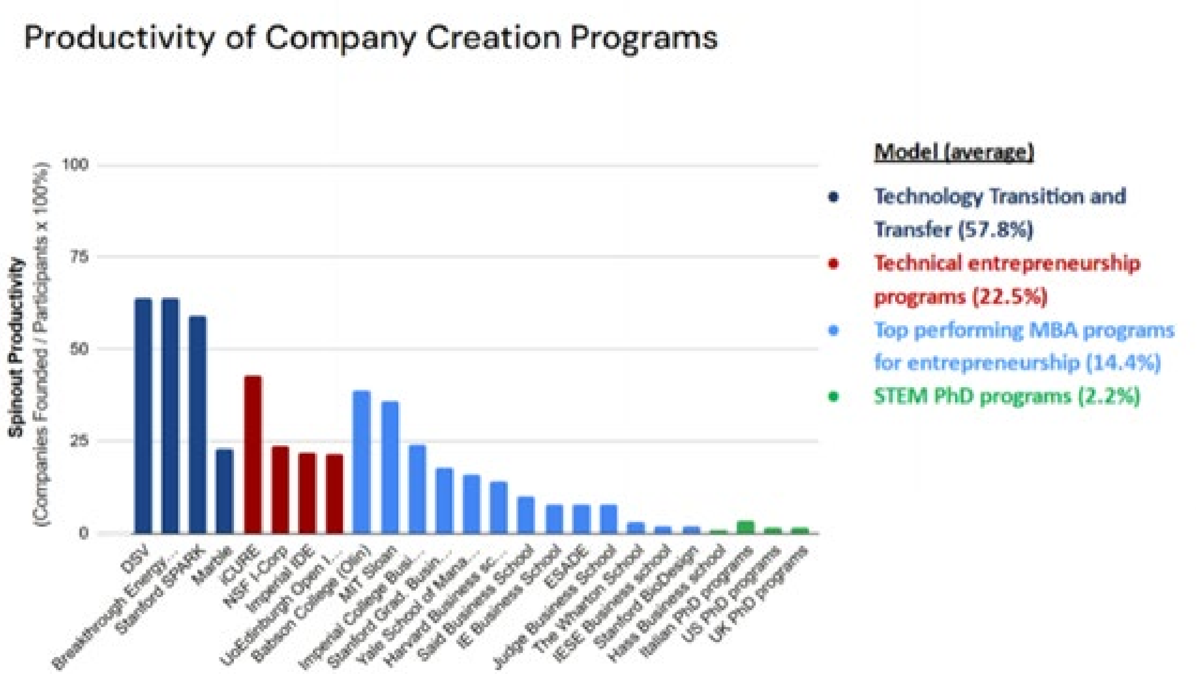
According to Paul Romer, a playbook for modern industry creation is a user-led, industrial, interdisciplinary, portable, scalable, three-year PhD fellowship. The VSD is such a program and updates these design constraints with the addition of i) accessing a broad base of talent and ii) venture-led innovation. The industrial, user-led and interdisciplinary aspects are combined to most rapidly establish new industries, instead of waiting decades for new industries to emerge from basic research.

The VSD is a PhD in moonshots and has been recognized in Forbes magazine as a frontier vehicle for the generation of high impact energy resilience at scale, alongside programs established by the DOE and Bill Gates. It has been endorsed by the Ministry of Education, Trade, and Industry in Japan as international best practice in workforce development, alongside programs of IBM and Mitsubishi Electric. Now with the support of Germany's ARPA (SPRIND), The VSD is well poised to repeat this success story across Europe as Germany's Federal Government has announced its intention to build 150 ventures, through this breakthrough PhD program, by 2029.

In the VSD, every scholar focuses on the process of generating a breakthrough. This three-year PhD fellowship gives scholars a framework for defining "currently impossible outcomes" for society and generating approaches that make those outcomes possible. Year 1 VSD PhD candidates dedicate to inventing and the developing skills and attitudes of elite deep tech founders. In Year 2 they generate proof-of-concept data and a policy white paper summarizing constraints in the innovation ecosystem which are slowing founders down. In Year 3 they build a working prototype, hire co-founders, and engage with several investors around milestones which they must meet to scale up commercially from the prototype. All this activity has financial sustainability as a requirement for success.

A portfolio approach to invention proceeds R&D. A research methodology called "scoping" combines scientific and market research to map the space of possible technology prototypes and business models to find optimal combinations. When a prototype fails, hypotheses adapt through a "Living Lab" approach which draws technologies from disparate fields and protocols from many research laboratories. Deep Science Ventures has partnered with more than 30 universities and national research assets worldwide, including Cornell Tech, The Helmholtz Association, GlaxoSmithKline, and CGIAR—the world's largest agricultural research network. With more than 100 physical sites, inventors can combine technology components across research disciplines to solve an important problem. Mastering "scoping" arms founders with a mindset that prioritizes impact over ideas and a framework for pivoting post-incorporation in response to market pressures. Composing ventures in a "Living Lab" enables pre-commercial coordination. Where technologies like photovoltaic panels took more than 100 years to emerge, now technologies that represent a step-change for an industry can be forecasted and their missing components built in parallel.

Although public procurement has contributed to the launch of the VSD, corporate and philanthropic dollars have too. As a fully accredited college, Deep Science Ventures has established the program, takes equity in, and thereby invests in companies formed. Deep Science Ventures is on a 10-year mission to generate 1,000 ventures per year—only possible if the companies it builds achieve significant returns on investment. By focusing on improving and making advances in the emerging field of venture creation, Deep Science Ventures have created one of the world's first commercialization co-pilots, Elman, which accelerates patent searching, invention, techno-economic analysis, and co-founder recruitment. "Venture Scientists" on the program have already used Elman to dive deep into new fields in materials science and achieve postdoctoral level mastery of the key technical and commercial considerations for their technology in just two months. In the hands of advanced users, Elman can digest an important problem, explore and rank commercially viable solutions, and suggest a team with the right skills mix in a day.



Dedicated T3 programs consistently achieve better outcomes than MBAs and translational research programs. The average conversion of participants to founders across the top MBA programs was 14.4%, with technical entrepreneurship programs having a 22.5% conversion rate. For T3 programs such as DSV's and Activate, which almost exclusively draw on PhDs and postdoctoral fellows, conversion rates are 64% and 100% respectively. T3 programs average 2-times more efficient company formation than technical entrepreneurship programs and are 20-times more efficient than STEM PhD programs. We believe a hybrid program can maximize conversion, at scale, through PhD education.

Complementary to VSD, the Activate ERF, supports scientists turned founders once they are ready to create a company and fully spin out after a traditional STEM PhD. Since 2015, Activate pioneered and scaled nationally the ERF, initially in partnership with the DOE and the Cyclotron Road Division of Lawrence Berkeley National Laboratory. The DOE has since formalized ERFs as Lab-Embedded Entrepreneurship Program (LEEP) and expanded it to other national laboratories. Activate also continued to scale the program, including a node at MIT Lincoln Laboratory, as well as other facilities across the country. Activate operates five ERF programs today.

The high touch fellowship was created to fill a very specific opportunity and resource gap. Entrepreneurs building new hardware-based businesses face unique obstacles when commercializing research and development breakthroughs. In particular, the business faces risk across four key dimensions: technology, team, market, and finance. All startups face financing risk—how can I convince someone to fund my vision? Software companies face a lot of market risk—who will use it, then buy it, and what will they pay? Pharma startups face a lot of technical risk—will this drug be effective and pass clinical trials—but almost no market risk because the product can command multi-billion dollar revenue per year with monopoly status. Hardware startups face both technology and market risk, making their journey even more challenging. This specific barrier is what leaves many academic inventions sitting on the shelf.

Key components of the Activate Fellowship

Table 1. Activate Fellowship

Activate Fellowship: What Makes Us Unique	
Two-year living stipend of $100k/year along with health insurance, travel and education stipend, and relocation support	Fellows are personally financially supported and able to commit full-time to commercializing their technology
Specializing in early-stage technology readiness levels (1-4)	Encourages pivots and early learning cycles to help increase chances of success
Concierge service providing access to a diverse community of peers and advisors, including over 500 hard tech venture capital investors and over 50 corporate partners	Provides risk-free opportunities for guidance, collaboration, education, and follow-on funding across a network of investors, corporations, other entrepreneurs, academics, government, mentors, and advisors
100% support: Activates takes **zero equity**	Offers support and resources without diluting fellows' ownership or diminishing their incentive
$100K R&D stipend and access to lab equipment and dedicated facilities with exclusive rights to their own intellectual property	Seed funding and research support helps budding entrepreneurs advance their technology
Additional pre-seed capital to advance fellow businesses	At least $75K in additional capital through Activate's flexible capital partnership program helps advance their business
Intensive in-person and virtual weekly classes and professional development services, with full-time, personal mentorship	Custom-built program develops scientists into commercial business founders

While most entrepreneurial programs work with existing companies to accelerate their success, Activate, like VSD, comes in at the earliest stage in the entrepreneurial journey to support scientists and engineers as they transition from lab to startup, when the risk of startup failure is at its highest and available funding at its lowest (Hermann, 2022). Many fellows apply to Activate while still in the final year of their PhDs, incorporate once they are accepted into the fellowship, and would not have formed companies without the ERF support. By investing in teams that are too early for accelerator programs, Activate brings to market high-risk technologies that have the potential for impact on a massive scale, bridging a critical gap in the U.S. innovation ecosystem. The fellowship enables a "zero-to-one" journey that transforms proto-companies from an idea to a first product, and Activate does not take equity in exchange for this support.

The Role of Graceful Pivots in Deep Tech Company Progression

Activate Fellows work at the cutting edge of science and engineering, developing technologies that have the potential to transform industries and address global challenges. Early-stage innovation is inherently unpredictable, and the path from concept to impact is rarely linear. Fellows often face evolving technical hurdles, shifting market dynamics, and changing customer needs—all of which require them to pivot. Whether refining their technology for a new application, rethinking their business model, or targeting an entirely different market, Fellows must stay agile and responsive. Activate's program is designed to support this flexibility, providing the time, resources, and mentorship that empower Fellows to make strategic pivots without compromising their long-term vision. This ability to adapt is crucial to maximizing the chances of success in bringing groundbreaking technologies out of the lab and into the world. Fellows are selected in part based on their open-mindedness, ability to learn, and adaptability because these capabilities are essential for any successful founder.

Activate is uniquely structured to help Fellows navigate the uncertain and often non-linear journey of deep tech commercialization, including making strategic pivots when necessary. First, Fellows receive up to two years of non-dilutive funding and a living stipend, which provides a critical financial runway to explore different technical pathways or market applications without immediate pressure to generate revenue or raise external capital. This funding frees Fellows to focus on problem-solving and iteration, not just pitching to investors.

Additionally, Activate offers tailored entrepreneurial training and one-on-one mentorship from their Managing Director who is a seasoned entrepreneur themselves. Along with other advisors, the Managing Director helps Fellows stress-test assumptions, evaluate market feedback, and explore alternative commercialization strategies when their original plans prove challenging. Fellows receive training on product-market fit frameworks as well as the soft skills needed to learn the most about a market. The program's flexible milestone planning process encourages Fellows to revisit and revise their technical and business goals regularly, ensuring their project evolves based on real-world insights. Activate's broad network of industry partners, potential customers, and investors also plays a vital role—facilitating early market validation and providing critical feedback loops that often trigger informed pivots toward higher-value opportunities.

Together, these resources create a supportive environment for thoughtful experimentation, enabling Fellows to pivot confidently—whether that means refining a core technology, shifting customer segments, or even reimagining their entire business model—while staying true to their long-term mission.

Activate believes that scientists can make fantastic entrepreneurs and are the most qualified to lead their companies through all the market learning cycles and pivots. The Activate ERF equips science entrepreneurs with the new mindsets and skills needed to navigate the complex journey of bringing transformative technologies to market. Fellows develop as rigorous, data-driven leaders, continuously seeking high-impact advice and investing in their own growth to make informed decisions—even with imperfect information. They cultivate resilience and adaptability, balancing optimism with healthy skepticism to sustain both themselves and their companies through inevitable challenges. Activate fosters a deep commitment to customer-centric problem solving, guiding Fellows to define clear value propositions and deliver impactful commercial products. By capturing and leveraging a broad network of resources, Fellows reduce risk and accelerate progress, acquiring funding that aligns with their mission, values, and stage of development. The program emphasizes the importance of strong teams, encouraging Fellows to build intentional, mission-driven cultures rooted in trust and collaboration. Through this comprehensive approach, Activate empowers entrepreneurs to pair technical excellence with entrepreneurial acumen, dramatically increasing their potential for long-term success and impact.

While every startup's journey is unique, typical outcomes of the program include one or more pivots, an industry-ready prototype or minimal viable product, specs for that prototype, beachhead market definition with initial customer engagement, follow-on funding raised ($5.3 million, on average which equals 13 months of runway, on average), advisors (three, on average), majority ownership of their companies, and defined next steps for product development and manufacturing milestones. Ninety-six percent of Activate companies are still operating today, but intentional "no-gos" also occur. Activate considers "no-go" decisions an important indicator of success, demonstrating that fellows have learned leadership skills and made a deliberate choice more quickly (than they otherwise might have) that there was not a clear path to market.

Since 2015, 249 Activate Fellows have created 197 science-based companies, some of which will go on to change the world. These companies have collectively raised $4 billion in follow-on funding, mostly in private capital. This amount translates to more than 50x leverage on every dollar spent to support the fellowships. Activate companies have created more than 2,800 jobs and earned more than $71 million in revenue. During the fellowship, companies raise an average of $5.3 million. Another leading measure of success is that 96% of Fellow companies are still active.

Results

The analyses in this manuscript indicate that a notable venture builder in the United Kingdom has led to 50 companies in just eight years with a half a billion dollar valuation and is now scaling through the VSD. Similarly, results of Activate's ERF indicate that in a similar eight year time frame, Fellows created nearly 200 companies which went on to raise nearly $4 billion. We derive recommendations for adopting lessons learned based on these analyses.

Recommendations on Adoption of VSD

Although several U.S. agencies offer various PhD fellowships, none are venture focused. A DoD-sponsored VSD program represents an attractive opportunity to explore hundreds more advanced technology avenues in parallel, every year. Generating more founders within the defense workforce will lead to more dual use technologies, a larger ecosystem of deep tech human resources, and technologies that can contribute to the continuous transformation process (Rainey, 2024). By focusing on founder-type recruitment, learning engineering for elite deep tech founder development, and venture capital fundraising, the VSD can enable the DoD to generate immediate, direct returns on university R&D investment. Doctoral training is the gateway into the deep tech workforce but admissions favor highly individualistic achievement styles and academic career ambitions, biasing against effective deep tech founders. There is a great opportunity to adapt some portion of the resources that go into existing degree funding programs and pivot them to focus on developing advanced synergistic technologies in parallel, and growing the number of technology experts that the DoD can draw on by growing the dual use economy. The VSD can also generate more ambitious talent for follow on programs like a DoD-sponsored ERF.

Recommendations on Adoption of ERF

By adopting the ERF model as other federal agencies, such as DOE, NSF, and NIST, have, DoD-sponsored Activate fellowships could further the DoD's mission by directing this talent and their product development to meet military needs. At the same time, the model captures private capital to accelerate the growth of these companies. The cohort-based model also means that the DoD as an engaged partner could access and inform the business model of all relevant fellows in the cohort regardless of their actual sponsor, quite literally having a multiplicative effect of shaping early company trajectories. This approach enables the DoD to capture talent and technology emanating from other federal agency's basic science investments. Fellows certainly choose their own path in product development and customer acquisition, but are informed and influenced by the stakeholders to whom they have access.

Imagine if the acquisition process was demystified for them and they had access to DoD product roadmaps with defined technology insertion points. Fellows would not only be prime candidates to receive R&D and prototype funding, but also build relationships that equip them to build for future requirements.

Discussion

We report on the success of the VSD and ERF to demonstrate how DoD agencies could enhance T3 of fundamental science across the academic/government nexus using best practices of VSD and ERF. By smoothing transitions across early Technology Readiness Levels (TRLs) working across the DOE, academia, industry, and the DoD, these practices improve the probability of private capital capture for promising technology, leveraging highly trained technical personnel, lab infrastructure, and adjacent market demands to catalyze an industrial base. Collectively, they enhance the availability and adequacy of external (venture) funding—poised with a strong track record of returning a 50X multiple to initial government investments, such as the $25 million appropriated for the LEEP. Just as the Naval Postgraduate School (NPS) has played a notable role in technology transitions from experimentation to operational use of autonomous systems, its proximity to Silicon Valley and being a use-inspired military research institution position NPS as a strong hub for instantiating the DoD's VSD programs and ERF. Tighter connection and synergy between DoD-funded venture science PhD students and their ERF can enhance T3 through collaboration among defense, industry, private capital, and academia—most importantly accessing financiers with their capital stacks that are ever more targeting deep tech.

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SUMMIT PANEL 6. BRIDGING THE VALLEY OF DEATH: LESSONS FROM EVTOL, CAPITAL ENGAGEMENT, AND PROTOTYPING

Thursday, May 8, 2025	
1225 – 1340 PT 1425 – 1540 CT 1525 – 1640 ET	**Chair: Dinesh Verma (Ph.D.), Executive Director, Acquisition Innovation Research Center (AIRC)** ***Navigating the Valley of Death: Lessons for Defense Acquisition from Transitioning eVTOL Technologies in the United States Air Force*** Jim Mignano, Assistant Policy Researcher, The RAND Corporation ***Beyond Industrial Policy: How Engaging Capital Markets Can Help our Industrial Base Scale*** John G. (Jerry) McGinn, Executive Director, George Mason University ***From Breakthroughs to the Battlefield: Best Practices for Tapping Into the Power of Prototyping*** Stephanie Halcrow, Senior Fellow, George Mason University

Dinesh Verma (Ph.D.)—is a Professor of Systems Engineering, School of Systems and Enterprises (SSE) at Stevens Institute of Technology, Executive Director of the Systems Engineering Research Center (SERC)/AIRC, and a Visiting Professor at Georgetown University Department of Biochemistry.

He served as the Founding Dean of the School of Systems and Enterprises at Stevens Institute of Technology from 2007 through 2016. During his twenty years at Stevens, he has successfully proposed research and academic programs exceeding $200m in value.

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. 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 continued to serve numerous companies in a consulting capacity, to include Eastman Kodak, Lockheed Martin Corporation, L3 Communications, United Defense, Raytheon, IBM Corporation, Sun Microsystems, SAIC, VOLVO Car Corporation (Sweden), NOKIA (Finland), RAMSE (Finland), TU Delft (Holland), Sandia National Laboratories, Johnson Controls, Ericsson-SAAB Avionics (Sweden), Varian Medical Systems (Finland), and Motorola. He also served as an Invited Lecturer from 1995 through 2000 at the University of Exeter, United Kingdom.

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, 2009).

Verma received the Ph.D. (1994) and the M.S. (1991) in Industrial and Systems Engineering from Virginia Tech. He was recognized 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.

Navigating the Valley of Death: Lessons for Defense Acquisition from Transitioning Electric Vertical Takeoff and Landing Technologies in the United States Air Force

Jim Mignano—is a PhD student at the RAND School of Public Policy and an Assistant Policy Researcher at RAND. His research focuses on emerging technology policy and national security. His work includes studies on technology promotion and protection, innovation policy, and lessons from commercial practices for the Department of Defense, as well as the application of flexible acquisition authorities to support the integration of commercial technologies in military applications.

Lauren A. Mayer, PhD— is associate director of the Engineering and Applied Sciences Research Department and a senior policy researcher at RAND. With more than 20 years of experience researching risk-related topics, her current research centers around improving the defense acquisition system, including requirements development; technology promotion and transition; and cost, schedule, and performance risks. Recent work has included improving requirements processes for the Space Force and Air Force, developing improved risk methods for Navy Analyses of Alternatives, and exploring pathways for technology acquisition and transition for the Air Force and Office of the Undersecretary of Defense, Research, and Engineering.

Abstract

The Department of Defense faces persistent challenges in transitioning emerging commercial technologies into military applications, often stalling in the "valley of death" between research and development and full-scale acquisition. This paper examines these transition barriers through the case of electric vertical takeoff and landing (eVTOL) technologies within the United States Air Force. Using a conceptual model, the study identifies four primary entry points—sponsored capability, small-scale purchase, prototyping, and experimentation—and six waypoints that facilitate transition. Analysis highlights common obstacles, including the "chicken and egg" problem of securing capability sponsorship, and emphasizes the role of flexible acquisition mechanisms such as Other Transactions, Commercial Solutions Openings, and procurement for experimental purposes. The case study of eVTOL technology demonstrates that small-scale purchases and iterative experimentation can serve as viable transition routes, even when immediate alignment with a defined capability gap is lacking. The paper concludes by outlining potential applications to support broader defense technology transitions and suggesting future research directions to extend the analysis. Findings derive from the RAND Project AIR FORCE report, Amping Airpower—Electric Vertical Takeoff and Landing for the U.S. Air Force.

Keywords: defense acquisition, technology transition, eVTOL, valley of death, Other Transactions (OTs), Commercial Solutions Opening (CSO), prototyping, experimentation, emerging technologies

Introduction

The Department of Defense (DoD) has long faced challenges in transitioning emerging technologies from research and development to a program of record. This transition gap, often known as the defense "valley of death," represents the period when promising technologies struggle to secure sustained funding, programmatic sponsorship, or integration into a formal acquisition pathway. The challenge is particularly acute for emerging commercial technologies that have potential military applications but lack clear alignment with an existing capability gap. Such applications often fail to progress beyond early-stage prototyping or limited operational experimentation, preventing the military from fully leveraging commercial innovation.

The problem is not new. Over the past two decades, numerous defense acquisition reform efforts have sought to accelerate technology transition, tailor risk tolerance, and create flexible mechanisms to onboard new commercial technologies. Provisions for Other

Transactions (OTs), Commercial Solutions Openings (CSOs), and procurement for experimental purposes have aimed to address these challenges. However, structural and institutional barriers—ranging from budgetary constraints to fragmented acquisition authorities—continue to impede the transition of emerging commercially developed technologies into deployment.

Research Problem: Transitioning Commercial Electric Vertical Takeoff and Landing Technologies

Electric vertical takeoff and landing (eVTOL) technologies offer a compelling case study of the valley of death in defense acquisition. Originally designed for commercial uses such as urban air mobility and logistics, eVTOL aircraft have potential to support a range of military missions, including personnel transport, logistics resupply, and medical evacuation.

While there is growing interest from the U.S. Air Force (USAF)—reflected in early experimentation efforts—no clear acquisition pathway currently exists for procuring these platforms for use in standard operations.[1] The primary acquisition challenges for integrating eVTOLs into USAF operations include:

- eVTOL technology does not align neatly with an existing operational capability gap, making it difficult to secure traditional programmatic sponsorship.
- Limited options without sponsorship, as traditional acquisition pathways are aligned with sponsored capabilities.
- Disincentives to sponsorship, including fixed budgets that prioritize current mission needs over emerging capabilities and the resource-intensive nature of pursuing capability sponsorship.
- Uncertainty in transitioning from experimentation to acquisition, even when early experimentation demonstrates operational potential, due to the absence of formal mechanisms supporting nontraditional acquisition paths.
- Limited influence on commercial design because the USAF is likely to remain a relatively small customer in the global eVTOL market and thus cannot easily shape platform development to meet defense-specific requirements (e.g., survivability, secure communications).
- Risks to supply chain security and reliability, as the eVTOL industry globalizes and production may shift outside the United States.

Purpose and Significance of the Paper

This paper examines the structural, policy, and acquisition challenges associated with transitioning eVTOL technology into the USAF. By analyzing existing transition routes—such as direct commercial purchases, prototyping, and operational experimentation—this paper develops a conceptual model for how emerging commercial technologies can navigate the valley of death. The findings are particularly relevant for defense policymakers, acquisition professionals, and industry stakeholders seeking to improve the military adoption of commercially developed innovations.

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[1] RAND research to date does not recommend large-scale procurement of eVTOLs by the USAF at this time, given ongoing uncertainties regarding operational utility, defense-specific adaptation, infrastructure requirements, supply chain security, and long-term integration feasibility. See Mayer et al. (2023).

More broadly, this paper contributes to ongoing discussions about modernizing defense acquisition to better leverage the speed and innovation of the commercial sector. The case of eVTOL technology offers insights that may apply to other emerging capabilities.

This paper derives from research commissioned by the Air Force Research Laboratory and was conducted within the Force Modernization and Employment Program of RAND Project AIR FORCE as part of a fiscal year 2021 project, “Leveraging Advanced Air Mobility for the Department of the Air Force.” The resulting report, *Amping Airpower—Electric Vertical Takeoff and Landing for the U.S. Air Force: Military Utility, Market Dynamics, and Warfighter Adoption*, is available online at: https://www.rand.org/pubs/research_reports/RRA1524-2.html.

Overview of the Paper

The remainder of this paper is structured as follows. The Policy Context section briefly presents prior research on technology transition challenges, relevant DoD policies, and historical case studies of commercial-military integration. The Conceptual Model of Transition Routes section presents a conceptual model for understanding different routes emerging commercial technologies can take to transition to operational deployment. The Application to eVTOL Technology section analyzes the application of this conceptual model to eVTOL, identifying key barriers and opportunities. The Extending the Analysis Beyond eVTOLs section 5 proposes potential applications to support broader defense technology transition and suggests avenues for future research to extend the analysis.

Policy Context

Unique Acquisition Challenges in Adapting Commercial Technologies

The DoD largely develops new military capabilities through a structured, multi-phase acquisition process. This traditional model emphasizes requirements-driven development, rigorous testing, layers of oversight, and long-term sustainment planning. While effective for major defense programs, this approach often struggles to integrate commercially developed technologies that evolve more rapidly and are driven by private-sector investment (Goldfeld et al., 2024).

Commercial technologies follow a different innovation pathway. Instead of being designed to meet military requirements from the outset, commercial innovations are developed to satisfy existing or anticipated market demand. The differences continue as idea becomes reality: defense acquisition tends to follow a relatively linear path from research and development to fielding with largely predictable but inflexible resourcing, while leading commercial practices feature iteration and more flexible resourcing that is often tied to progress (GAO, 2022).

Moreover, retrofitting commercial technologies to meet defense-specific requirements (e.g., survivability, secure communications) can be costly and time-consuming. These adaptation challenges are compounded by the fact that most government acquisitions are governed by statutes and regulations, such as the Federal Acquisition Regulation, that companies are not required to follow when developing for commercial markets. As a result, traditional acquisition processes often impose compliance burdens and procedural delays that many commercial developers, particularly nontraditional firms, are neither structured to meet nor incentivized to navigate (Mayer et al., 2020, pp. 5–8). The challenge for the DoD is determining how to effectively integrate these technologies without requiring full-scale, long-term acquisition commitments upfront.

Comparing eVTOL technology transition with other emerging defense technologies, such as hypersonics and autonomy, reveals distinct challenges and strategies. For example, hypersonic technology development has predominantly followed a government-driven model, with significant DoD investments directed toward research laboratories and defense contractors. This approach contrasts with the commercial market-driven development of eVTOLs, which necessitates different transition strategies. Similarly, autonomy applications tend to blend commercial innovation and defense interest, leading to initiatives that aim to bridge commercial solutions with military needs, such as those managed by the Defense Innovation Unit (DIU).[2] Understanding these varied pathways underscores the importance of tailoring acquisition strategies to the specific development and market contexts of each technology.

Key Statutory Mechanisms and Related Initiatives

Recognizing the challenges of transitioning commercial technology, Congress and the DoD have provided several mechanisms to support greater acquisition flexibility. Among the most significant are Other Transactions (OTs), the Commercial Solutions Opening (CSO) process, and procurement for experimental purposes, all of which can help bridge the gap between innovation and fielded capability by streamlining processes and enabling rapid experimentation and prototyping.

OT agreements allow the DoD to fund research, prototyping, and certain follow-on production efforts outside the traditional Federal Acquisition Regulation framework, enabling faster development cycles and closer collaboration with commercial firms that might otherwise be hesitant to engage in standard government contracting (DAU, n.d.-b). The CSO streamlines the process for DoD components to solicit and evaluate innovative commercial solutions (DAU, n.d.-a). This mechanism is particularly useful for identifying and testing emerging technologies before committing to large-scale acquisition. The DoD also has special authority to procure certain commercial technologies for experimental use, allowing operational units to test new capabilities in real-world conditions (DAU, n.d.-c).

The DoD has increasingly relied on these flexible funding mechanisms to accelerate the adoption of innovative technologies. For example, the DIU pioneered the use of CSOs to engage non-traditional vendors and has awarded 450 prototype OT agreements totaling $5.5 billion since its inception, with an average award time of just a few months (DIU, 2024, p. 14). Over 50% of DIU projects have transitioned to fielded technologies, demonstrating the efficacy of the CSO-OT combination in rapidly integrating commercial innovations into military applications (DIU, 2024, p. 14). The DoD (2023, p. 3) reports that from fiscal year 2017 to fiscal year 2022, the number of OTs awarded for prototype projects increased from 496 to 4,391, with total obligations increasing from more than $2.2 billion to nearly $10.7 billion. The report found that 92% of these transactions involved non-traditional contractors—companies that typically did not do business with the DoD—indicating success in attracting innovative commercial entities (DoD, 2023, p. 7).[3]

Within the Department of the Air Force, the Air Force Research Laboratory launched AFWERX to help integrate emerging commercial technologies into USAF and U.S. Space Force operations. AFWERX leverages partnerships with industry, academia, and government to accelerate innovation and streamline the transition of commercial solutions into military applications. Within AFWERX, the Agility Prime initiative focuses on advancing military applications of commercial advanced air mobility vehicles, including eVTOLs, by collaborating with industry to assess the technology and facilitating access to funding (AFWERX, n.d.).

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[2] For further information about the DIU and its work related to autonomy, see DIU (n.d.).

[3] Mayer et al. (2020) provides an extensive review of the uses and challenges of OTs for prototype projects.

Still, transitioning emerging commercial technologies remains challenging. This is particularly true in the case of eVTOLs, where barriers include misalignment with defined operational capability gaps, uncertainty in securing long-term programmatic support, hurdles in meeting both civilian and military certification requirements, and financial uncertainty among firms reliant on venture capital investment.

Lessons Learned from Prior Cases

Several prior cases illustrate that successfully integrating emerging commercial technologies into military applications requires a tailored approach that acknowledges the distinct origins and dominant markets of the technology. Programs such as Blue sUAS and Falcon 9 Spacelift, which originated in the commercial sector, face unique challenges when adapted to defense needs, such as aligning civilian certification standards with military requirements. By contrast, initiatives such as Palletized Munitions and the MQ-1 Predator, developed primarily within the defense community, have leveraged established military processes and warfighter input to iterate quickly and field effectively.

Across these examples, key takeaways include the importance of early operational experimentation, prototyping, and flexible funding mechanisms that enable iterative learning and adjustment. These insights provide valuable guidance for integrating other commercial technologies, such as eVTOLs, into the defense portfolio.[4]

Conceptual Model of Transition Routes

As part of its evaluation of eVTOL technologies for the USAF, RAND examined broader pathways for integrating emerging commercial technologies into military applications. Through discussions with DoD and USAF stakeholders, as well as an analysis of relevant policies and statutes, we developed a conceptual model that maps the prevailing routes available to the USAF for transitioning emerging commercial technologies to the warfighter (see Figure 1).

This model identifies four entry points to transition, represented by large arrows, with gray rectangular waypoints denoting specific actions that the acquisition system can take to mature and adapt technologies for military use. The model illustrates how these routes can be sequenced and iterated in different ways, depending on the alignment of the technology with an operational capability gap. Dotted lines indicate portions of routes where alignment with a defined capability gap has been established, while solid lines represent pathways that do not require such alignment but remain open to it. Ultimately, all routes culminate in deploying the technology to the warfighter, underscoring the model’s focus on operational relevance and military utility.

[4] For detailed examinations of each case, see Goldfeld et al. (2024, pp. 131–138).

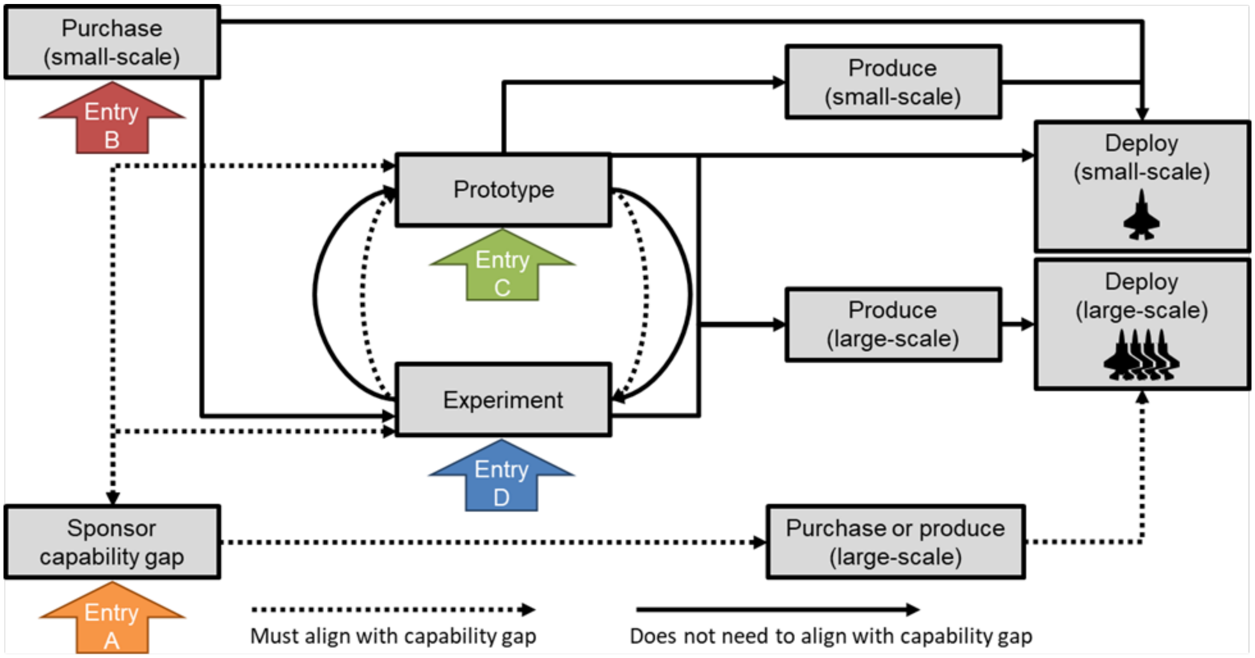

Figure 1. Possible Transition Routes for Emerging Commercial Technologies
(Goldfeld et al., 2024, p. 81).

Figure 1 illustrates that technologies can follow different transition routes and that these routes can be iterated based on feedback or real-world observation. For example, a technology entering via small-scale purchase (Entry B) might first be tested in a limited operational setting. If successful, it could then loop back to secure capability sponsorship or move forward to production and deployment.

Entry Points

Four entry points represent the main starting points from where emerging commercial technologies can begin their transition into military use. Each entry point offers distinct advantages depending on the technology's maturity, alignment with operational needs, and acquisition processes.

A major command (MAJCOM) or USAF organization with equivalent acquisition authority can pursue any route shown in the figure. USAF organizations subordinate to a MAJCOM (e.g., a USAF base) are limited to starting at Entry B, Entry C, or Entry D.

Sponsored Capability Gap (Entry A)

This entry point is used when a technology directly aligns with an existing or potential capability gap. A USAF MAJCOM or organization with equivalent acquisition authority sponsors the technology, enabling its progression through established acquisition pathways.

Small-Scale Purchase (Entry B)

A technology entering at this point is acquired through a limited commercial purchase. This allows for initial operational testing or limited deployment, particularly when the technology has not yet been tied to a validated capability requirement.

Prototyping (Entry C)

The technology is developed into a preliminary model with defense-specific modifications. Prototyping serves as a means to validate technical feasibility and operational potential before committing to larger scale production.

Experimentation (Entry D)

This entry point involves testing the technology under operational conditions without an immediate commitment to full-scale procurement. Experimentation, often carried out through partnership agreements, can be instrumental in demonstrating value and refining requirements.

Six Key Waypoints

The model also identifies six types of waypoints that represent sequential or iterative actions a technology can pass through as it transitions to the warfighter. Several of these waypoints can also serve as entry points, described above.

- **Prototype.** The technology is designed and built as a physical or digital working model. This waypoint tests basic functionality and potential for adaptation to military needs and full scale production.
- **Experiment.** The technology is subjected to operational testing in controlled or real-world environments. This helps determine if the technology meets performance expectations and operational requirements.
- **Sponsor Capability.** At this waypoint, the technology is presented to a sponsoring organization (e.g., a MAJCOM) to secure programmatic support. This step is critical for ultimate integration into the defense acquisition system.
- **Purchase.** The technology is acquired by buying, leasing, or contracting for it as a service. Small-scale purchases provide an initial testbed for further evaluation. Large-scale purchases must align with a capability gap.
- **Produce.** This waypoint involves engaging with the vendor(s) to scale up production with defense-specific modifications. It can follow successful prototyping or experimentation. Successful prototype OT projects, in particular, can use a streamlined follow-on production process authorized at 10 U.S. Code § 4022(f).
- **Deploy.** The technology is fielded for operational use. Deployment can occur at a small scale, with potential for large-scale adoption once operational value is clearly demonstrated.

Analysis of Routes and Barriers to Transition

This model reveals several useful insights. First, emerging commercial technologies face many barriers to successful transition. USAF acquisitions traditionally begin with a sponsored capability (Entry A). However, as in the case of eVTOL, some commercial innovations do not (yet) align with a capability gap, creating numerous disincentives to MAJCOM or equivalent sponsorship. This can create a “chicken and egg” problem; it can be difficult to obtain capability sponsorship without having first demonstrated value through experimentation, but it can also be difficult for emerging commercial technologies to access experimentation without alignment to a sponsored capability. Second, lacking a sponsored capability closes off several routes (i.e., all of the dotted lines in the figure). Absent a sponsored capability, remaining transition routes begin with a small-scale commercial purchase (Entry B), prototyping (Entry C), or experimentation (Entry D). In addition to MAJCOMs, subordinate organizations (e.g., USAF bases, wings) can use these routes, likely concluding with small-scale deployment (e.g., fielding a commercial technology at one base).

Another important insight involves how prototyping and experimentation are critical waypoints in a number of transition routes. They are central gateways that can unlock additional resources to bridge the defense valley of death, especially in cases that do not align with a sponsored capability. They are also versatile activities that—among many other virtues—can demonstrate operational relevance, validate a technology's scalability, and accommodate the speed and culture of innovation enterprises.

Working through this model also illuminates the value of mechanisms such as OTs, CSOs, and procurement for experimental purposes. Prototype OTs are the only such mechanism for large-scale production that do not require capability sponsorship (i.e., through a follow-on production OT). As a result, the routes and mechanisms available to achieve large-scale deployment are significantly limited for emerging commercial technologies that cannot garner capability sponsorship.

Application to eVTOL Technology

Current State of the eVTOL Market and Military Relevance

The eVTOL market is rapidly evolving, driven by advances in distributed electric propulsion and improved battery technologies. Commercially, eVTOL aircraft are positioned to transform urban mobility and logistics by offering faster, more efficient transportation solutions. The technology has attracted significant investment and has moved from early-stage prototypes to companies nearing commercial production.[5]

For the military, eVTOLs offer potential advantages such as rapid personnel transport, agile logistics support, and emergency medical evacuation in austere environments. While current publicly available data on eVTOL performance in military contexts is still emerging, preliminary figures indicate promising cost and performance metrics. Early estimates provided by Goldfeld et al. (2024, p. 95) indicate that operating costs for eVTOL aircraft could range between $8.50 and $13.51 per nautical mile—substantially lower than conventional aircraft such as C-130s ($20.90 per nautical mile) and C-17s ($39.20 per nautical mile). Independent analyses and projections from eVTOL manufacturers also suggest that, when produced at scale, these aircraft could be significantly cheaper to acquire and operate than traditional helicopters (Goldfeld et al., 2024, p. 15). Initial flight test data indicate that eVTOLs can achieve competitive endurance and payload capacities for short-range missions. However, comprehensive operational testing at military facilities is needed to validate these figures and assess factors such as maintenance turnaround times, reliability, and real-world mission adaptability. Furthermore, the technology's commercial origins mean that eVTOL systems are not natively designed for military operations and might need to incorporate defense-specific adaptations.

Why eVTOLs Do Not Fit Neatly into a Sponsored Capability Approach

Despite interest from the USAF—as exhibited by the Agility Prime effort—no clear acquisition pathway exists for fully integrating these eVTOL platforms into operations. The primary challenge is that eVTOL technology does not align neatly with an existing operational capability gap, making it difficult to secure long-term programmatic backing. Critically, Goldfeld et al. (2024, p. 44) finds no MAJCOM that "appeared willing to sponsor a capability requirement that could lead to the development or acquisition of eVTOL aircraft." While some expressed interest in the technology's long-term potential, they expressed a desire to wait for improvements in range, payload, and maturity before considering formal sponsorship.

[5] For examples and current news, see Vertical Flight Society (2025).

Several structural factors complicate this challenge. Although Agility Prime has enabled early experimentation with eVTOLs, transitioning from experimentation to a formal program of record remains uncertain due to the absence of a sponsoring organization. Without formal sponsorships, access to traditional acquisition pathways is severely limited. Furthermore, the USAF's ability to shape these platforms to meet defense-specific needs is also constrained by its relatively small share of the commercial-dominated market. As predominantly commercial technologies, eVTOL platforms must simultaneously meet civilian airworthiness standards and defense-specific performance standards, adding cost and complexity. Finally, many eVTOL firms rely on venture capital investment and anticipate globalization of the industry, which introduces risks related to long-term financial stability and the resilience and security of future supply chains.

These factors collectively underscore the difficulty in applying a sponsored capability approach to eVTOL technology, highlighting the need for alternative, flexible transition routes.

Feasible Routes for Transitioning eVTOL Technology

Given the barriers to transitioning eVTOLs through a sponsored capability, alternative transition routes become more attractive. Our conceptual model readily identifies two such alternative routes as particularly feasible and useful for eVTOL technology. Neither route requires immediate alignment with an existing capability gap.

The first begins with Entry B, in which a MAJCOM or subordinate USAF organization could buy, lease, or acquire as a service a modest number of eVTOLs for operational testing, which occurs at the "Deploy (small-scale)" waypoint. This route allows the USAF to evaluate the technology's performance in real-world conditions without committing to large-scale production. By purchasing a few units, the USAF can gather valuable operational data, assess the aircraft's suitability for various missions (e.g., base security, intra-base transport), and determine what modifications might be needed for broader deployment. The test results could then be used to inform next steps including resuming at Entry A, C, or D with the intent to deploy at large scale.

Alternatively, Entry D could be used, in which a MAJCOM or subordinate USAF organization could begin by partnering with industry to conduct experimentation without initially purchasing any platforms. Through partnership agreements, the USAF can conduct operational tests and simulations using eVTOLs. This method allows for iterative learning, where feedback from live exercises and controlled tests can inform subsequent decisions. Experimentation provides a low-risk environment to validate the technology's potential benefits and understand its limitations. Such approaches have been successfully used in other cases where emerging commercial technologies were evaluated before full-scale adoption. The results could unlock additional waypoints including capability sponsorship, defense-unique prototyping, and production for large-scale deployment.

By leveraging either of these two transition routes—small-scale purchase or experimentation—the USAF could build a practical evidence base to support future capability sponsorship and large-scale deployment. These approaches allow for incremental investment, reducing the risk associated with adopting unproven commercial technologies, while also providing flexibility to adapt as the eVTOL market and technology mature.

Extending the Analysis Beyond eVTOLs

A more detailed comparison of successful and unsuccessful commercial technology transitions using these mechanisms could further strengthen the analysis and potentially support generalization beyond eVTOL technologies. Additional empirical evidence is needed to evaluate the record of using routes involving small-scale purchase, prototyping, and experimentation to bridge the valley of death. Such comparative and empirical analyses could provide valuable guideposts and underscore the potential for eVTOL technologies, as well as other commercial innovations, to follow similar transition routes.

Role of Flexible Mechanisms and Iterative Feedback in Overcoming Transition Barriers

While the valley of death is littered with transition failures, the conceptual model presented in this paper suggests that emerging commercial technologies do have a number of routes for safe passage. Choosing the right one may not be sufficient, but it greatly increases the prospects for success. Key strategies for defense organizations to help navigate transition include:

- **Small-Scale Purchase and Incremental Acquisition:** Defense organizations can initially acquire a limited number of commercial innovations to conduct operational testing and gather real-world data. This approach allows for technology assessment and potential modifications without initially committing to a full-scale program of record.
- **Leveraging Flexible Acquisition Mechanisms:** Utilizing OTs and CSOs enables a more adaptive and streamlined acquisition process. These mechanisms support faster prototyping and experimentation and, under certain conditions, can facilitate large-scale production without necessitating capability sponsorship.
- **Partnership Agreements for Experimentation:** Collaborating with commercial providers through partnership agreements allows for iterative testing and continuous feedback. This minimizes upfront costs and supports defense-specific modifications as the technology evolves.
- **Iterative Experimentation:** Defense organizations can validate technology performance through small-scale experimentation, refining both the technology and operational concepts. This can also build an evidence base for future capability sponsorship.
- **Adaptive Prototyping:** Supported by flexible mechanisms such as OTs, adaptive prototyping develops defense-specific versions of commercial technologies. Real-world feedback during each iteration helps reduce risks associated with transitioning technologies into operational use.
- **Flexible Funding and Contracting Approaches:** Incremental funding based on demonstrated milestones manages the risks of adopting unproven technologies. This approach aligns resource allocation with the technology's maturity and performance.
- **Pilot Programs:** Implementing pilot programs to test commercial technologies in operational environments provides important data on performance and integration. These pilots can serve as a steppingstone to larger-scale acquisition once value is demonstrated and necessary modifications are identified.

Future Research Directions

While flexible acquisition mechanisms such as OTs and CSOs have gained traction, defense organizations will face increasing pressure to ensure that such tools are effectively used to transition emerging commercial technologies. As commercial innovation continues to outpace defense-led development, the DoD will increasingly need to find agile, risk-tolerant routes and mechanisms for integrating capabilities that are not initially designed with military use in mind. The failure to identify workable routes and mechanisms for transition—particularly for technologies such as eVTOLs that originate in fast-moving commercial markets—poses a significant risk to maintaining operational advantage.

The conceptual model presented here, while preliminary, offers a starting point for understanding how such transitions might be structured. Further research is needed to validate and refine this framework, identify additional enabling mechanisms, and anticipate the pitfalls that may arise when adapting informal or nontraditional pathways. If the DoD is to remain competitive in the face of evolving threats and technological disruption, acquisition organizations must develop and test new approaches for bringing commercial innovation into the defense enterprise, including potentially revolutionary technologies that will only materialize if institutions are willing to experiment and accept higher levels of risk. Specific research areas include:

- Examining the long-term benefits and challenges of small-scale purchases and experimentation can inform technology transition decisions and potential reforms to acquisition frameworks.
- Analyzing the application of OTs and CSOs across various technologies could reveal best practices and enhance transition performance.
- Identifying practices and processes to support deeper collaboration in technology transition between interested defense organizations, their DoD counterparts, and industry stakeholders.
- Exploring different possible transition routes and supporting mechanisms for emerging commercial technologies could further refine the conceptual model and provide a more complete decisionmaking picture.
- Tailoring transition routes and supporting mechanisms to different defense organizations' specific objectives, internal processes, and external relations might provide more value to individual decisionmakers while identifying more universal conclusions.
- Investigating approaches the Office of the Secretary of Defense or the Department of the Air Force could develop (e.g., new mechanisms, organizational changes) to mitigate barriers that existing pathways and approaches do not address.

Bridging the valley of death for eVTOL and similar technologies can necessitate a shift from traditional acquisition processes to more flexible, adaptive strategies. Illustrating how these strategies can be implemented in various ways, such as through the conceptual model presented in this paper, raises awareness among defense organizations about the many routes available to harness the potential of emerging commercial technologies.

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Beyond Industrial Policy: How Engaging Capital Markets Can Help Our Industrial Base Scale

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Abstract

Industrial policy is all the rage in the United States. Dramatically increased investments in Defense Production Act (DPA) Title III programs, the first-ever National Defense Industrial Strategy (NDIS), and the $52 billion Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act have clearly demonstrated U.S. government commitment to address industrial base weaknesses.

Despite these efforts, however, weaknesses abound. We cannot build munitions fast enough to resupply Ukraine, much less U.S. military stockpiles. Major systems continue to deliver late and in quantities that could not match wartime production needs. Moreover, it is not at all clear that DPA or CHIPS investments will be enough to fully address those vulnerabilities in our defense industrial base.

This paper examines the impact and challenges of industrial policy through large-scale industrial base investments and explores options to attract and scale private sector capital investment to scale production and address industrial base weaknesses.

Introduction

There are currently two major themes in the defense industrial base. The first focuses on fostering innovation to increase the speed of the delivery of capabilities to the warfighter and ramping up the scale of the delivery of these capabilities. There are many efforts across DoD to increase the speed of the development of systems through prototyping. These include the use of Other Transactions Authorities (OTAs) and other approaches to incentivize new high-tech companies to bring commercial technology to bear against defense challenges.

The second theme focuses on strengthening industrial capacity. Industrial policy is all the rage in the United States. This involves reshoring or friendshoring of industrial capabilities, many of which were previously produced in the United States. Industrial policy is one key tool in helping build industrial capacity that has been used with increasing frequency and scale since the COVID-19 pandemic. Dramatically increased investments in Defense Production Act (DPA) Title III projects, the first-ever National Defense Industrial Strategy (NDIS), and the $52 billion Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act have clearly demonstrated U.S. government commitment to address industrial base weaknesses.

These efforts are mutually reinforcing and making substantial progress, but weaknesses in the defense industrial continue apace. Experiences in the past several years have demonstrated challenges in the ability to produce systems at scale to support allies, refresh U.S. military stockpiles, or meet expected attrition rates in simulations of major overseas contingencies. Major systems continue to deliver late and in quantities that could not match wartime production needs. Supply chains remain a challenge for production.

Many of the difficulties in scaling production originate in how the DoD acquires capabilities and builds industrial capacity. Changing DoD acquisition processes and increasing resources are indeed part of the solution. Numerous efforts are underway to address these challenges, from reform of DoD's Planning, Programming, Budgeting, and Execution (PPBE) process and the FORGED Act under consideration in the FY2026 National Defense Authorization Act (NDAA). I separately addressed many of these issues in a 2024 report focused on industrial mobilization (McGinn, 2024b), and there have been numerous other recent reports have focused on fostering innovation in how DoD engages with the defense industrial base.

It is becoming increasingly clear, however, that efforts will not be sufficient to address national security challenges in the defense industrial base. Absent a major war or a national emergency, there appears to be little appetite in Congress or the Executive Branch for dramatically raising defense spending to Cold War levels given concerns about the national debt.

Research Question

Given this constrained environment, there have been growing calls for greater private sector investment to help strengthen the defense industrial base. These have ranged from appeals for increased company spending on research and development (R&D) instead of stock buybacks to co-investment, cost-share, and commercialization strategies. Many of these are already key components of industrial base investments. How effective have they been, and what can these efforts tell us about the future?

Thus, this paper examines the following research question: what type of incentives would change the dynamic of private sector investment in defense?

Approach

The paper starts with a baseline examination of current company R&D incentive models (e.g., share buybacks, IRAD, etc.). These structures do not appear to incentivize industry investment beyond explicit government spending plans. I then turn to current industrial base programs that require some level of industry co-investment or cost share (e.g., consortia, industrial base investment programs (DPA Title III and IBAS)) to examine their effectiveness.

I then examine alternative methods to create industry incentives to invest in scaling in market areas pertinent to national security. This includes an examination of previous DPA loan efforts and emerging OSC funds as well as potential efforts such as advanced depreciation and even sovereign wealth funds.

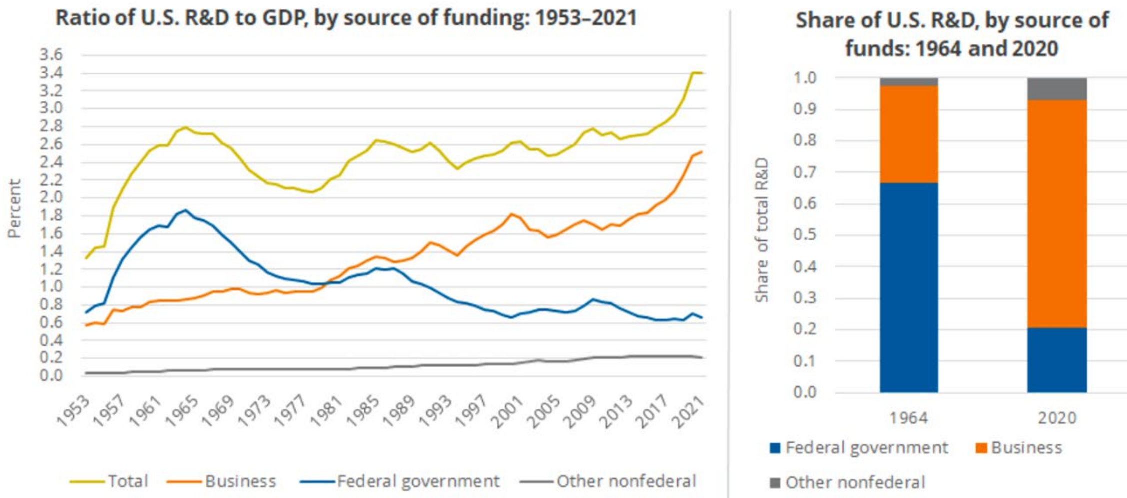
Current R&D Incentive Structures

Despite a decade's focus on innovating with commercial technology, the defense acquisition system largely remains focused on efficiency and cost savings. While this is a worthwhile goal, this regularly leads to limited production runs built precisely to the terms of the contract and results in industrial capacity that is very difficult to scale quickly as well as decades-long franchise programs that reduce competition.

This situation is principally the result of incentive structures that have existed largely since the end of the Cold War. As defense spending shrank from 6% of gross domestic product (GDP) to 3% in the early 1990s, DoD customers changed their buying behaviors. An increased focus on getting the most out of every shrinking acquisition dollar ironically led to longer acquisition timelines and greater cost.

Commercial vs. Government R&D Trends

In R&D, there have been more longstanding trends that have impacted incentive structures for defense companies. As Michael Brown and Pavneet Singh demonstrate in their 2024 report, federal R&D spending peaked in the 1960s at almost 2% of gross domestic product (GDP) or close to 70% of all R&D. That percentage has declined steadily in the intervening decades and private sector R&D has surpassed federal spending to rise to 2.4% of GDP in 2021 and over 70% of all R&D. Figure 1 illustrates this trend:



GDP = gross domestic product.

Figure 1: U.S. R&D, by Source of Funds

Source: National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series)

This trend is well known and helps explain the rise of private capital in private equity- and venture capital-backed firms in defense, but its impact on traditional firms' R&D practices is less well understood.

Stock Buybacks and More

Stock buybacks have been a perennial source of tension between government leaders and industry executives. Senior DoD officials have raised concerns when companies doing business with DoD use free cash flow to buy back existing shares of company stock in lieu of additional investments in R&D or production capacity. Comments by former Secretary of the Navy Carlos del Toro last year captured the essence of this critique: "You can't be asking for the American taxpayer to make greater public investments while you continue to goose your stock prices through stock buybacks, deferring promised capital investments, and other accounting maneuvers" (Demarest, 2024).

Why do defense companies pursue stock buybacks and not make large scale capital investments? As I noted with two co-authors last year,

> The issue revolves around the capital allocation decision. If large defense primes are not making significant investments, it is because they believe that this incremental dollar is unlikely to materialize into a profitable contract in the future. For that to change, these primes need to see a better return for the earnings they intend to retain and re-invest either via growth opportunities, greater frequency and volume of competitions, or margin improvement. (McGinn et al., 2024)

Stock buybacks are principally used by large publicly traded defense primes like Lockheed Martin, Northrop Grumman, or General Dynamics. Publicly traded defense firms number around 100, an extremely small percentage of the overall defense industrial base of well over 100,000 firms. Smaller publicly traded companies like Kratos and AeroVironment do not typically buyback shares because they see significant defense and national security opportunities in their market segments of unmanned systems, advanced electronics, and autonomy. If similar incentives existed for the larger primes, that is where their capital would go (McGinn et al., 2024).

Another major topic that is often raised is company independent research and development (IRAD). IRAD is available to traditional defense firms (i.e., those that are compliant with the Cost Accounting Standards). IRAD is used by companies to conduct research on promising technology areas that are not currently funded by DoD. Major primes can spend over $1 billion on IRAD. While IRAD is often termed as "company-funded," it is actually an allowable expense that is charged back to the government (DoD, 2023a; Lofgren, 2022).[1]

Beyond the allowability of IRAD, one of the points of contention is the degree to which company IRAD investments focus on areas of particular interest to DoD. During the 2010s, for example, then Under Secretary of Defense for Acquisition, Technology, and Logistics Frank Kendall attempted to establish a review process whereby companies engaged with DoD customers before and during IRAD projects. The intent was to make these engagements light-touch, but the industry was concerned that the review stage would add time and cost (Maucione, 2015). The initiative was eventually abandoned, but the need for a better alignment between DoD and industry on IRAD remains an issue. Revitalizing IRAD reviews is one option that merits further consideration (McGinn & Hyatt, forthcoming).

As the preceding makes clear, current structures do not incentivize significant independent R&D investment in the defense space. We will now look at recent efforts to spur innovation and industrial base investments to understand how they are impacting the incentives structures in the defense industrial base.

The Rise (and Peak?) of Industrial Policy

Industrial policy, as broadly defined by the Organisation for Economic Cooperation and Development and many others, is the use of government assistance to businesses to incentivize or directly subsidize the expansion of certain economic sectors (Siripurapu & Berman, 2023). U.S. government leaders have long avoided the use of industrial policy in most cases in favor of free market economics. This approach helped fuel U.S. economic growth but also led to the offshoring of industrial capabilities from the United States over time. The production, for example, of rare earth mineral processing, batteries, specialty chemicals, and other capabilities with significant environmental impact migrated to more favorable and lower labor cost markets such as Asia.

Despite this overall reticence, industrial policy has been part of defense sector for decades with Buy America laws focused on spurring domestic production of defense systems. With built in exemptions for close allies and partners and the natural need to make the most sensitive defense systems in the United States, it is not surprising that aerospace and defense is one of the strongest domestic manufacturing industries, with a $114 billion positive trade balance in 2023 (Aerospace Industries Association, 2024).

[1] See Appendix 3 of the DoD Contract Finance Study Report for a description of Independent Research and Development.

The real rise in the use of industrial policy in defense began in the late 2010s, however. In 2017–2018, Executive Order 13806 launched a presidentially directed comprehensive review of the U.S. manufacturing and defense industrial base to address current and future U.S. national security needs and to make policy, regulatory, legislative, and investment recommendations to the president. This review identified that Chinese firms had become single or sole source suppliers in numerous areas such as rare earth mining and processing, batteries, and specialty chemicals where the United States had once had a leading role. The final report of this review recommended immediate investment to rebuild U.S. capacity in these and numerous other areas (U.S. Department of Defense, 2018). DoD, under the Defense Production Act Title III, launched a series of projects beginning in 2019 to invest government resources in these areas.

COVID-19 dramatically accelerated industrial policy through a $1 billion appropriation to DPA in the CARES Act (McGinn, 2020). The Biden Administration continued this focus on industrial policy in its EO 14017 review of critical supply chains and subsequent investments through DPA as well as the Industrial Base Analysis and Sustainment (IBAS) program.

DPA Title III and IBAS

DPA Title III and IBAS are the two major defense industrial base investment programs and their funding levels have dramatically increased since COVID. Title III is one of three active sections of the DPA, which was originally passed in 1950. Title III gives the president the authority to make purchases, purchase commitments, loans, and loan guarantees to address a domestic industrial base shortfall. Prior to COVID, Title III was funded at around $50–$70 million per year. In the aftermath of COVID and a series of presidential executive orders during the Trump and Biden administrations, Title III investment increased tenfold on an annual basis (Defense News, 2024). IBAS was established in 2013 to improve the readiness and competitiveness of the U.S. industrial base. It was even more modestly funded in the mid-2010s, averaging under $20 million annually. IBAS has similarly grown in funding levels since 2020, including over $830 million in appropriations in FY 2023 (Manufacturing Capability Expansion Investment Prioritization, 2024).

Impacts and Challenges

The significant rise in funding levels is the first obvious impact of increased industrial base investments since 2020. Figure 2 illustrates the dramatic changes in both DPA Title III and IBAS (Manufacturing Capability Expansion Investment Prioritization, 2024).

Figure 2: DPA Title III and IBAS Funding, FY15–28
(Office of the Assistant Secretary of Defense for Industrial Base Policy, n.d.)

A significant number of projects have been launched in industrial capability areas such as rare earth and other critical minerals, castings forgings, microelectronics, and numerous other areas. In FY2023, for example, almost $520 million was appropriated for critical chemicals; hypersonics; strategic radiation hardened microelectronics; microelectronics packaging; strategic and critical minerals; castings and forgings; energy storage and batteries; and solid rocket motors (Office of the Assistant Secretary of Defense for Acquisition, 2024a).

The direct impact of the industrial base investments is critical, but the overall objective of these efforts is to create a sustainable industrial capability that can survive and thrive after the conclusion of the DPA or IBAS project. These have always been a major component of these industrial base investments, executed through cost share or commercialization strategies. This follow-on impact is critically important because most of the capabilities created have a substantial or even dominant portion of their respective markets that are commercial. Rare earth magnets and advanced batteries, for example, are overwhelmingly commercial with less than 1% of the market for defense purposes.

With most of the major recent DoD industrial base projects still underway, it is impossible to definitively measure how well they are achieving their overall commercialization objectives. There have been a number of follow-on or concurrent investments by private capital, government, as well as commercial customers that are promising, however. Some examples include:

- DoD supported the redevelopment of Mountain Pass, the nation's first operating rare earth mine and processing facility, now managed by MP Materials, through both DPA and IBAS investments in 2020 and 2022, respectively (DoD, 2020). This government funding was a critical signal to the commercial market that helped MP Materials secure two essential subsequent contracts: a long-term supply agreement with GM (MP Materials, 2021) as well as a $59 million award administered by the Department of Energy to build their own fully-integrated rare earth magnet manufacturing facility in Fort Worth, TX (MP Materials, 2024). This tax credit allocation helped advance the construction of that facility.
- IperionX, a high-performance titanium producer, received a $12.7 million DPA award in 2023 (DoD, 2023b), recently announced a framework agreement to sell 80 metric tons of titanium products to United Stars every year for 10 years. United Stars is a key supplier of aerospace, defense, and commercial parts to Boeing, BAE Systems, Lockheed Martin, General Electric, Lucid Motors, GM, Toyota, Caterpillar, Oshkosh, and John Deere, among others (Businesswire, 2025).
- Concurrent with DPA investments of $6.4 million in Fortune Minerals for cobalt production and $8.3 million in Lomiko Metals for graphite (DoD, 2024b), the Canadian government announced $7.5 million and $4.9 million in funding for the companies, respectively (Canadian Broadcasting Corporation, 2024). The projects represent the first U.S.–Canadian government partnerships supporting Canadian critical minerals initiatives for the benefit of both countries' supply chains.
- The Munitions Campus pathfinder project has secured 1,100 acres of land near Crane, IN, entirely funded with private capital, creating a shared supply chain ecosystem from critical chemicals through munitions production. This includes a signed agreement with Prometheus Energetics, a joint venture between Kratos Defense & Security Solutions and RAFAEL Advanced Defense Systems, which will serve as the first anchor tenant of the campus, as well as signed commitments from at least 13 additional smaller companies (ACMI, 2025).

Getting a better sense of these types of follow-on investments will be critical to understanding whether the government market signal is having the desired return on investment. Currently, there are no concerted efforts underway to measure the impact of follow-on activities and assess the sustainability of industrial capacity being developed through industrial base investment. This always been one of the major concerns about using industrial policy-focused tools like DPA. Many of the industrial capabilities that the United States is attempting to strengthen or reshore previously migrated to other markets that are more commercially profitable. While these significant industrial base investments will have an impact, it will take years for these investments to build industrial capacity, and it is not clear that these investments will build self-sustaining domestic industrial ecosystems in areas ranging from rare earth processing and specialty chemicals to microelectronics and small drones.

The Inflation Reduction Act and CHIPS

The Biden Administration employed industrial policy in two of its major legislative accomplishments, the Inflation Reduction Act (IRA) and the CHIPS and Science Act. President Biden issued a presidential determination in June 2022 providing the Department of Energy (DoE) with the authority to utilize the DPA to "rapidly expand American manufacturing of five critical clean energy technologies" including solar panels, heat pumps, and critical power grid infrastructure (U.S. DoE, 2022). The IRA's DPA investments of $500 million were evenly split between DoE and DoD (U.S. DoE, n.d.-a).

CHIPS, meanwhile, was one of the largest-ever appropriations focused on rebuilding U.S. domestic manufacturing of semiconductors. With semiconductor manufacturing heavily concentrated in Taiwan and East Asia, U.S. policy-makers were increasing concerned with ensuring the availability of semiconductor technology in the United States given potential trade disputes or even armed conflict. After almost 2 years of debate, Congress passed and President Biden signed into law the CHIPS and Science Act in 2022 that appropriated $52 billion to boost domestic semiconductor manufacturing through grants and other financial incentives (Blevins et al., 2023).

Impacts and Challenges

The Departments of Commerce, Defense, and Energy spent the remainder of the Biden Administration working to obligate these funds and incentives to companies. With the IRA, for example, DoD awarded $250 million to 12 companies through DPA Title III to establish "domestic manufacturing capability for a reliable and sustainable supply of strategic and critical materials for large-capacity batteries and other supply chains key to national defense." These awards went to the development of capabilities such as lithium mining, high quality graphite, battery-grade manganese, and other areas (Office of the Assistant Secretary of Defense for Acquisition, 2024). By January 2025, the CHIPS Program Office in the Department of Commerce had awarded over $36 billion to numerous companies across the United States (National Institute of Standards and Technology, n.d.).

The change in presidential administration in 2025, however, led to the pause of many of these investments. The Executive Orders for the IRA DPA Presidential Determinations, for example, were rescinded in March 2025 (Federal Register, 2025), and many IRA projects in other agencies were cancelled (IRA Tracker, n.d.). With CHIPS, it is currently unclear what the future holds for the program and the awards made during 2024 (Shephardson, 2025).

These difficulties illustrate some of the challenges with large scale industrial policy efforts. The IRA, for example, was not a bipartisan effort. No Congressional Republicans voted for the bill, and there was a great deal of partisan disagreement about the appropriateness of invoking the DPA for solar cells, heat pumps, and other IRA priorities (U.S. House Committee on Energy and Commerce, 2023). Thus, when industrial policy is not done on a bipartisan basis, it becomes at risk when there is a change in political power.

The CHIPS Act, on the other hand, was passed on a bipartisan basis. It was not a large bipartisan majority, but there was a broad national consensus about the need to revitalize domestic semiconductor manufacturing. The inherent challenge with CHIPS was that such a large Congressional appropriation requires political concessions or considerations to help secure passage. Thus, controversial provisions about child care and project labor agreements were included in the final bill that passed Congress (Blevins et al, 2023).

The IRA use of the DPA has played a major role in the discussions of DPA reauthorization. The House Financial Affairs Committee held two hearings in 2024 on DPA reauthorization, and the focus of these hearings was the importance of keeping DPA focused exclusively on defense and national security issues, in particular threats from our pacing competitor, China (U.S. House Committee on Financial Services, 2024). This year's DPA reauthorization debates in Congress will certainly center around these issues (McGinn, 2024a).

Limitations of Industrial Policy

While the rise of the use of appropriations and—by extension—industrial policy to address defense industrial base weaknesses has had an impact, the preceding also demonstrates that there are two clear limitations to significant use of appropriations to achieve industrial base goals. The first limitation is that the larger the investment of public funds, the greater the chance for these investments to get caught up in political considerations. While most of the individual DPA and IBAS projects were narrowly focused on specific industrial capabilities, the much larger IRA and the CHIPS and Science Act efforts came to be seen, particularly in the former, as partisan initiatives, which significantly undermined their ultimate viability.

The second limitation is that there is simply not enough money to fix all of our industrial base weaknesses. There is no appetite for perpetual government subsidies to sustain uncompetitive industries. Even the massive CHIPS and Science Act is widely seen as insufficient to reestablish domestic semiconductor manufacturing. With ever-growing budget deficits, the appetite for additional massive public sector industrial base investment programs is just not there in the absence of a major war or a true national emergency. In retrospect, it appears that CHIPS was likely the peak for industrial policy and the large-scale use of appropriated funds for industrial base assessment.

Despite these clear restraints, the need for defense industrial base strengthening remains essential. How can U.S. policy-makers square this circle? That's where the power of U.S. private capital, one of the nation's global discriminators, comes to bear.

Innovation Excursion[2]

Before turning to potential solutions, it is important to briefly describe some of the important innovation efforts that have helped to reengage private capital in defense markets. Many of these issues have been treated in depth elsewhere (Brown & Singh, 2024), but the experiences of these efforts underscore the need for additional methods to engage private capital in defense.

Innovation Hubs

The Defense Innovation Unit (DIU) and respective military department innovation organizations have played a major role in bringing in startups and non-traditional companies, many of which have never done business with DoD. These organizations have played a major role in growing the use of Other Transactions Agreements, in particular Commercial Solutions Openings, that have enabled experimentation and prototyping on a wide range of national security challenges (Defense Innovation Unit, 2024).

SBIR/STTR

Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) are long-standing innovation programs across the U.S. government. Their attractiveness has grown substantially in recent years across Federal agencies. As illustrated in Figure 3, DoD obligated almost $3 billion in SBIR/STTR in FY2023, almost three times that in 2013 and roughly half the total USG investment in SBIR/STTR. Still, their low initial values and struggles with transition discourage many smaller companies. Air Force AFWERX has developed the STRATFI/TACFI programs to help companies transition from Phase II projects and bridge the proverbial valley of death (AFWERX, n.d.). These programs require various levels of matching funding that can from sponsor or private sources and have been widely lauded by private capital-backed firms. Pursuing these types of approaches will help early-stage companies grow and scale rapidly.

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[2] This section draws heavily from McGinn and Hyatt, "Novel Ways to Incentivize Industry," (forthcoming).

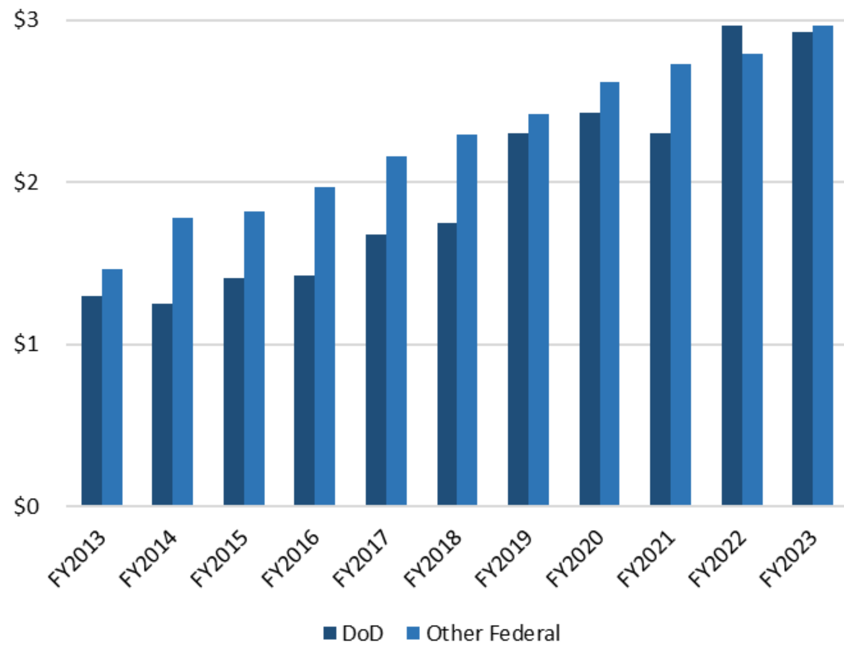

Figure 3: SBIR/STTR Funding, FY2013-2023 ($B)
(Source: SBIR.gov, Baroni Center analysis)

The tracking of the impact of SBIRs, however, has been a longstanding issue because there is no straightforward current way to track the transition of SBIRs as they move out of Phase II. This hinders the ability of government to track the impact of SBIR funding, but it also affects the ability of both government and the private sector to track the impact of venture dollars in defense. In-Q-Tel developed a methodology for tracking the impact of venture dollars from its intelligence investments through PitchBook, so DoD should explore similar methodologies for its SBIR investments.

Public-Private Partnerships

Public-private partnerships (PPPs) have become more common in recent years. PPPs "describe the cooperative relationship between public and private organizations in which the two or more parties share costs, resources, and risk associated with the delivery of goods and services" (Roumboutsos & Saussier, 2014). They allow for more private sector participation than can be achieved through traditional means, and can be harnessed for a wide array of defense needs and priorities, including AI advancement, depot maintenance, efficient defense acquisitions, and many others. Private companies may also have access to additional sources of capital or revenues. For the federal government, PPPs offer several advantages, allowing the public sector to offset risk and acquire lower-cost, and providing more reliable services while also promoting economic growth and employment opportunities. PPPs typically require an agency to work with the private partners and to oversee the planning efforts. To establish a strong PPP, it is important that all parties commit to a long-term relationship, and that they bring complementary skillsets. All stakeholders should also be committed to resource sharing in support of PPP objectives.

DoD has increasingly focused on PPPs as contractual arrangements to elicit more participation from industry, especially to collaborate on innovations that benefit Pentagon strategy and operations. One major example has been the creation of DoD Manufacturing Innovation Institutes (MIIs). These MIIs focus on areas such as additive manufacturing, flexible electronics, lightweight metals, and advanced textiles that leverage the commercial sector to promote innovations in manufacturing technologies that support the U.S. warfighter (Manufacturing USA, n.d.).

Overall, PPPs are not a mechanism guaranteed to promote innovation in every scenario, and do entail transaction costs, but they constitute an impactful tool to facilitate greater DoD-industry collaboration. With over three-quarters of domestic R&D spending originating from the private sector, PPPs offer a pathway to onboard that innovation and capitalize on the resources of entrepreneurs through more close-knit collaboration.

Consortia[3]

The consortia model is another tool in the defense acquisition toolbox. From a single consortium in 2000, this method of fostering partnerships and collaboration has grown rapidly with at least 42 consortia by 2022. Membership has also expanded at a brisk pace with estimates of more than a fifteenfold increase from 2010 to 2019. When used appropriately alongside other acquisition methods, it fosters innovation, expands the industrial base, and accelerates procurement. The key to maximizing its potential lies in maintaining flexibility, improving data transparency, and ensuring the government workforce remains skilled in both traditional and alternative acquisition pathways.

Consortia offer numerous benefits to both government and industry. First, they can aid federal acquisition efforts by promoting government–industry collaboration resulting in early engagement and open discussion which can translate into better-defined requirements and innovative solutions. Second, consortia can facilitate industry partnerships and collaboration, which can occasionally be missing in government contracting while also creating new links in defense supply chains. Third, it can help expand the defense industrial base as the majority of members are often non-traditional contractors and small businesses, segments of the defense ecosystems that DoD is actively trying to recruit. Fourth, consortia can provide vital surge capacity by furnishing a collection of primed potential supplies while also increasing resources available to help manage and navigate the complexities and nuance of federal procurement. Lastly, consortia can help provide federal program offices with experience and necessary skills that may be absent in the existing workforce.

Impact and Challenges

These and other innovation efforts have made tremendous progress in fostering innovation across the DoD community. The dramatic rise in OT agreements and spending, for example, is illustrated in Figure 4:

[3] This section relies heavily on Schwartz and Halcrow (2022).

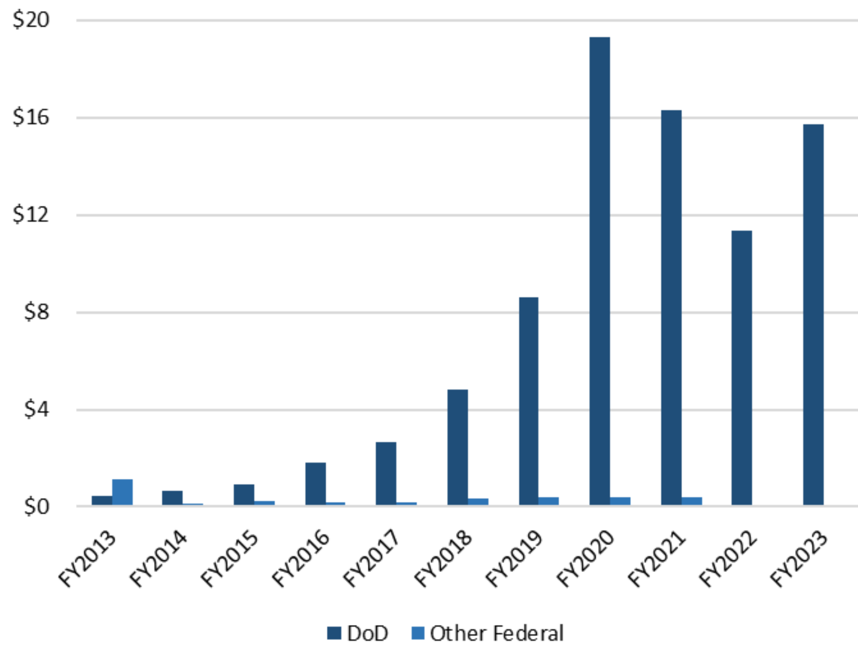

Figure 4: Other Transactions Authority Obligations, FY2013-2023 ($B)
(Source: SAM.gov, Baroni Center analysis)

From 2018 to 2023 alone, DoD use of OTAs increased over 220% to $16 billion.

While this progress has been dramatic, the challenge with all these innovation efforts has been transitioning from prototypes to programs of record. This has been a major focus of recent reform efforts such as the Congressional Commission on PPBE Reform (2024) and could be a focus of the recently announced Executive Order review focused on defense acquisition reform (Executive Office of the President, 2025). The increased deployment of private capital in defense could have a major impact in helping to transition from innovation to production so we turn to that now.

New Models for Capital Markets in Defense

The power of U.S. capital markets is one of nation's major competitive advantages in the global marketplace. The increasing private sector investment in defense through private equity and venture capital funds has led to an emerging focus on how to harness the power of our capital markets to spur increased production capacity and other industrial capabilities in our defense industrial base.

Interestingly, this spurring of increased industry investment is relevant for companies across the defense industrial base. These companies, however, have different time horizons which impact the types of opportunities that will be attractive to different types of firms. Large traditional businesses, whether they are publicly traded or privately held, are primarily concerned with near-term contracts. Because of their size, however, they have the backlog of existing business to develop longer-term opportunities and navigate government processes. Private equity-backed firms, meanwhile, typically have a 5-to-8-year horizon. They are focused more on income and look to grow and position their companies for eventual transaction. Venture capital (VC) firms, meanwhile, typically have a 10-year horizon with their portfolio companies. VCs are more focused on growth so having visibility into future opportunities is of key importance to them.

OSC and Beyond

The Office of Strategic Capital (OSC) has created a loan authority in DoD for the first time in decades. While private capital investment has flowed freely into software-heavy capabilities for years, there is an increasing need to spur private capital into the development of critical hardware-focused capabilities (Brown & Singh, 2024; Murphy et al., 2024). OSC was established to address this specific need. Using authority granted under Section 903 of the FY24 NDAA, OSC was able to launch its first funding opportunity in early 2025 to issue direct loans to companies in the critical technologies value chain. OSC received $9 billion in credit applications, well in excess of the nearly $1 billion in initial lending authority (DoD, 2025b). This is a tremendous start and shows the significant private capital desire to invest in defense.

OSC has also established the Small Business Investment Company Critical Technologies Initiative (SBICCT Initiative), which is a partnership between DoD and the Small Business Administration to attract and scale private investment in DoD critical technology areas. The first cohort of funds is projected to invest over $4 billion into over 1700 portfolio companies, from traditional and non-traditional firms (DoD, 2025a).

Beyond OSD, the DPA already has loan and loan guarantee authority under Title III, but this authority has not been utilized for decades. Several attempts have been launched to revitalize this authority, as recently as during the COVID-19 pandemic, but none have been successful to date.

Finally, there have been increasing calls for the establishment of a U.S. sovereign wealth fund. Sovereign wealth funds are traditionally found in countries with excess natural resources and therefore excess funds for investment. That is not the case in the United States, but President Trump issued an executive order calling for the creation of such a fund and the leadership of the Intelligence Community's In-Q-Tel (IQT) have similarly argued recently (Bowsher & Sewall, 2025).

Purchase Commitments, Credit Guarantees, and Off-Take Agreements

A key market signal for private sector investment is recurring demand. This is difficult in defense because resources are appropriated year-by-year and there are often significant swings in demand. Recent multi-year procurement programs in some munitions have helped create that kind of demand signal, but Congressional support for a major expansion of multi-year procurement is not readily apparent.

Another way to achieve this kind of demand signal, either through venture funding or traditional contractor's use of capital expenditures (CapEx) funding is through the establishment of purchase commitments, credit guarantee programs, off-take agreements, or strategic supply agreements. Policy-makers can establish credit guarantee programs that would help PE and traditional industry (and perhaps VC) derisk their investments in CapEx and other longer-term investments. Establishing loan guarantee program like the Department of Energy's would help address that financing gap(U.S. Department of Energy, n.d.-b).

Purchase commitments under DPA Title III would be additional way of helping set a constant demand signal to help spur private sector investment. DoD is looking to establish purchase commitments for specialty chemicals and critical minerals, but purchase commitment projects are not an option currently because Congress has appropriated DPA funds over the past several 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 (McGinn, 2024a).

Accelerating Depreciation Costs

Alternatively, DoD could also increase the amount or speed of depreciation allowed on CapEx or major investments. This would increase the attractiveness of private capital investment for production facilities ahead of direct appropriations. This will require Congressional legislation, but provisions are currently under consideration by a couple of committees that may address this issue.

Changing Margin Incentives

Finally, federal contractors are currently limited to a certain percentage of profit on non-fixed price contracts. Current levels generate cash and steady levels of profits, but do not readily facilitate increased investment, particularly in publicly traded companies, but also in venture-backed firms. Enabling companies to earn greater margins and therefore greater profits would frankly incentivize them much more than anything else. If DoD structured incentive contracts to enable higher margins for greater performance, for example, DoD could unlock tremendous sources of private capital in defense, much greater than even larger production contracts. This would likely require significant changes in or the elimination of Cost Accounting Standards, which would likely require significant legislative and regulatory change.

Way Ahead

This paper helped to analyze the benefits and limitations of efforts to utilize industrial policy through appropriated funds to strengthen the defense industrial base. The final section identified some methods that could be used to help incentivize the greater use private capital in the defense marketplace. Each of these models needs additional development to determine their feasibility and use cases, but the experience of CHIPS and other appropriations-based efforts has made it clear that we are at, or likely beyond, "peak" industrial policy. It is time to move beyond large scale industrial policy efforts such as CHIPS and put the tremendous power of our capital markets to work to help strengthen our defense industrial base for the future.

The key with all these incentives is that they address the metrics on which traditional, private equity, and venture capital firms are evaluated by their investors and shareholders. Addressing some or all of these incentive structures will spur the level of private capital investment needed to address DoD's needs and today's national security challenges.

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From Breakthroughs to the Battlefield: Best Practices for Tapping Into the Power of Prototyping

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Abstract

Discussions of prototyping often invoke references to the Valley of Death, with blame frequently placed on the acquisition community for not transitioning prototypes and repeated calls for acquisition reform. If done right, however, prototyping programs can sit at the intersection of technology risk reduction, systems engineering and integration, acquisition and production efforts, and end operational use, with benefits that extend beyond developing knowledge and operational capacity. With the intent to rethink the prototype process and reconsider how successful prototyping is designed and measured, this paper assesses the value of prototyping, challenges and barriers to prototyping, and the DOD prototyping ecosystem.

The research team conducted surveys, organized webinars, held workshops, and arranged one-on-one interviews with government, industry, and academia representatives to identify the benefits of prototyping, document best practices, capture the challenges of achieving successful prototyping, and offer a way forward. The findings from the working groups, interviews, and internal research were consolidated into a draft report that will be submitted to a group of expert external reviewers prior to publication.

The paper concludes that many challenges to successful prototyping lie in a disconnect between stakeholders on what constitutes a successful prototyping program and outcome, along with a dearth of reporting and documentation infrastructure. This leads to a failure to take advantage of the numerous benefits of prototyping, including those less considered such as workforce development and enhancing manufacturing capacity. The paper also provides actionable best practices for production and policy recommendations for DOD, Congress, and industry to address these issues. These include resolving disparate definitions and standards, developing processes to measure success and evaluate outcomes, effectively leveraging all readiness levels to accelerate prototype maturity, aligning prototyping efforts with Services acquisition strategies and stakeholders, building avenues for user and technical community feedback to prototyping

programs, and committing to knowledge capture and sharing across the disciplines to truly learn at the speed of relevance and create prototypes that work today.

Executive Summary

> ***prototype: an original model on which something is patterned***
>
> *merriam-webster.com*
>
> ***prototype: a model (e.g., physical, digital, conceptual, and analytical) built to evaluate and inform its feasibility or usefulness.***
>
> *DoD's Prototyping Guidebook*

Discussions around prototyping frequently lay blame on the bureaucratic acquisition process for not transitioning the prototype to production; calls for acquisition reform then echo.

This report explores the power of prototyping and how this power can be amplified beginning with the initial breakthroughs and continuing all the way to use on the battlefield. What if the benefits of prototyping were better appreciated? What if best practices for prototyping were consistently adopted? What if successful prototyping was defined and measured? Is it time to discuss prototyping reform?

Tapping into the power of prototyping begins with acknowledging the benefits of prototyping are not limited to simply learning fast, furthering knowledge, or even transitioning the prototype to a program of record. Prototyping offers many more benefits. Sometimes, these include improving an existing weapon system. Other times, the power of prototyping lies in enhancing the defense industrial base's manufacturing capacity and efficiency. Prototyping always serves to develop the next generation's workforce.

This report notes that the power of prototyping is realized when certain best practices are adopted. When done right, the best prototyping starts with a customer willing to commit the necessary resources and provide feedback. Best practices for prototyping also include an obsession with understanding the customer's real problem. This, in tandem with questioning legacy requirements in the prototyping effort, ensures tangible results for the customer. Other best practices include an unwavering commitment to digital acquisition, pursuing simple and open designs, using internationally recognized standards, and prototyping iteratively—all critical for a successful prototype. Without this type of comprehensive and collaborative effort between industry, academia, and the customer, prototyping would be limited to exploring technical and engineering dimensions of a problem, with limited ability to drive adoption.

But why do we prototype, and what is a successful prototype? Is it the same for every effort? What organization does it best? These questions are often asked—but not answered—by the DoD, Congress, and industry. Finding consensus is difficult due to the conflicting definitions of prototyping, and resolving the difference would be a first step towards defining success. Once success is defined, evaluating the outcomes of current efforts is achievable. This then allows for identifying, replicating, and resourcing the most successful organizational models—maximizing the power of prototyping.

To this end, this report offers several recommendations for tapping into the power of prototyping, from breakthroughs to the battlefield. These include:

- Resolving conflicting definitions between the DoD, Congress, and industry.
- Measuring success, evaluating outcomes, and then modeling the most successful organizations.
- Leveraging all types of readiness levels to support assessment throughout the prototyping process to include technology, software, manufacturing, and sustainment readiness levels

- Aligning prototyping efforts with stakeholders and Services acquisition strategies.
- Capturing and sharing knowledge across the scientific disciplines to truly learn at the speed of relevance and create prototypes that work today.
- Adopting best practices in all prototyping efforts.

Introduction

This report is the result of a partnership between the National Defense Industrial Association's Emerging Technologies Institute and the Greg and Camille Baroni Center for Government Contracting at Costello College of Business, George Mason University. This unique collaboration between academia and industry seeks to inform a better way of defense prototyping to maximize the impact of taxpayer dollars and put the best products in the hands of the customer. The collaborative research team conducted surveys, organized webinars, held workshops, and arranged one-on-one interviews uncovering the benefits and best practices for successful prototyping, document challenges, and offer a way forward.

Survey

Sectors Represented

Over 200 individuals from industry organizations, academia, and even some government entities responded to the survey distributed through multiple industry and academia electronic mailing lists. All sectors of the defense industrial base were well-represented in the survey, to include those supporting the individual Services as well as Munitions, Electronics, and Cybersecurity activities (see Figure 1).

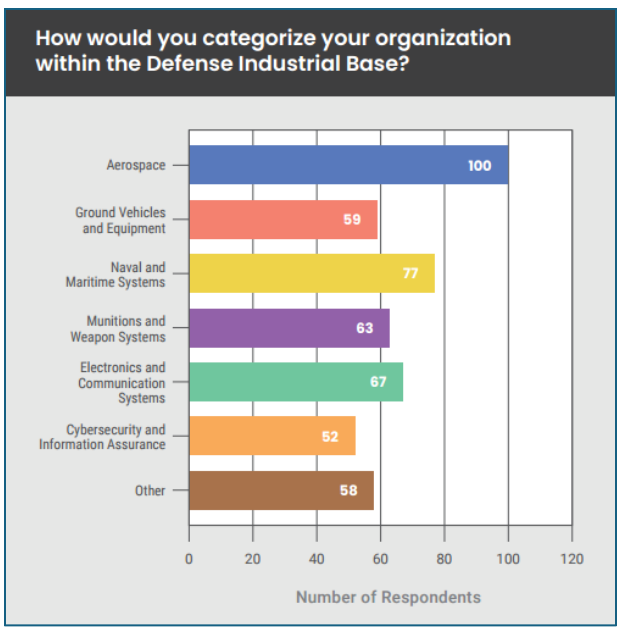

Figure 1. Defense Industrial Base Sectors Represented in Survey
(Note: Respondents could select more than one choice.)
Organizational Types Represented

The survey captured input from a diverse set of organizations, including small businesses and primes as well as traditional and nontraditional defense contractors. Academic institutions, including federally funded research and development centers (FFRDCs), also participated. While the vast majority identified as part of the defense industrial base, 20 respondents identified as non-defense contractors (see Figure 2).

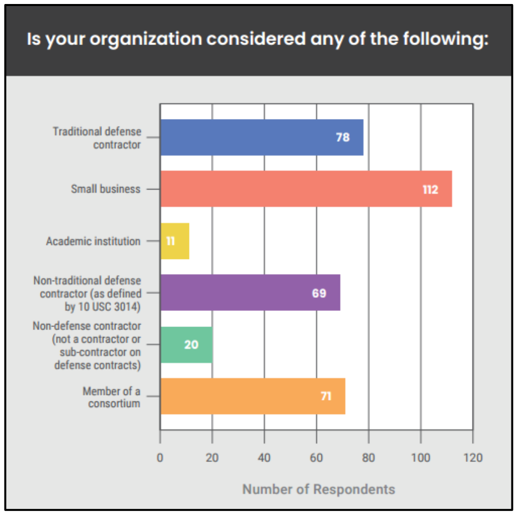

Figure 2. Organizational Types Represented in Survey

Webinars, Workshops, and One-on-One Interviews

Two public webinars were held featuring discussions between consortia and think tanks as well as former senior DoD officials and congressional staff (Clark et al., 2023; Halcrow et al., 2023).

In addition, two workshops were held with a curated group of representatives from both traditional and nontraditional defense contractors varying in size, FFRDCs, academia, and consortia. These workshops focused on four topics, to include approaches to prototyping, the contracting process, best practices for successful prototyping, and the expectations for and circumstances leading to follow-on prototyping activities.

Finally, the authors solicited feedback from peer reviewers to ensure the findings were reasonable and the recommendations actionable.

With all that said, the authors see this report as the start of the conversation, not the final word.

The Power of Prototyping

> ***The Power of Prototyping***
> - *Transition to a Program of Record*
> - *Improve Existing Weapon Systems*
> - *Develop the Next Generation's Workforce*
> - *Enhance the Defense Industrial Base's Manufacturing Capacity and Efficiency*
> - *Further Knowledge*
> - *Learn at the Speed of Relevance*

One of the key findings of this research is that industry and the DoD have differing views of the purpose and power of prototyping. Prototyping often endeavors to learn more about technology and at other times is intended to drive toward acquisition and procurement of a product. Some of the powers of prototyping are more obvious than others, and they range in both actual and perceived impact. When surveyed, industry responded that the power of prototyping lies in transitioning prototypes to programs of records and improving existing weapon systems. In contrast, DoD guidance focuses on the benefits of speed in prototyping to include rapid learning and failing fast (OUSD R&E, 2022, p. 3). In between the aspirations of industry and the goals of the DoD are several other tangible benefits, to include developing the next generation workforce and enhancing the defense industrial base. The power of prototyping can and should be viewed as multifaceted and is amplified when more than one facet is realized in the prototyping effort.

Transition to Program of Record

From an industry perspective, transitioning a prototype to a program of record is the "holy grail." When industry was surveyed, nearly 40% ranked transitioning to a program of record as the most important metric for a successful prototype (Figure 3). This position was also supported by the workshop participants in that ultimate success was when the prototype was transitioned to industry to produce a deliverable product. Interestingly, the *DoD Prototyping Guidebook* does not formally list transitioning a prototype to a program of record as a benefit of prototyping (OUSD R&E, 2022). Although the power of prototyping is multilayered, for industry, the optimal culmination of prototyping activities is transitioning a product to a program of record.

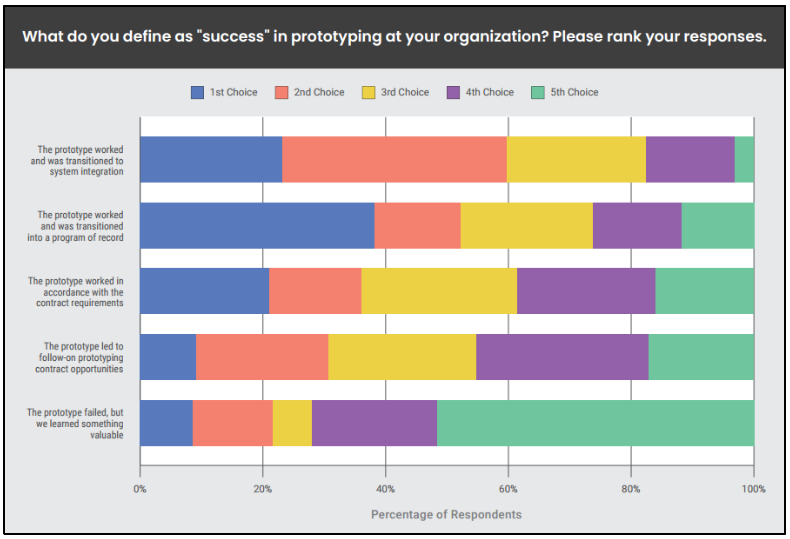

Figure 3. Definition of a Successful Prototype by Survey Respondents

Improve Existing Weapon Systems

Prototyping efforts often result in improving an existing weapon system. While industry participants are often eager to push to transition a prototype to a program of record, the quickest way to adapt to a changing market or environment is to upgrade an existing system, not deliver a new one. Notably, over 60% of the industry survey respondents ranked system integration to improve an existing weapon system as a successful prototyping effort as their first or second choice. This was higher than the first and second responses for transitioning a program to record (see Figure 3).

Develop the Next Generation's Workforce

Another often-overlooked power of prototyping is workforce development. Participation in prototyping efforts accelerates the learning and experience of the next generation's workforce as well as provides motivation and sense of meaning. Take, for instance, the opportunity for students early in their careers to participate in prototyping activities. These opportunities can inspire a lifelong commitment to a particular field of study or even public service.

The Department of Defense (DoD) executes fewer large scale prototyping programs compared to the past. This then leads to situations where, for junior professionals, large scale, high priority, high-cost programs, like the next generation bomber (B-21), are the first opportunity to work on the development of a complex prototype.

Prototyping programs also provide workforce experience with systems integration, hardware and software interfaces, as well as human factors engineering. These challenges are best examined through well-designed prototyping efforts.

Case Study A—Prototyping to Inspire Next Generation of Leaders

The National Defense Authorization Act for Fiscal Year 2020 directed the DoD to establish the Defense Civilian Training Corps (DCTC) to target critical skill gaps necessary to achieve the objectives of the national defense strategy and national security strategy and prepare scholars for DoD careers in fields like acquisition, digital technologies, engineering, and finance.

The DoD established the ROTC-like program to prepare future DoD civilians at four universities: North Carolina A&T, Purdue University, the University of Arizona, and Virginia Tech University. The program includes targeted education and development during the school year as well as summer internships.

For the summer internships, scholars are organized into cohorts from different universities and matched with DoD program offices to collaborate on real-world problems. Each 8-week internship is project-based and product-focused, in many cases involving the development of a prototype. At the end on the internships, the scholars turn the prototyped product back to the sponsor for continued development, which could include involvement of the scholars during their academic year. The summer internship has proven to be the highlight of the DCTC scholars' experience.

Interview with John Willison, AIRC fellow and DCTC Strategic Partnership lead

Enhance the Defense Industrial Base's Manufacturing Capacity and Efficiency

Prototyping is often visualized as creating and testing a "widget"—a physical item. However, prototyping can also involve creating and testing a process. Prototyping a manufacturing process is not often top of mind when considering the benefits of prototyping, but for a widget to be relevant, it needs to be manufactured. Prototyping a manufacturing process requires sourcing the materials at scale, developing repeatable methods, building the required tooling, and training the workforce. In some cases, prototyping a manufacturing process is an independent and distinct prototyping effort from creating a widget. Prototyping a manufacturing process is a valuable, albeit underused, activity for expanding the capacity and efficiency of the defense industrial base.

Case Study B—Prototyping Manufacturing Processes for the COVID-19 Vaccine

Manufacturing enough vaccines for every person on the planet had never been done before, and manufacturing 100 million doses of a vaccine had also never been attempted. But early in the response to the COVID-19 pandemic, this is exactly what was needed—not just developing an effective vaccine but also the ability to manufacture the vaccine at scale.

Operation Warp Speed, a partnership between the DoD and the Department of Health and Human Services, scoped the colossal challenge as a prototype: a prototype to not only develop but manufacture 100 million doses of a vaccine with the ultimate goal of manufacturing enough vaccines for every person on the planet. This approach ensured the development of the vaccine was done with the understanding that the vaccine must be able to be manufactured quickly and within the existing industrial base. Practically, this meant that the materials needed to be sourced quickly, the methods would need to familiar, the tooling would need to already exist or be built quickly, and the additional workforce could be easily trained.

The first contract was awarded in July 2020, and the first COVID vaccines were administered in December 2020. While developing the vaccine was monumental, the ability to manufacture at scale was the real triumph of Operation Warp Speed.

Further Knowledge

Undoubtably, prototyping is a way to further knowledge. Most great scientific advances are rooted in the ability of research to further knowledge, leading to novel real-world applications. Prototyping is part of the feedback loop to help “prove out” these advances. It can shape the customers’ awareness of the engineering and cost “trade space,” allowing them to be a more discerning and engaged transition partner. It can also serve to shape the customer’s understanding of technical possibilities and limitations, improving the quality of requirements generated that drive acquisition programs, and creating knowledge that can shape personnel, training, and maintenance strategies.

Learn at the Speed of Relevance

While furthering knowledge is the primary goal of academic research, the ability to do this at the speed of relevance is even more important. This is especially critical when focused on delivering to a customer in need. Prototyping not only provides the feedback loop but accelerates the cycle time towards further development, production, and use.

Best Practices for Tapping Into the Power of Prototyping

Recognizing and acknowledging the various benefits of prototyping serves to expand and extend the power of prototyping efforts. However, this is not enough. Fully tapping into this power includes adopting best practices. The following best practices, identified in the survey, webinars, workshops, and one-on-one interviews, lay the foundation for future successful prototyping efforts, whether the goal is to transition to a program of record or to simply gain further knowledge.

Best Practices for Tapping into the Power of Prototyping

- *Commitment and Collaboration of Resources*
- *Develop Thoughtful Requirements*
- *Understand the Real Problem*
- *Embrace Digital Acquisition*
- *Pursue Simple and Open Design*
- *Use International Standards*
- *Prototype Iteratively*

Commitment and Collaboration of Resources

Commitment and collaboration of resources is key for tapping into the power of prototyping. Resource commitment includes funding but also includes the focus and attention of the government sponsor as well as the customer. A collaborative spirit should accompany this focus and attention, one where the government sponsor and customer work with industry and academia throughout the entire prototyping process.

Develop Thoughtful Requirements

Developing thoughtful requirements balances an understanding of the needs of the customer and quality market research. Thoughtful requirements include enough specificity to signal to industry they should invest in the effort. Thoughtful requirements should always question legacy requirements and rationalize them with the current operational environment.

Understand the Real Problem

Whether a prototype is furthering knowledge or transitioning to a program of record, understanding the technical or operational problem trying to be solved is a best practice. Understanding the problem keeps the focus on the customer and how the prototype will solve their problem. With a focus on the customer, the probability the prototype is successful increases—however success is defined.

Embrace Digital Acquisition

All prototypes should be “born digital.” Digital acquisition is using digital tools to support the acquisition process, an approach where all aspects, both technical and management, of the prototype are digital across the entire life cycle. Digital acquisition is much more than just digital engineering, technical data management, modeling and simulation, but encompasses requirements and resourcing, continues through contracting to program management, and lives on in sustainment. Digital acquisition even supports audit compliance and is the thread that ties together all acquisition and prototyping reform.

Pursue Simple and Open Design

Simple and open designs are key to tapping into the power of prototyping, especially as a path to production. Simple designs are easier to manufacture as well as sustain; simple designs avoid using “unobtanium.” Open designs, for example as conceived under Modular Open System Architecture (MOSA) approaches, use common interfaces and are a building block to supply chain resiliency avoiding risks like single and sole source suppliers as well as diminishing manufacturing sources and material shortages. Just like being born digital, simple and open designs should be first principles of prototyping (Shaffer & Whitley, 2023).

"With MOSA, rather than building a 'perfect' closed system, the U.S. can field 'good enough' systems and build them up later with rapid and agile technology upgrades. Traditional, closed systems have to be upgraded as a whole, forcing DOD to wait for major upgrades. With MOSA, the Pentagon can incrementally and continually upgrade weapons systems at the pace of technological advancement."

Use International Standards

If prototyping is viewed as a path to production, internationally recognized standards should be the gravel foundation. Over time, the DoD has created their own standards for products and materials. In some cases, military specifications need to be more stringent than non-military standards. In most cases, internationally recognized standards are sufficient. DoD engineers must challenge their use of military standards and shift to using internationally recognized standards whenever possible. This will allow the DoD to fully leverage open designs to incrementally upgrade systems. An added benefit is the number of companies participating in the defense industrial base will expand and diversify.

Prototype Iteratively

Prototyping should be done iteratively, not only building on what already exists, but continuously experimenting. If the original is the result of the previously identified best practices, then the iterative prototype will simply build on that foundation. If not, the iterative prototype can transition to embracing prototyping best practices. Over time, legacy systems will be digitally reborn with open designs and use internationally recognized standards.

Pain Points in Prototyping

Even if all the best practices of prototyping are adopted, challenges exist with realizing the power of prototyping as well as optimizing the use of resources. Conflicting definitions of the purpose of prototyping lead to challenges to measure success, evaluate outcomes, and identify high performing organizational models. These pain points impact the DoD, Congress, and industry alike.

Conflicting Definitions

Words matter, and definitions matter even more. Definitions create clarity of purpose and focus of effort and shape incentives for all participants and the evaluation of outcomes. The disconnect between definitions of prototyping leads to misalignment of priorities and resources on behalf of the DoD and Congress and misunderstanding of strategic outcomes for industry.

In the *DoD Prototyping Guidebook*, prototyping is defined as "a model (e.g., physical, digital, conceptual, and analytical) built to evaluate and inform its feasibility or usefulness" (OUSD R&E, 2022). The DoD's definition of the prototype ends when the feasibility or usefulness is determined. The definition does not include any intent to do anything with this determination.

Congressional use of the word prototyping falls more in line with the dictionary definition of creating a model to be patterned. While there is no official statutory definition of a prototype, statute does describe *prototyping activities* in multiple sections. Section 4022 of Title 10 U.S. Code outlines several definitions of prototype projects to include "the creation, design, development, or demonstration of operational utility." This is aligned with the DoD's definition. However, the other projects listed in 10 U.S.C. 4022 are more focused on creating something to be patterned: developing a prototype to prove a concept, reverse engineering a part for production, or demonstrating an application of commercial technology.

10 U.S.C. 4022 – Authority of the Department of Defense to carry out certain prototype projects
(5) The term "prototype project" includes a project that addresses- (A) a proof of concept, model, or process, including a business process; (B) reverse engineering to address obsolescence; (C) a pilot or novel application of commercial technologies for defense purposes; (D) agile development activity; (E) the creation, design, development, or demonstration of operational utility; or (F) any combination of subparagraphs (A) through (E)

In recent years, Congress has highlighted the need to prototype for a purpose and placed additional requirements for prototyping efforts to promote the creation of minimally viable products (Defense Acquisition System, 2017) and fielded prototypes (Planning and Solicitation Generally, 2019). Most recently, Congress again defined prototyping when it established the Joint Energetics Transition Office. In the context of energetics, Congress clearly stated its expectations of transitioning prototypes as the purpose of the office (NDAA, 2023). Additional responsibilities of the Transition Office include activities to "mature, integrate, prototype, test, and demonstrate" as well as testing, evaluating, and acquiring novel energetic materials and technologies. All of these are focused on prototyping for a purpose with a path to production (Joint Energetics Transition Office, 2023).

While industry doesn't have a formal definition of prototyping, an informal definition was gained for this report through information gathered from the survey, webinars, workshops, and interviews. Not surprisingly, industry's definition of prototyping is more in line with the dictionary definition as well as statutory views that prototypes are original models to be patterned. When surveyed on participation in the prototyping activities outlined in 10 U.S.C. 4022, industry supported "creation, design, development or demonstration of operational utility" as much as it participated in "proof of concepts, model or processes." Only half of the activities were for a "pilot or novel application of commercial technology," and just a quarter were for "reverse engineering to address obsolescence" (see Figure 4).

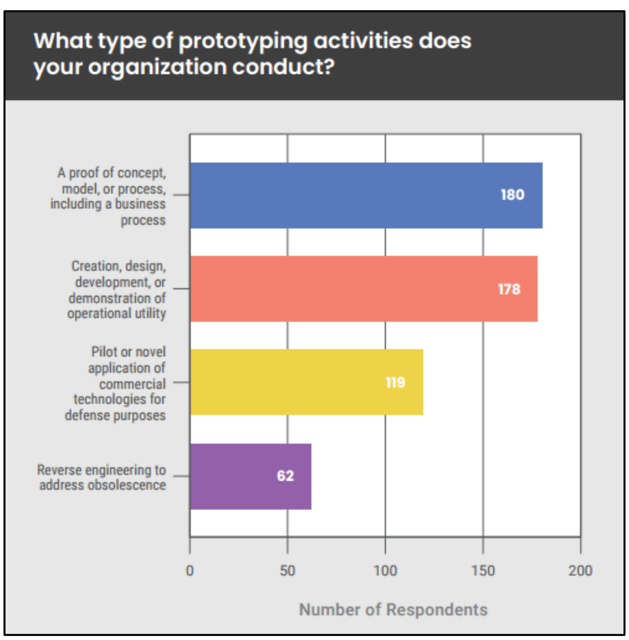

Figure 4. Prototyping Activities of Survey Respondents
(Note: Options were selected based on the definition of prototyping activities in 10 U.S.C. 4022.)

Disagreement on What Constitutes Success

The conflict among the definitions of prototyping used by the DoD, Congress, and industry leads to ambiguity in purpose and more importantly in what constitutes success. The DoD's definition suggests rapid learning and failing fast to learn constitutes success. However, this is not how industry views a successful prototype. When industry was asked to define a successful prototype, over 50% of the industry survey respondents viewed a failed prototype, even if it provided further knowledge, as the least successful prototyping effort (Figure 3). Instead, industry defines success as transitioning to a program of record and integrating the prototype into an existing system. It is worth noting that the DoD definition of failing fast may lean more towards finding disruptive technologies than the industry definition, which seems to seek an outcome that can lead to continued revenue streams under development or procurement programs.

Ability to Evaluate Outcomes

Evaluating the outcomes of prototyping efforts is difficult without clear measures of success. Typical current prototyping programs do not have formal evaluation or reporting requirements. In comparison, the DoD annually evaluates and reports the outcomes of its high priority testing activities in Operational Test and Evaluation Reports (Office of the Director, Operational Test and Evaluation, 2025), and major defense acquisition programs are evaluated through annual Selected Acquisition Reports by their cost, schedule, and performance outcomes (DoD, n.d.). However, there are limited examples of data collection and reporting on outcomes of prototyping efforts, and those that are reported are scattered in annual reports and testimony or independent assessments made by the Government Accountability Office (GAO) or other organizations. Prototyping activities should be evaluated and reported in a comprehensive manner—publicly to the extent possible. Without a comprehensive approach to evaluating the outcomes of prototyping efforts, determining follow-on investments based on prototyping efforts is challenging for the DoD, Congress, and industry.

Assessment of Organizational Models

Many DoD organizations fund the development of prototypes. Certainly, some organizations are more successful than others. However, the lack of metrics on what constitutes success makes it difficult to assess these organizations or even identify organizational best practices. Assessing the most successful organizational models and practices in concert with evaluating prototype successes would enhance the ability of the DoD, Congress, and industry to determine where to allocate future investments.

Resource Requirements

Successful prototyping requires a commitment of budget, personnel, and research, manufacturing, and testing infrastructure. More realistic prototyping, well connected to real-world operational challenges and constraints, will generally also require more exquisite engineering and testing capabilities. Agile software programs, which prototyping with frequent cycles and require the participation of technology developers, acquisition experts, and operational users are extremely personnel intensive. Additionally, timely prototyping can often be misaligned with the DoD's regimented, bureaucratic, and slow budget request and appropriations processes. All of these resource issues can increase the difficulty of the DoD and industry effectively executing prototyping programs.

Prototyping Organizations and Funding Across the DoD

Many DoD organizations have activities focused on prototyping, from consortia to FFRDCs to innovation hubs. A closer look at the organizational models, how they operate, and how they are funded can provide a starting point for assessing the most effective, capturing lessons learned, and improving outcomes.

Consortia

Leveraging the consortia model is a popular choice for DoD Research Development, Test, and Evaluation (RDT&E) organizations to conduct prototyping efforts. As detailed in *The Power of Many* (Halcrow & Schwartz, 2022), government sponsors use the consortia model to access industry and academia for a particular technology area. Comprised of three entities, the government sponsor, the consortium, and the consortium management firm (CMF), most consortia models utilize other transactions (OT) authority as their contracting vehicle. Other transactions can require significant participation of nontraditional defense contractors creating access for the DoD to an expanded defense industrial base. In 2022, a survey of 12 of the 42 existing consortia revealed there were over 4,500 companies that did not traditionally work with the DoD participating in those consortia.[1]

Another benefit of the consortia model is the partnership with consortium management firms (CMFs). CMFs provide administrative functions for both the government sponsor and industry, including nontraditional defense contractors. The CMF functions often include managing the solicitation process, program management, invoice receipt and payments. When used appropriately, CMFs can provide support and surge capacity to the government acquisition workforce (see Figure 5).

Consortium Management Firm Functions	
For the Government:	For the Consortium:
• Solicitation Preparation/Webinars	• Consortium Leadership Support
• Submission Portals	• Member Training and Mentoring
• Whitepaper & Proposal – Receipt/Compliance Review	• Collaboration Portal and Website
• Award Processing/Cost Analysis Support	• Collaboration Events/Membership Meeting
• Project Administration/Close-out	• Member Application Processing
• Milestone/Deliverable Tracking	• Member Database (DD-2345, "good standing" tracking)
• Invoice Receipt/Payment	• Dues/Assessment Invoicing and Collection
• Technical and Financial Reporting	• Program Status & Financial Reporting
• Nontraditional Tracking/Reporting	• Conferences/Booth

Figure 5. Examples of Consortium Management Firm Functions[2]

The consortia model promotes collaboration between industry and the government sponsor. When surveyed on the most important aspects of a successful prototyping contract, industry respondents overwhelmingly ranked communication with the government sponsor as the most important (see Figure 6). Access to follow on contracting opportunities—something which consortia-based OTs provide—was the next most important. Rounding out the top three most important inputs for successful prototyping was time to award.

[1] 10 USC 4021, 4022, and 4023 outline the conditions to be met for utilizing other transaction authorities.
[2] Interviews with Advanced Technology International (ATI), a consortium management firm.

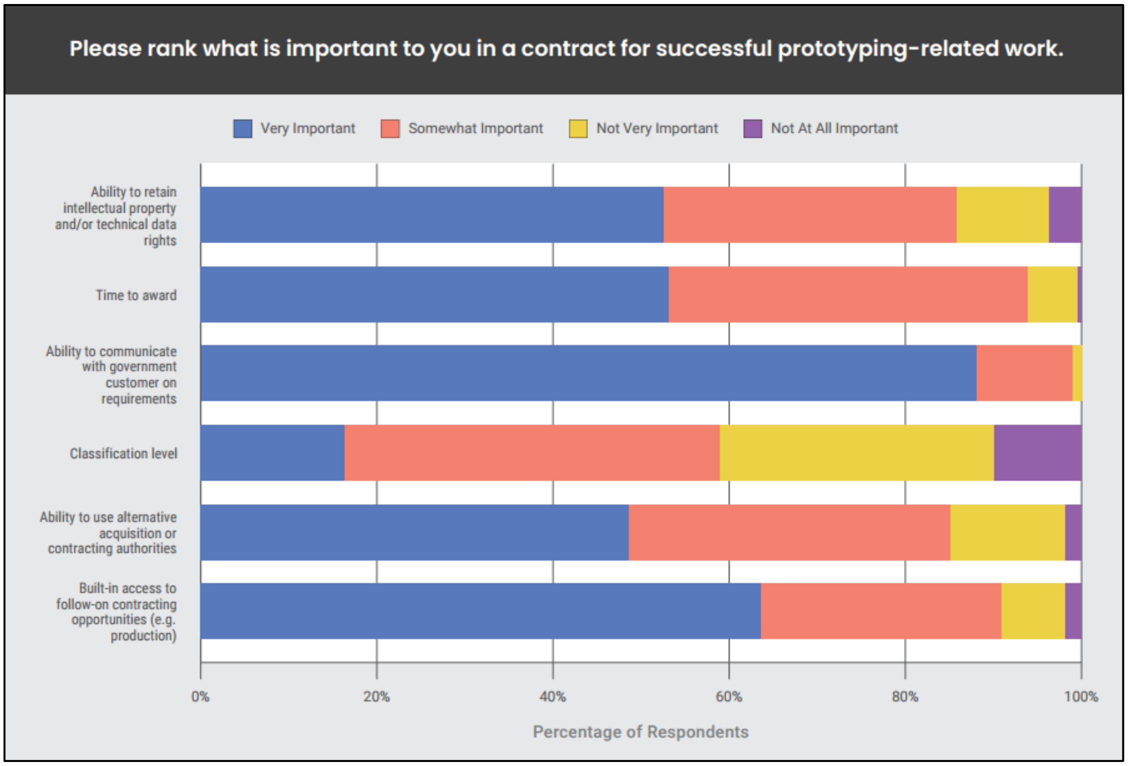

Figure 6. Most Important Characteristics of a Contract to Survey Respondents

One challenge faced by the DoD is transparency of its use of other transaction authorities, especially when leveraged in a consortia model. If the DoD collected and reported this information, the impact, effectiveness, and outcomes of the consortia model prototyping efforts could be better evaluated and used to improve the execution of activities.

Many consortia provide visibility of individual solicitations, awards, awardees, and amounts of awards on their individual websites. However, the DoD does not report these awards in a consolidated, online, publicly available location even though Congress has directed the DoD to report on the activities for many years. Most recently, Section 825 of the Fiscal Year 2022 National Defense Authorization Act (NDAA), (10 USC 4021 Notes), directed the DoD to collect and report the use of other transaction authority as well as any individual task orders awarded under each consortium's overarching other transactions agreement in a consolidated online publicly available location. Statute specifically directed the General Services Administration (GSA) to create the necessary fields in the Federal Procurement Data System (FPDS) and for the DoD to report the data in FPDS. While the GSA has created the fields, they remain blank from the lack of input from the government personnel.

Defense Research and Engineering Enterprise

The Defense Research and Engineering (R&E) Enterprise includes both the funders and performers of research and development activities, such as Service laboratories, warfare centers, and engineering centers, large and small businesses, universities and research centers, FFRDCs, and University Affiliated Research Centers (UARC). The Defense R&E Enterprise conducts forward-looking research and development but also has missions to support technical needs of operational units and the acquisition community, transition new technologies and innovation into acquisition programs to address defense requirements, and transfer technologies into the private sector for commercialization or further development and systems integration. Laboratories are primarily organizationally aligned to the Services and operated by the Army, Navy, Air Force, and Defense Health Agency. Each organization participates in a range of prototyping activities, either performing the engineering and technical work internally, funding such activities in other government or private sector organizations, or working in partnership with external partners.

Defense Units and Agencies

Several defense agencies conduct prototyping activities, including the Defense Innovation Unit (DIU). The DIU has a mission to leverage commercial technology for national security missions and awards funds for research and prototyping efforts (DoD, 2020).

The Defense Advanced Research Projects Agency (DARPA) is another agency that supports defense innovation and historically leverages high-risk, high-reward awards for external research. DARPA currently has about 250 active programs. DARPA's activities range from basic research to systems-level prototyping, including funding complex prototypes (such as unmanned systems, satellites, and battlefield networks). Historically, DARPA prototyping activities have led to modern military capabilities, such as stealth aircraft, precision munitions, and tactical networking systems.

Another government organization, the Strategic Capabilities Office (SCO), focuses on existing DoD systems and invests in repurposing them as complex prototypes for future conflict through "application to new missions, integration with other systems, incorporation of recent technology, or adoption of non-traditional operational concepts" (DoD, 2016).

Considerable prototyping activity of relevance to the DoD occurs in the private sector as well, sometimes funded by the DoD's extramural research programs and sometimes through industry independent research and development (IR&D) or other private sources. This often occurs at engineering centers such as those found within major research universities, FFRDCs, UARCs, and in the corporate research labs of large defense and commercial firms.

Each of the government agencies, along with the Military Services science and technology programs, invests considerable resources in prototyping activities with the intent of transitioning systems or capabilities into acquisition programs and then to operational use. It is difficult to measure the effectiveness of these efforts due to a lack of data collection, common language and metrics, and the cost of such collection and analysis. A 2015 GAO report on DARPA transition of technologies, for example, found that "inconsistencies in how the agency defines and assesses its transition outcomes preclude GAO from reliably reporting on transition performance across DARPA's portfolio of 150 programs that were successfully completed between fiscal years 2010 and 2014. These inconsistencies are due in part to shortfalls in agency processes for tracking technology transition" (GAO, 2015). Specifically, DARPA's process for tracking transition outcomes does not include technology transitions that occur after a program is completed. This is a gap in tracking that the science and technology community struggles with generally, as there is no contractual requirement for reporting during this time frame.

One effort to track prototyping activities can be found in the DIU's annual report, which includes metrics on program activities, to include the number of solicitations, proposals, and awards as well as time to award. Additionally, the DIU reports on the number of prototypes transitioned to production. In 2023, the DIU made 90 prototyping awards for a total of $298 million. Ultimately, 10 of those 90 transitioned to production, with the DIU's definition of transition being "when the prototype successfully completes and results in a production or service contract with a DoD or U.S. government entity" (Defense Innovation Unit, 2023; see Figure 7). To support more effective prototyping and transition of the products of prototyping activities, more organizations should be reporting on their achievements and lessons learned, as well as what constitutes success needs to be defined.

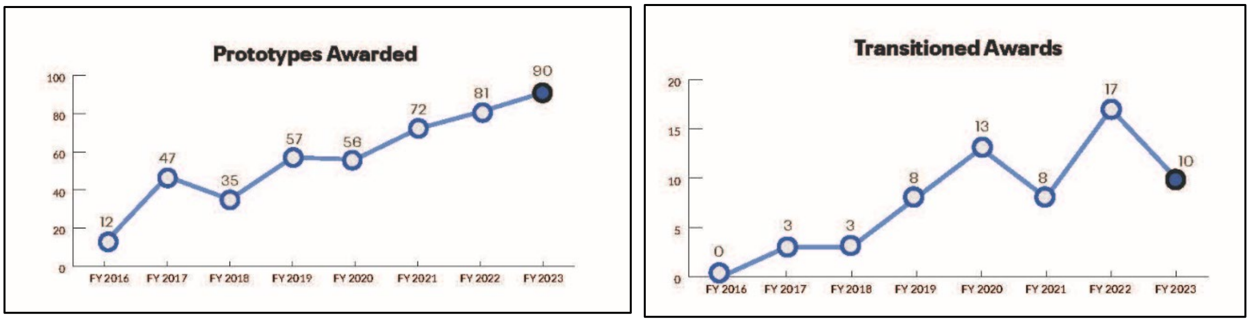

Figure 7. Defense Innovation Unit Prototypes Awarded and Transitioned
(Defense Innovation Unit, 2023)

Innovation Organizations

According to the DoD's chief technology officer, there are 300 organizations that make up the "innovation pathways" across the DoD (see Figure 8). Visibility into the consolidated activities of the innovation organizations is difficult, and assessing the results of these activities is even more challenging. As a first step to evaluate outcomes of prototyping, Congress directed the Under Secretary of Defense for Research and Engineering to report on transitioning innovation efforts for critical technologies in Sec. 217 of the FY2021 NDAA. Surprisingly, the DoD's report to Congress is marked as controlled unclassified information (CUI) even though much of the activity at the innovation organizations is conducted at an unclassified level and in partnership with nontraditional defense contractors, commercial firms, and universities. Interestingly, the DOT&E Annual Reports (DOT&E, 2025) and Selected Acquisition Reports (DoD, n.d.), which are more focused on near-term capabilities and ongoing acquisition efforts, are unclassified and publicly available online.

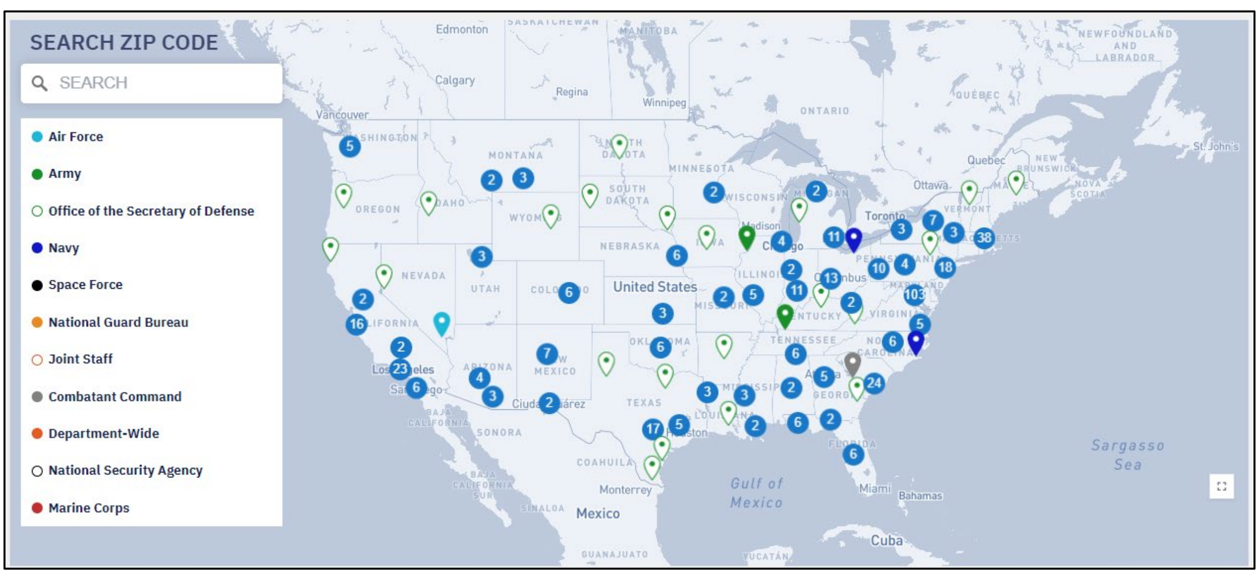

Figure 8. DoD Innovation Organizations
(Office of the Under Secretary of Defense for Research and Engineering, n.d.)

Funding – Budget Activity Codes

To fund the organizations listed above, RDT&E appropriations requests are required by the DoD's Financial Management Regulation to include a budget activity (BA) code that generally corresponds to the RDT&E technology readiness level (see Figure 10). This coding is unique to RDT&E budget requests and is more granular than procurement programs which are only identified by the procurement program name. Prototyping is typically associated with programs funded under BA codes 2 through 4, and total funding for these budget activities has doubled since 2001. However, the lack of transparency from the DoD in the outcomes of prototyping efforts makes it is difficult to assess the return on investment of this increase in funding over the years (see Figure 9).

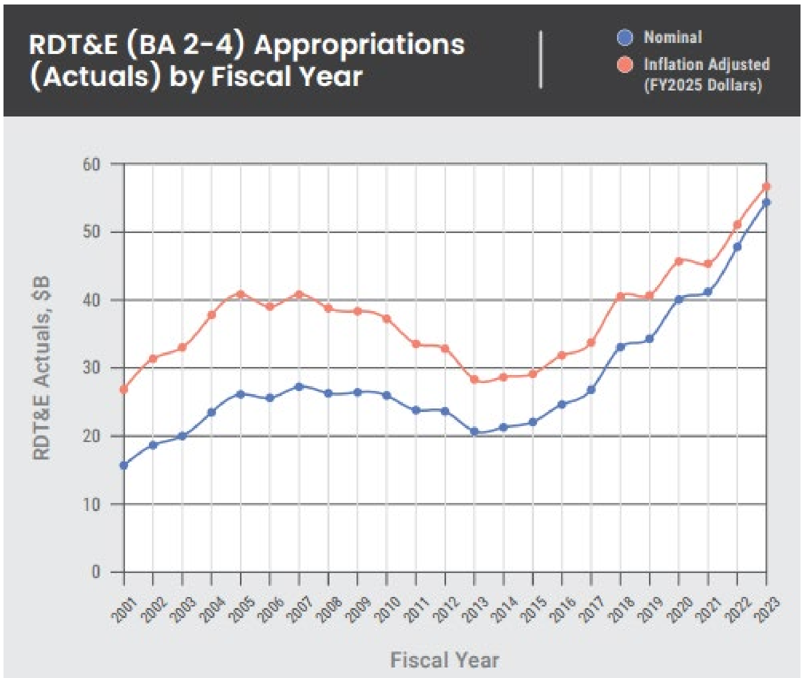

Figure 9. RDT&E (BA 2-4) Actuals by Fiscal Year

Technology Readiness Levels

Technology Readiness Levels (TRLs; OUSD R&E, 2023) are closely associated with appropriations funding. TRLs assess the technology maturity of RDT&E activities. First developed by NASA, the same definitions are used by industry, academia, and the DoD.[3]

Technology Readiness Levels (TRL) classify the progression of technology from basic research through prototyping and finally into a program with 1 being the least mature technology and 9 being the most mature. An organization that focuses on initial RDT&E may have different expectations of the next steps than an organization that participates in later stage efforts. To consider this, the survey asked about the maturity level, or TRL, of the respondents' prototyping activities.

[3] National Institutes for Health uses a technology readiness level hierarchy like the DoD with definitions tailored for medical research.

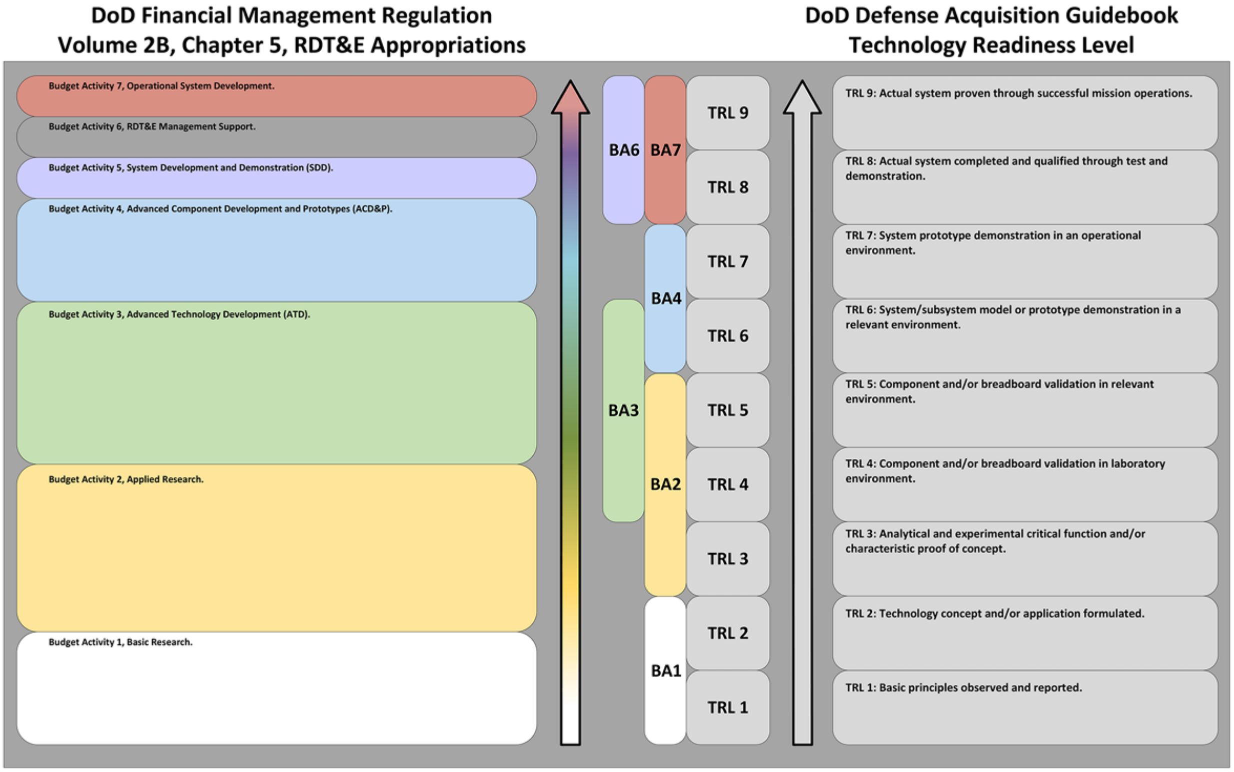

Figure 10. Budget Activity Codes and Technology Readiness Levels
(Defense Acquisition University, 2024)

Other Readiness Levels

DoD policies and guidebooks include readiness level frameworks for software, manufacturing, integration, systems, and even sustainment maturity (see Figure 11). Only software readiness levels get top billing, while the others are relegated to the ends of the documents or appendices.[4] Unlike TRLs, other readiness levels are not employed in formulating the DoD's budget request or appropriations. For this reason, these useful frameworks are rarely used in conversations or decisions about the future viability of prototyping efforts.

[4] In the DoD's *Technology Readiness Assessment Guidebook*, Technology Readiness Levels and Software Readiness Levels are the core of the document. Manufacturing, integration, systems, and even sustainment maturity are in the final chapter. In GAO reports, other readiness levels are listed in the appendix.

Readiness Levels Other than Technology	
Software Readiness Levels (SRL)	SRLs follow the TRL framework closely.
Manufacturing Readiness Levels (MRL)	MRLs are tied to TRLs and described in the Manufacturing Readiness Level Deskbook. which is not an official DoD publication but offered on a .com website as best practices (Department of Defense, Office of the Secretary of Defense Manufacturing Technology Program, 2022).
Integration Readiness Levels (IRL)	IRLs measure the maturity level of systems integration. Surprising, this is not used more often since many prototyping activities are for existing weapon systems.
Sustainment Maturity Levels (SMLs)	SMLs are included in the Product Support Manager Guidebook. Of note, SMLs do not address critical sustainment challenges that could be addressed in technology development like Modular Open Systems Approach (MOSA), Diminish Manufacturing Sources and Material Shortages (DMSMS), or Supply Chain Risk Management (SCRM).

Figure 11. Readiness Levels Other Than Technology
(OUSD R&E, 2023)

Next Steps for the DoD, Congress, and Industry

To fully capitalize on the power of prototyping, Congress, the DoD, and industry should take the necessary steps to resolve conflicting definitions, define and measure success, evaluate outcomes and model successful organizations. In addition, the DoD, Congress, and industry should collaborate to better leverage all readiness levels and seek better alignment of prototype efforts. Through all this, a concerted effort to capture and share the knowledge gained from prototyping must be accomplished. Finally, to unlock the full power of prototyping, adoption of the best practices identified in this report is imperative.

Next Steps for DoD, Congress, and Industry

- *Resolve Conflicting Definitions*
- *Measure Success, Evaluate Outcomes, Model Successful Organizations*
- *Leverage All Readiness Levels*
- *Align Efforts with Stakeholders*
- *Capture and Share Knowledge*
- *Adopt Prototyping Best Practices*

Resolve Conflicting Definitions

The DoD should update its definition of prototyping to include a path to production so there is a direct connection to the customer who might use the end item patterned after the original model. Congress should support and encourage the DoD’s efforts. Resolving the definition disconnect between the DoD, Congress, and industry would be a first step to provide clarity of purpose, focus of effort, and evaluation of outcomes of prototyping activities. To reiterate, the DoD’s definition is focused on rapid learning and failing fast. It does not include any of the other benefits of prototyping, especially not transitioning to production.

Measure Success, Evaluate Outcomes, Model Successful Organizations

The DoD should establish clear criteria for what constitutes success of a prototyping effort and then require all organizations engaged in prototyping to report to these measures of success. To this end, Congress should expand the requirements of Sec. 217 of the FY2021 NDAA and establish publicly accessible reporting requirements in the vein of those required for testing and acquisition efforts.

What constitutes success for one organization might be different than another, but holding organizations accountable for a return on investment is essential. This is an effort the DoD can benefit from immediately. Funding for prototyping activities doubled in the past 20 years, but the return on this investment remains unclear (see Figure 10).

Over time, the DoD can use this information to evaluate the most successful prototyping organizations, duplicate their best practices, and resource accordingly. Congress should support this effort of realigning resources to the most successful organizations.

Leverage All Readiness Levels

The DoD should begin better leveraging all readiness levels (e.g., software, manufacturing, systems integrations, sustainment) for program management by formally establishing in policy a process to integrate the other readiness levels with TRLs. Congress should support this effort by directing the GAO to evaluate the DoD's use of all readiness levels as they relate to prototyping activities. Prototyping efforts would benefit from prioritizing the use of all the available readiness levels in addition to technology readiness levels to include manufacturing, integration, system, and sustainment maturity. This would guarantee the research communities keep the acquisition life cycle top of mind when working to transition prototypes.

Align Efforts With Stakeholders

The DoD should that acquisition leaders and stakeholders are cognizant of proposed and ongoing prototyping efforts. Successful prototypes are aligned with the priorities of Service acquisition leaders and stakeholders to support the customer. Service acquisition leaders and stakeholders set the requirements to solve the customer's problem, and prototyping efforts should be aligned to respond to those requirements.

Capture and Share Knowledge

The DoD and industry should develop a useful knowledge capture system based on the latest technology. To truly further knowledge and learn at the speed of relevance, capturing and sharing this information is critical. The lack of knowledge capture and information sharing was raised multiple times by workshop participants from industry and academia. Even individual research organizations noted a lack of an internal comprehensive knowledge capture system.

Adopt Prototyping Best Practices

The DoD should update its Prototyping Guidebook with the best practices identified by this report. At the same time, current prototyping efforts should commit to the best practices now to ensure the power of prototyping is realized from breakthroughs to battlefields.

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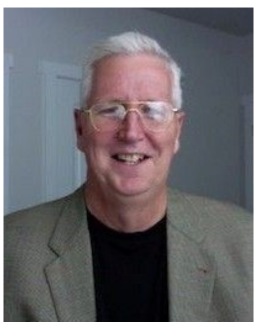
SUMMIT PANEL 7. INNOVATING NATIONAL SECURITY: MODELS, METHODOLOGIES, AND UNBOUND POTENTIAL

Thursday, May 8, 2025	
1225 – 1340 PT 1425 – 1540 CT 1525 – 1640 ET	**Chair: Dr. Dave Lewis, VADM USN (Ret), Professor of the Practice, Naval Postgraduate School** ***Developing a Model of National Security Innovation: Systems, Types, and Enablers*** William Greenwalt, Senior Fellow, American Enterprise Institute ***Prometheus Unbound*** Dr. Dave Lewis, VADM USN (Ret), Professor of the Practice, Naval Postgraduate School ***An Exploration of Methodologies Used to Measure Technology Maturity in Department of Defense Non-ACAT 1 Programs*** Commander Jeff Legg, Industrial Supply Officer, Fleet Readiness Center Southwest



Dr. Dave Lewis, VADM USN (Ret)—Dr. Lewis is a retired United States Navy Surface Warfare Officer and Engineering Duty Officer. He currently serves as a Professor of the Practice at the Naval Postgraduate School, Monterey, CA as an intermittent employee. He works full time in the Defense Industry.

His leadership assignments included duty as the Aegis Shipbuilding Program Manager, Program Executive Officer, Ships, Commander, Space and Naval Warfare Systems Command, and prior to his retirement, as Director of the Defense Contract Management Agency.

His afloat tours were in USS Spruance (DD-963), USS Biddle (CG-34) and USS Ticonderoga (CG-47), all in combat systems and communications assignments.

David Lewis earned bachelor's and master's degrees in computer science and a certificate of completion in Weapons Engineering. He recently completed his Ed.D In Leadership and Learning in Organizations. He is a graduate of the Naval War College, Vanderbilt Peabody College, the Naval Postgraduate School and the University of Nebraska.

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Developing a Model of National Security Innovation: Systems, Enablers, and Types

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Abstract

This paper presents a proposed taxonomy of innovation terms that can be arranged into a larger explanatory model of defense innovation. After outlining the case for a capabilities-based definition of the term innovation, the concept of innovation systems (international, domestic, commercial, military/governmental, and civil-military integrated) is introduced. Innovation enablers are then described as the means or factors to produce capabilities-based innovation. These include diffusion, invention, culture and politics, the industrial base, the workforce, the legal and regulatory environment, finance, leadership, and time. Next, innovation types or strategies are introduced to describe the incentive structures that can be deployed within each innovation system. These types include stasis, minimally reactive sustaining, incremental proactive sustaining, reactive and proactive time-based, revolutionary step change, and disruptive. DoD since World War II has employed each of these innovation types in defense acquisition. Disruptive, revolutionary, and time-based innovation primarily occurred in the early Cold War period until it was primarily replaced in the 1960s by an incremental proactive sustaining model. This model has dominated U.S. acquisition ever since. To compete in any new Great Power competition, defense innovation approaches will need to become more time based and disruptive and more integrated with the commercial innovation system.

Introduction

Innovation is perhaps an overused concept in discussions about national security and business competitiveness. Innovative nations are assumed to succeed on the battlefield and dominate markets. To be innovative distinguishes a company or country from its peers. It is a sought-after goal in commerce as it is government. Whatever innovation is we tend to want more of it. Except when we don't—reflected in the many barriers put in place to maintain a status quo in the balance of power, market share, or employment.

Despite these countervailing pressures, in national security debates calls for improving defense innovation are consistently made in Congress and the Pentagon. Policies are deliberated on the basis of what increases or slows down this innovation. Yet, without further defining what is meant by the term or actually being sought, policy-makers risk talking past one another and making poor decisions. That is important as proposed reforms to the acquisition, budgeting, requirements, technology security, and personnel processes are often linked to what is believed to support "greater" innovation or to protect our current advantages.

In an effort to provide greater clarity and rigor to discussions related to developing new defense capabilities this paper will propose a taxonomy of innovation terms that can be arranged into a larger explanatory model of defense innovation. This effort is informed by the current literature on commercial innovation and by the history of U.S. defense acquisition.

After outlining the case for a capabilities-based definition of the term innovation, the concept of innovation systems—international, domestic, commercial, defense, and civil-military—is introduced. Elements or components within these systems can either serve as enablers or barriers to innovation and comprise the next level of complexity of analysis. These factors such as invention, diffusion, the workforce, or finance are the means or factors to produce innovation. If the wrong policies or circumstances prevail, these supporting functions can also impede desired results within an innovation system.

Next, innovation types are described as part of a spectrum or cycle of innovation strategies. These types describe the workings and outputs of the incentive structures that are deployed within each innovation system (i.e., stasis, sustaining, reactive, proactive, predictive, time-based, incremental, revolutionary, or disruptive). A test of the explanatory benefits of the model is found by describing the history of U.S. defense acquisition through the lens of these concepts.

I do not pretend for this paper to be the be-all end-all authoritative guide to the topic but it is designed to begin a conversation on trying to make more sense out of cacophony of thoughts about defense innovation. Many may disagree with its premises. Hopefully, however, a dialogue on this topic could eventually lead to instilling more discipline in the debate over weapon systems acquisition issues and perhaps even larger discussions of innovation in the global economy in general. While it may be a false hope that armed with a more rigorous classification model better decisions will be made in the future, perhaps at least more effective questions could be asked when promises are made about future innovation and modernization that create expectations for one thing but may deliver another.

Defining One's Terms: What is Defense Innovation?

Innovation in national defense has been a hard concept to describe with any precision. A lack of rigorous definition allows the concept to mean different things to different people that can mask serious disagreement on policy and approaches. Having been involved in many of the acquisition reform debates since the Federal Acquisition Streamlining Act of 1994 (FASA) where leveraging commercial "innovation" was a primary goal, I have watched this dynamic play out in how acquisition law is made, but perhaps more importantly in how the law has been implemented.

We should attempt to measure innovation or at a minimum be able to recognize it when it has happened. I will argue that innovation needs to be discussed in a tangible, capabilities-based manner. This does not just mean the creation of new technology, but just as importantly, how that technology is used. New capabilities created from hardware and software origins can comprise one aspect of innovation and then equally, if not more of a marker of progress, is how a human or group of humans can use this capability in new and different ways.

But first how to get there. Defense innovation, while a critical concept to understand, has proven to be extremely difficult to describe or measure. It is ill-defined as it rests upon the much more nebulous concept of innovation in general. Nonetheless, many areas of inquiry provide insights into refining these concepts. In the field of business management, innovation has received significant attention (Christensen, 1997; Collins, 2001; Drucker, 1985; Kim & Mauborgne, 2005; Thiel, 2015). Although he didn't expressly explore the concept of defense innovation, Christenson (1997) is helpful in not only trying to address the issue of the quality of innovation, but also the effects of innovation.

Another relevant field of innovation inquiry has been in the area of economic history, particularly on the identification of technological turning points and their relationship to economic growth, often with a lag as new technologies require time to be adopted (Gordon, 2012). Defense innovation can be categorized using a classification of significant turning points in defense technologies and capabilities, grouping into historical periods various disruptive technologies such as gunpowder, the longbow, firearms, the machine gun, iron-hulled ships, submarines, tanks, aircraft, radar, the jet engine, missiles, reconnaissance satellites, nuclear weapons, stealth and precision guided weapons, and navigation.

Both of these paths of inquiry are useful for a discussion on defense innovation and helpful in framing questions such as: What is defense innovation? Why focus on technological change? Is there a U.S. defense innovation problem? Are there limits to growth in innovation?

Webster's Dictionary defines innovation as a new idea, method, or device, or the introduction of something new. But newness for the sake of newness may not always define the best types of innovation needed by the Department of Defense or the market. Ideas are important but may be better defined as an initial enabler of innovation. New methods of using technology imply innovation, but improved methods or process that led to the production of new technology capabilities can also be categorized as innovation enablers.

In a practical sense, and at its most basic level, innovation can be looked at as some given output to a series of inputs (financial resources, personnel, equipment or capital, research, or ideas) that come together to deliver some new thing or process that is markedly different from and (this part is key) provides some advantage over the previous output. Innovation is more than just a new thing or process, and to adequately be considered innovative, it becomes necessary to identify this advantage. Attempting to measure or quantify the impact of a new technology or process—generally a subjective comparison of two different circumstances or states in time—is not always easy. Innovation as a concept becomes much more complicated when attempting to come to terms with the *quality* aspect of change, or the level of advantage over the previous thing or process, but that concept is critical. Something may be new and different but may not be better.

Innovation is tangible, but also intangible. It can be software or hardware. It can then be a way to use that software and hardware in new ways. For this effort, innovation is defined as a capabilities-based variable. It is something that is distinct and better than what was used before, and the difference that this new capability can provide is the quality measure of the innovation. Thus, there are two aspects to the capabilities-based innovation equation—a technological or process one and then a quality one.

Innovation is not invention. Invention will be defined subsequently as an enabler of innovation. A key data point for innovation analysis is to be found in the later stages of technology development, particularly in the operational prototyping and fielding of a defense capability or weapon system where operators use and test the system. A similar point in commerce would be at the stage of the marketing of a new product where consumers for the first time decide whether to buy such a product. Most prototyping is useless as a marker for innovation and more appropriately classified as advancing science or knowledge. It is not until a prototype is "operational" where there is a minimally viable product that users can operate and test, and if needed, use on the battlefield or sell in the market.

Once usage happens, a threshold has been crossed that provides for a real basis for analysis. It is for that reason that science and technology development once it has led to a first deployment as a capability is an appropriate measure of defense innovation. When this line is crossed and an operational prototype is created, the acquisition system is in new territory. This aspect of congressional acquisition reform efforts where Middle Tier acquisition and OTA prototyping are linked to operational capability has seemingly been missed by the acquisition community. Prototyping and operational prototyping are different. One furthers knowledge. The other provides capability, albeit without all of the "ilities" being worked *out.* The measurement of defense innovative efforts should first be focused on the physical weapons system capabilities that are tested, deployed, and used by a military force.

Thus, on one level, defense innovation can be defined as the changes that are made with technology as demonstrated in the tangible and measurable output of a deployable defense capability. These deployed or operational programs are material and calculable. When trying to measure or define defense innovation, it often becomes practical and logical to focus on weapon systems. This is not only where most data are, but also where there has been the greatest focus of governmental and academic literature on defense management and acquisition.

But focusing just on defense technology or solutions is incomplete. Defense innovation also occurs in many other non-technology areas, and just because there is not a 50-year history of Selected Acquisition Reports data to analyze in a sector does not mean that innovation is not happening. Process innovation can be argued as being equally as disruptive or innovative. In looking beyond defense technology, defense innovation can be found in a number of personnel, process, and operational adaptations.

Innovation can occur through the use of different strategy and tactics, such as the application of forces and technology in new combinations, for example, the Blitzkrieg of the 1940s, the Airland Battle of the 1980s, the concept of All Domain Operations, or potentially “Mosaic Warfare” in the future. The French had more tanks than the Germans at the start of WWII, but they also had a different and ultimately unsuccessful concept of operating them. James Q. Wilson thought the secret to the German success against France was better organization: “The key difference between the German army in 1940 and its French opponents was not in grand strategy, but in tactics and organizational arrangements well-suited to implement those tactics. Both sides drew lessons from the disastrous trench warfare of World War I. The Germans drew the right ones” (Wilson, 1989).

Finally, when coming to terms with innovation, we have to be extremely careful not to be obsessed with data. Just because something can be measured and there is data, we tend to want to focus on that and then risk extrapolating a wrong conclusion. Many of the most important variables may not be conducive to quantification. Intuitive and sometimes subjective analysis in these cases will be more important to policy-makers. Inevitably, if innovation is judged to be capabilities-based, the quality of this innovation will be a subjective call until it is used in a conflict or has been judged in the commercial marketplace. If we only focus on what we have data for, it is highly likely we will miss some hugely important idea and prospect for future innovation. The widely attributed to but unverified comment of W. Edmunds Deming, “In God we trust. All others must bring data,” is helpful in certain types of innovation, particularly in the incremental quality-based management process that Deming advocated, but may close out pathways to more disruptive innovation.

Innovation Systems: International and Domestic, Commercial, Defense, and Civil-Military Integration

After defining innovation as the creation and adoption of new technological, process, or use-case capabilities that are better than before it is important to understand where any of this innovation is taking place. In this section, I will begin with proposing a foundation of one overarching international innovation system comprised of many separate domestic innovation systems. Within each domestic system there exists a commercial and a governmental defense system that normally act in parallel and separate from each other. A third distinct and often superior domestic system occurs when interaction is incentivized between the commercial and defense systems that can be described as a civil-military integrated (CMI) system.

As much as many may currently despair of globalization, a global system that eventually leads to technology and knowledge transfer has always existed. The timeframes of this transfer say in the Bronze or Iron Ages may have been incredibly slow, but interaction and technology and knowledge diffusion eventually did occur—ether by conquest, migration, or espionage. We have essentially been living in an international system of innovation since the dawn of agriculture or when humans first picked up a stick and used it as a tool. The difference is the rate of diffusion of knowledge or technology. That rate has been radically ramped up in the information age.

Within the international innovation, system creation and adoption occur at uneven rates in different geographical units and economic systems. Thus, the international system is comprised of potentially hundreds of separate domestic innovation systems (Figure 1). The level of interaction between these domestic innovation systems will vary by the level of globalization and trade, conflict, and the establishment of military alliances. New capabilities, whether embedded in new technology or new ways of using technology, have usually occurred in one national domestic innovation system and then diffused to other systems, although joint research can lead to the development of joint capabilities, for example, the F-35. Still, it is necessary to recognize that while joint innovation programs occur, most innovation primarily resides in competitive nation states with national or regional champions vying for supremacy (i.e., Boeing vs. Airbus or founders toiling in Silicon Valley, the Oxbridge corridor, and Shenzhen) sometimes cooperating across domestic innovation systems, but mostly competing.

There is a strong tendency toward autarky writ large in each domestic innovation system that attempts to limit interaction with other domestic systems in the international system. Countries will often want to protect their intellectual property and advantages created in their domestic innovation systems and reduce any dependencies on other systems. Complete autarky may be impossible, but an attempt to do so will likely lead to unbalanced innovation—breakthroughs on one hand and decline on another. North Korea is a splendid example of an autarkical domestic innovation system seeing advances in nuclear and missile technology while lagging behind in most other technologies and use cases. Ricardo's concept of comparative advantage still rings true in commercial innovation magnified by a willingness to allow Smith's invisible hand of commerce drive the Wealth of Nations. A similar effect can be seen in the strengthening of military alliances through the sharing of technological knowledge and joint cooperation.

While markets and military competition and cooperation may indeed be global and international, I will begin this exercise with something simpler by describing one domestic innovation system with the understanding that similar forces are at work in other domestic systems. These many domestic systems of course interact, and as one wants to add in complexity, those interactions can be described and evaluated primarily through the innovation enabling variable of knowledge diffusion. It is far likelier that innovation is occurring first in domestic systems either through domestic market competition or by the internal recognition of external threats that drives defense innovation. The U.S. system is thus one of many domestic or country innovation systems that collectively make up the overarching international innovation system and can be first looked at through its domestic framework.

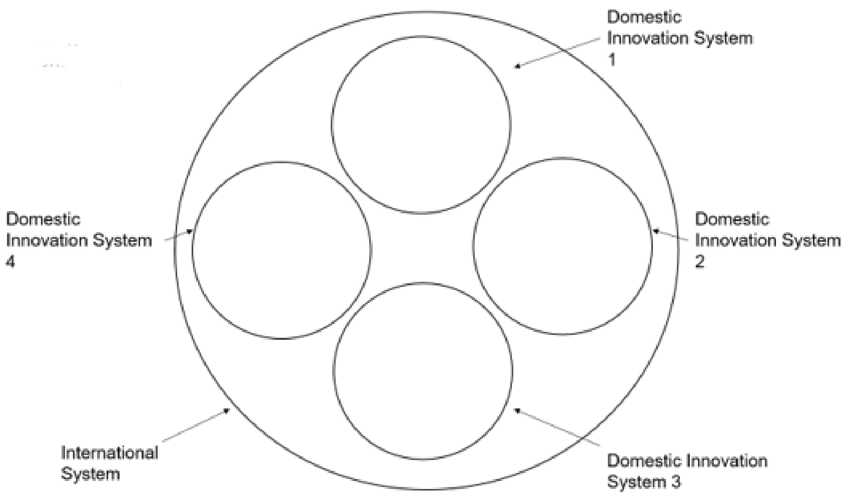

Figure 1. The International Innovation System

At its simplest, the domestic innovation system is comprised of two parts: a domestic commercial system and a governmental backed defense system (Figure 2). These systems are first displayed as tangential to one another and not interacting. This reflects much of the peacetime history of the U.S. prior to WWII. The military system valued the independence of its government operated arsenals and shipyards. It was only in wartime that major interaction between the commercial and military innovation systems occurred at scale. In peacetime that interaction was usually limited to the commercial system selling raw materials into the defense system.

The commercial innovation system essentially operates based on market forces and incentives to address the needs of the consumer and businesses. Wherever the government controls the means of civilian production, that sector of the commercial innovation system moves to the right and becomes part of the military/government system. There would be a very small if not non-existent commercial sector in a traditional communist system like North Korea. Thus, each domestic innovation system in the world is different based on policy choices of what portions of the economy the government decides to control and which is left to the market. Innovation can occur in either commercial or governmental systems, but outputs can vary greatly.

As the United States has found out in its economic history when the commercial and government systems are encouraged and incentivized to interact, some truly amazing leaps in innovation can occur. It was primarily during longer conflicts that a greater degree of this type of integration was allowed to take place. After these conflicts ended, the two innovation systems drifted apart—although this did not completely happen for a time after WWII, which is significant. During these periods of wartime commercial-military cooperation, a push-pull dynamic occurs that immediately leverages commercial technology into the military side while initiating a slower pace of diffusion of military technology to the commercial side. Over the subsequent intervening period of time between conflicts, this technology is then modified and improved upon in the commercial system by market forces (see Figure 3).

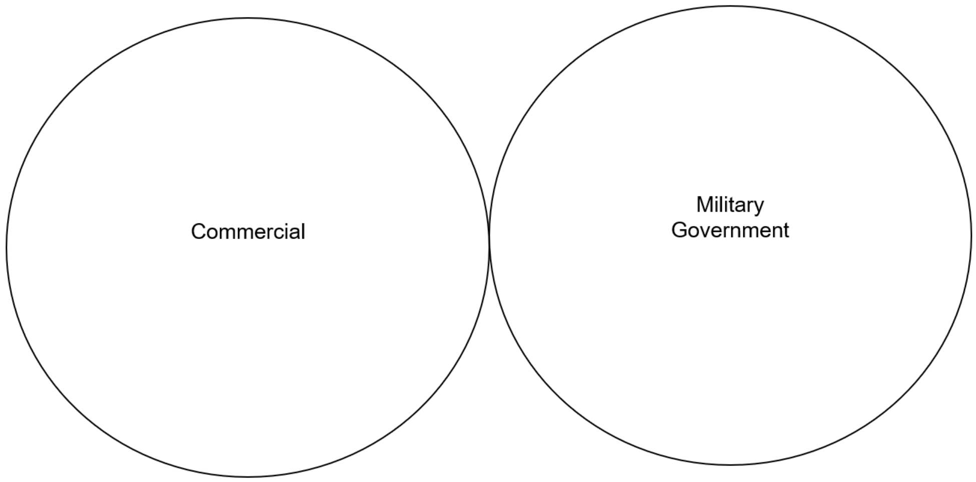

Figure 2. The Domestic Innovation System

There is a direct link between defense and commercial innovation and the two are intertwined. The concept of Civil-Military Integration (CMI) that Jacques Gansler advocated for during the FASA period, and that the Chinese have now adopted as Military-Civilian Fusion, is a real phenomenon and does not need to only happen just in wartime.

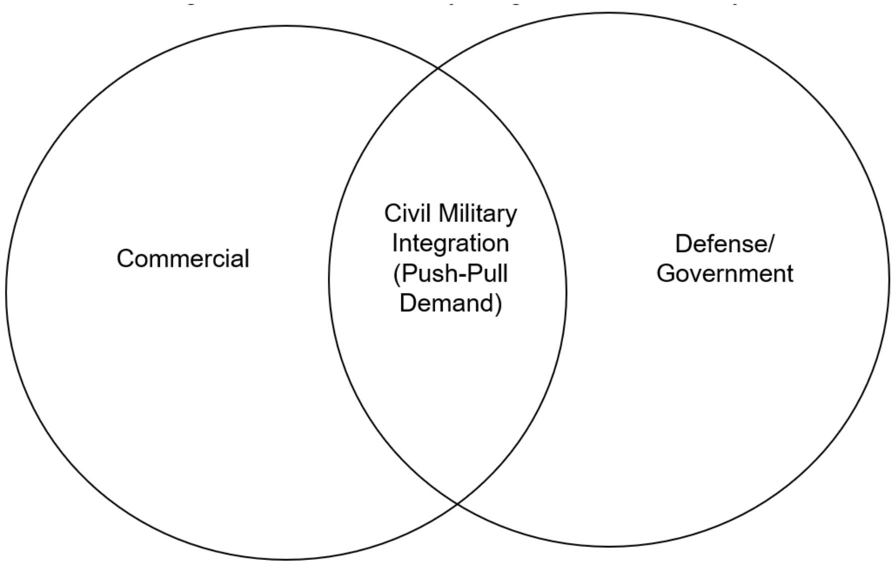

Figure 3. The Civil-Military Integration Innovation System

Defense technological innovation in the United States and elsewhere has been greatly influenced by these periods of cooperation and integration of the commercial and military unique industrial bases. The level of this technological cooperation can be described as the degree of CMI present in the national industrial base at the particular point in time. CMI was a widely-used defense term of art and policy objective in U.S. in the 1990s, but never really gained traction. It became mostly forgotten a decade later. CMI discussions began as a reaction to the rapid rise of commercial R&D that was described by the Packard Commission in the 1980s, but has roots that go back much farther.

For example, the shipbuilding demands of the Royal Navy in the 16th and 17th centuries required complex industrial processes to produce pulleys, rope, sails and other fittings in quantity furthered the development of new technologies and manufacturing techniques that were applied to commercial shipbuilding and vice-versa. The evolving military need for interchangeable parts that would eventually revolutionize commercial manufacturing received its first significant boost through the evolution of cannon production in France in the 1700s (Madhavan, 2015). European improvements in military manufacturing brought forth knowledge that eventually spread to European commercial enterprises and then across the Atlantic Ocean, just as in the last several decades manufacturing knowledge proliferated to China and other parts of the developing world.

This initial diffusion of intellectual property and manufacturing knowhow from Britain and Europe would ultimately lead to the creation of the "American System" of manufacturing or mass production and is a prime example of how the CMI push-pull process works. This began in the Springfield arsenal in Massachusetts in the early 1800s. Mass production's development in the United States was advanced by military research and development generated by the U.S. Army's specific and quite rigorous military requirement to achieve interchangeable parts in gun manufacturing. "Believing that interchangeable weapons would mean easier field repairs and cheaper manufacture, the officers of the Ordnance Department urged development of uniform small arms, with detailed written specifications and gages for inspection purposes" (Raber et al., 2009). This did not happen overnight as it took "thirty-five years of sustained effort at making essentially uniform muskets, succeeding to the satisfaction of Armory mechanics in 1849" (Raber et al., 2009).

The manufacturing solutions for this requirement once developed at the Springfield U.S. Army arsenal eventually spread throughout the U.S. economy (Hindle & Lubar, 1986; Howard, 1978). These techniques were further refined in the commercial marketplace over many decades as workers left the arsenal and built their own enterprises. This knowledge applied to clocks, furniture, bicycles, and eventually automobiles ultimately created the industrial capacity and ability to mass produce at scale.

The development of interchangeable parts at the Springfield arsenal became the first of many examples of the need to solve hard military problems or requirements that exceeded what was available in the commercial marketplace. This triggered research into new technologies, and once these hard problems were solved, that knowledge was eventually transferred back to the commercial sector where it took on a different life of its own. Those advances would eventually return to serve the military in times of subsequent conflict or competition. A similar arc happened after military efforts to miniaturize electronics for ICBM development jumpstarted Silicon Valley in the 1950s, and advances there began to trickle back to the military in the 1980s. In our own era, this dynamic is one that is incentivizing many artificial intelligence, robotics, and data analytics firms to enter the defense market to try to solve difficult military problems and then use the knowledge that comes from that research on more profitable commercial uses.

The reality though is that at least until WWII, CMI in the United States was the exception and not the rule and U.S. defense innovation was episodic. Periodic pockets of U.S. innovation arose in wartime, particularly during the Civil War and World War I. The Civil War saw the introduction of new innovations such as the repeating breach loaded rifle, the machine gun, naval mines and torpedoes, and the iron-clads, along with the adoption of new innovations from the commercial market to military uses (railroads, telegraph, and balloons for aerial reconnaissance).

World War I continued to build on some of these advances but added tanks, submarine warfare, airplanes, flamethrowers, poison gas, and radios to the mix. The first lesson to be learned is that each of these wartime innovations came about or were significantly advanced due to the time constraints of meeting the threat. Thus, time and a sense of urgency is an innovation enabler. Still, like most U.S. defense innovation in the pre-WWII period, these technologies were largely forgotten and unfunded by the government after a conflict and, if applicable, moved out into the commercial market and drove new commercial advances in, for example, continuous wave technology in radios after World War I (Gertner, 2012; Nagle, 1999). In similar fashion, the Civil War propelled the clothing industry into the industrial age through the standardization of clothing sizes.

At times in U.S. defense economic history, the commercial sector has been the lead change agent for technological advancement and at other times military needs drove innovation. David Mowery outlined several cases studies of military to civilian spin-offs: machine tools, commercial aircraft, semiconductors, electronic computers, the internet, and nuclear power (Mowery, 2010). From the late 1800s to the present day, the materials, telecommunications, and transportation industries each grew and expanded, through a push-pull mechanism of national security and commercially competitive needs. As a result, both the military and consumers benefited from the cross-pollination of ideas, research, and breakthroughs in technology, manufacturing, and business practices.

This now seems to be a lesson that China is embracing at scale. It may currently have the best understanding and execution of the concept of CMI (despite its U.S. origin) in its own version of military-civil fusion of its industrial base. Michael Brown, a former head of DIU recently commented on this phenomenon stating “that two-thirds of the business of the top ten suppliers to the Pentagon is defense only; in China, the equivalent figure is 30%” (*The Economist*, 2025). The United States has struggled since describing the concept of CMI in the 1990s with achieving it in peacetime, and the barriers to doing this have resided in the enablers of innovation.

Innovation Enablers: The Factors Behind Innovation

In this section, nine factors are considered that can enable or, as if often the case, serve as barriers to innovation (see Figure 4). These are diffusion, invention, culture and politics, the industrial base, workforce, the legal and regulatory environment, finance, leadership, and time. One may quibble over whether these are the only factors and that others should be included, but for purposes of this discussion, these factors should suffice to start the conversation.

Another distinction to be made is the potential overlap of these factors on the commercial, defense, and civil-military integration innovation systems. In Figure 4, I have singled out diffusion and invention as being substantial common factors that can impact all three innovation systems in relatively the same manner, although understanding that there is some variability in effect. The other seven may evolve more distinct and separate variability depending on the innovation system. This may impact one innovation system in a more dominant way than the others so are identified separately. The reality is these enablers are all related and interact with one another, serving either as building blocks or barriers to innovation. Effective policies designed to enable innovation are necessary in each of these areas and an understanding of their interactions is required to prevent them from becoming brakes on future innovation.

Invention

Innovation must be distinguished from invention. In this context, invention is new knowledge. It is distinct from the creation of a new capability. It is knowledge for knowledge’s sake or if adopting a more goal-oriented view, a stepping stone to innovation. In a defense context this is quite important, as invention is the source of new discoveries and knowledge, funded as research, which then become the building blocks for future innovation. Invention occurs in the university system and in laboratories around the world. In DoD it corresponds to 6.1-6.3 funding levels (Basic Research, Applied Research, and Advanced Technology Development). Advanced component development and prototypes or 6.4 is an invention and innovation grey zone. Where prototyping is for a minimal viable product and thus is a capability that can be used, the line to innovation has been crossed. All other prototyping can be classified as invention. Funding of invention is of course important, but the quality and productivity of this funding is even more so. Research grant funding where a majority goes to unproductive administrative overhead will cause invention to suffer. Process, cultural, and institutional pushback against any so-called Kuhnian paradigm shifts serve as additional barriers to invention. The rise of commercial R&D that overtook government-directed R&D in the 1980s and the subsequent globalization of that R&D infrastructure is perhaps the biggest trend influencing invention and innovation in the modern era. Much of this commercial R&D though is geared to creating new capabilities so is more innovation rather than invention focused. Each innovation system mines the invention ecosystem for its knowledge, ideas, and experimentation results to be incorporated into capabilities.

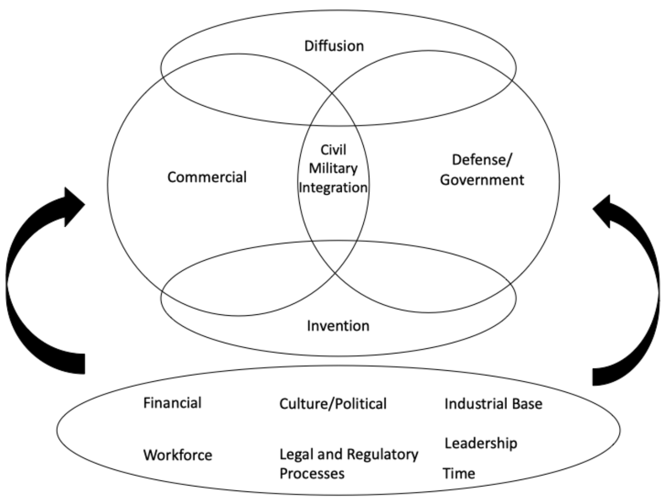

Figure 4: Innovation Enablers

Diffusion

Beyond trade, the foundation of globalization is knowledge and technology diffusion. Because of this diffusion, innovation is taking place in many new areas around the globe. Technology diffusion between companies, countries, and innovation systems occurs through cooperation, duplication, reverse engineering, the stealing of intellectual property, and espionage. Security arrangements and export controls are designed to prevent or slow down this diffusion, but also become barriers to cooperation between actors that the government may want to see work together. These arrangements can serve as a sort of Gresham's Law for innovation by incentivizing behaviors that prevent CMI within a domestic innovation system or between allied innovation systems such as in AUKUS (Greenwalt & Corbin, 2024). Commercial companies desire not to be encumbered with export controls and security mandates and then choose not to work in defense. This leads to the situations where leading technology can be available to the global commercial market but not to DoD.

Regulatory and Legal Processes

Security arrangements to prevent diffusion are just one type of governmental process that can enable or detract from innovation. Governmentally-generated rules in law and regulation establish the underlying process, procedures, and ultimately culture of a defense management system that is organized and divided into various budget, finance, requirements, personnel, acquisition, contracting, systems engineering, security policy, and oversight management regimes. These management regimes, particularly if they operate in a linear manner can result in enormous amounts of bureaucratic time and process hurdles that can slow down and destroy innovation.

To participate in the federal or defense marketplace, a commercial entity must be cognizant of and compliant with these regimes. Depending on how regime incentives are orchestrated, they will have a direct impact on the quality of innovation, the rate or time it takes to innovate, and the level of participation that can be generated from the industrial base. Processes can encourage participation or preclude participation. They can influence the level of innovation that is desired or achieved. This framework, or operating "rules of the game," provide the pathway a public or private sector entity to eventually innovate on behalf of the government, as they are the primary means that influence managers to organize labor, capital, and financial resources to meet defense needs.

Industrial Base

This refers to the productive capacity and industrial structure of an innovation system. It is based on past investments, incentives, and shaped by governmental mandates and processes. The components of the industrial base include the workforce, intellectual property or proprietary knowledge, invested infrastructure, and technologies generated from years of research and development, production capacity, and maintenance and support capabilities of not only military equipment, but also dual-use capabilities that support defense and the wider commercial market.

The organization, nature, and characteristics of who participates in the defense industrial base depend on the resources, funding decisions, and priorities directed at defense; the processes that determine those decisions; the incentives put in place by the government; and the overarching economic market. The current U.S. industrial base of importance to defense includes government arsenals and shipyards, traditional defense companies both large and small, non-traditional contractors to include venture backed emerging technology firms, commercial firms with defense subsidiaries and contracts, allied owned companies, and finally a large portion of the commercial dual use industrial base that has chosen not to do business with DoD.

Education and Workforce

The workforce that directly enables innovation includes entrepreneurs, managers, the STEM (science, technology, engineering and math) workforce, and production labor. The defense acquisition and other management regimes' workforce are also critical and need to have an understanding of how the innovation system works as do regulators, congressional and policy staff, teachers, and university professors. The quality of primary, secondary, university education, vocational training and associated curriculums are key factors in developing the workforce necessary for future innovation. Weakness in any sector of the workforce or educational system can serve as dead weight for future innovation progress. Past federal programs including the GI Bill and the National Defense Education Act of 1958 were instrumental in expanding the number of scientists and engineers at a critical moment of rapid innovation in the United States. Immigration is another critical factor. U.S. innovation efforts in WWII and in the immediate Cold War period were greatly enhanced by the large immigration of highly educated scientists and engineers from Europe who escaped the Nazis in the run up to the war.

Cultural and Political

Culture, norms, and political dynamics are key enablers or barriers to innovation. Significant innovation is highly disruptive to society and a threat to entrenched interests, companies, and workers. Innovation is dependent on an openness to any such disruption. The English political system made some extremely difficult political decisions in the 18th century that enabled the industrial revolution (Frey, 2019). China under Deng made similar calculated risks. A nation's tolerance for risk and change is tested with new innovation by the companies that go out of business, workers that lose their jobs, and politicians who come under pressure to "do something." This can fuel a populist backlash that can smother avenues to new innovation. When modern day Luddites win the culture or political wars, a nation's innovation system can risk inertia and decline.

Leadership

Effective leadership in both the public and private sectors is critical for innovation to succeed. It is leadership that must establish the processes and incentives for innovation to take place and then manage and limit the fallout from potential disruption. Chinese President Xi's initial crackdown on the entrepreneur class can be viewed as a recognition of the political dangers inherent in innovative disruption. His subsequent reversal and rehabilitation of Jack Ma illustrates that China is struggling with the need to be open to disruption and more tolerant of pesky entrepreneurs if it wants to be globally competitive. Leaders determine the types of innovation paths to invest in either with private or public resources. They also are instrumental in putting in place the right mechanisms and incentive structures for other enablers. If leaders don't pay closer attention to the incentives behind the plumbing processes of government and the private sector such as contracting, personnel, or financial systems, a desire for innovation may prove difficult to achieve.

Financial System

Everything must eventually be paid for. The financial system is the engine that drives innovation and the tolerance for risk and desire for return are key factors in this equation. A vibrant stock and bond market and an open and free market that encourages the free flow of investment underpin economic growth, prosperity, and the opportunities for innovation. On the other hand, financial markets will reward monopolistic status quo providers if the returns are high enough and thus inhibit investment in potential disrupters.

The government innovation system is dependent on the success of the overarching commercial system for resources to tax and then invest in its own innovation efforts. The country with the largest economic pie is at an advantage in a global competition. In the defense sector, the willingness of the financial market to invest will determine the health and innovativeness of these companies. Low margins and high regulatory costs as exist in the current DIB will inhibit that investment. Venture capital in the United States has only started to substantively invest in the defense sector in the last decade. Without seeing new entrants increase defense sales at scale, this investment will likely dry up.

Time

Time is an often forgotten variable. A driving factor in innovation success is whether there a sense of urgency or not. As Dan Patt and I have argued, time focuses efforts and weeds out technologies and ideas that are not yet ready to operationalize (Greenwalt & Patt, 2021). It can, if allowed to, constrain bureaucracy, calling for a responsive industrial base and engineering incentives and methods. As we observed, some of America's most innovative periods came about when time as a variable was constrained either arbitrarily or in a crisis. When time is not a variable and there is no compelling urgency, stasis and risk averseness creep into the innovation system.

Innovation Types: Where Innovation Does or Doesn't Happen

The following discussion begins by building on the foundation that Clayton Christenson outlined in his work classifying commercial innovation (Christensen, 1997). His description of commercial innovation types while addressing the relationship between business firms provides a useful nomenclature for describing certain types of defense innovation that arise in the competition between states. Christenson's definitions, though, need to be adapted and take on different connotations when looking at a national security environment rather than a business environment.

The incentives and objectives that Christenson focused on to address why companies fail will be different within a business market than in the national security enterprise, where competition among states is not tested in the same way or as quite as often as in the market. In fact, success in deterrence strategies may involve never having to test the competitive balance between powers. Still, there are enough similarities that the Christenson model of sustaining and disruptive technologies can become a useful explanatory tool in defense. To this initial design will be added the concepts of stasis, reactive, proactive, predictive, time-based, and revolutionary approaches.

In this proposed construct, there are seven innovation types or strategies that can be pursued (Figure 5). A key variable in many of these strategies, as they are in Christenson's analysis, is the degree in which culture change is required. Stasis is the starting point and can be described as the status quo innovation state. Minimally sustaining and incremental proactive sustaining are two types of strategies comparable to Christenson's sustaining model of innovation where innovation happens as a way of maintaining one's competitive advantage and one's underlying culture and outlook do not change. Time-based innovation strategies (both reactive and proactive) can straddle Christenson's sustaining and disruptive concepts modified for a defense application. A revolutionary step change while significant is not quite as substantial of a change that occurs through disruption. Finally, a disruptive strategy is an order of magnitude improvement in the quality of innovation and serves to undermine the underlying culture and outlook. Another key aspect to consider in each of these types is the degree of CMI in the domestic innovation system. CMI will likely achieve greater innovation within each innovation type when compared to just being conducted in the commercial or military/governmental system.

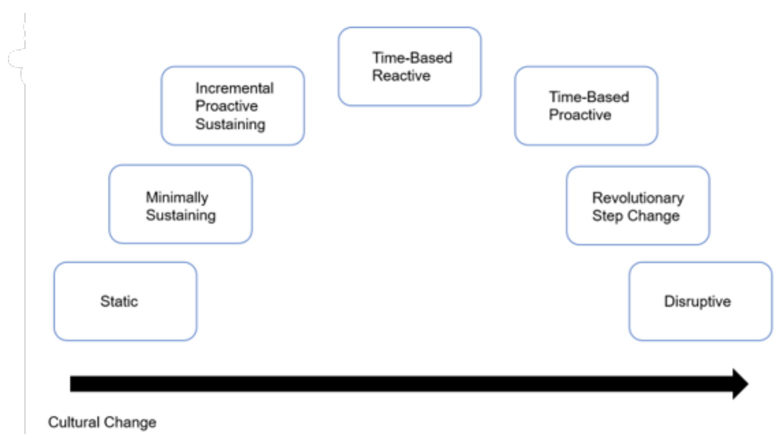

Figure 5. Typology of Innovation Strategies

Stasis and Decline

The first approach and one that is the foundation of this analysis is to start when innovation doesn't occur. No innovation is stasis and is the natural order of things. Stasis is the status quo and what elites and vested interests (be they labor or capitalists) are most comfortable with and often prefer. It is the foundation of world civilizations, order, and stability—except when it is not—and it is then the foundation of decline, disorder, and collapse. Advocates of stasis embark on policies to constrain changes wrought through innovation and advocates for greater innovation embark on policies to overcome the negative barriers put in place by those who favor the status quo.

While Figure 5 appears to outline innovation as a seemingly progressive order, the reality is that innovation, even in its non-disruptive forms, creates a backlash and a desire to return back to stasis. Innovation, thus, may better be described as a circle or cycle (Figure 6). What once were highly disruptive innovative capabilities eventually are absorbed into stasis and become the new status quo. These technologies or processes become entrenched, and then barriers are erected around them so as not to be disrupted by something else.

So, the cycle of innovation begins with stasis or the status quo. After all of the turmoil or disruption caused by something new, the system wants to revert back to a new status quo and put up its barriers and spines and protect itself against new innovation. In *The Technology Trap*, Carl Benedict Frey (2019) brilliantly describes this situation over history. Stasis is the political default choice for governments, dominant industrial firms, labor, and the financial community. The enablers of innovation become barriers. Processes and laws are created to limit and control innovation and maintain the status quo. The political and economic interests aligned against disruptive innovation often leads to decision gridlock and an embrace of what is current.

Labor wants to maintain its current jobs. Industry enjoys market dominance. Finance profits from this. In this environment, the question is why change? The problem is the longer stasis lasts, the greater the chance of such a system being disrupted, most likely from outside the domestic innovation system. U.S. industry after WWII, for example, was caught up in a stasis innovation period until the 1970s. Retooled during WWII by wartime expenditures and having most of its international competition destroyed in conflict, it could focus on existing products and meeting unmet consumer demand that built up during the war. It was not until Japan armed with Deming's incremental quality management tenants that American industry was disrupted.

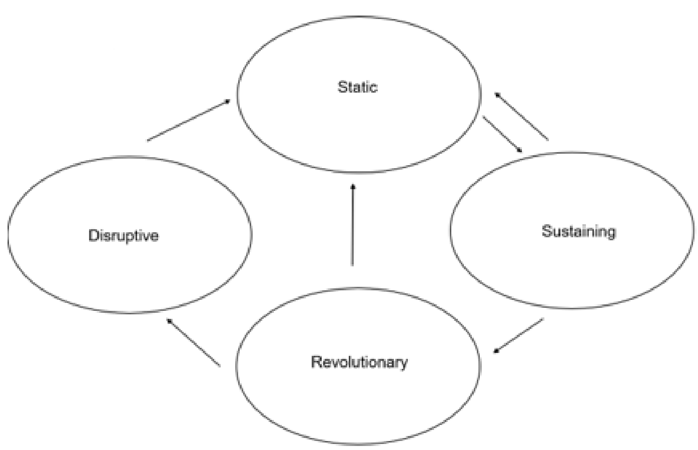

Figure 6. The Cycle of Innovation Types

Minimally Sustaining (Reactive)

Eventually stasis is no longer tenable. Market competition or international challenges begin to appear on the horizon that could threaten a company's market share or nation's security. Christenson (1997) describes the reaction to this situation as sustaining innovation or continuing to make only those improvements necessary to maintain market competitiveness. It requires no change to culture or operations and is the way a firm can continue to maximize its profits over the long term. In a national security context, this can be thought of as the minimum effort necessary to maintain the balance of power.

The first rung on the innovation ladder beyond stasis in this analysis is minimally sustaining. This is a reactive strategy used with a hope of doing as little as possible before moving quickly back to the old order. What is the least one could do to get by in addressing the competition? In the commercial world, that may involve a new marketing and pricing approach or the release of a limited new version of an old model. Cost cutting and personnel reductions are another minimally sustaining commercial strategy to shore up margins and the balance sheet. In defense, minimally sustaining approaches could manifest themselves in diplomacy, a reallocation or deployment of forces, and budget signaling—announcing increases in the defense budget or new programs designed more to deter than actually be executed. Perhaps a "commercial catch-up" effort can be pursued as well. FASA can be viewed in hindsight as primarily such a catch-up strategy when it became obvious that DoD had fallen behind the commercial market in information technology. Greater innovation from CMI through a more expansive interpretation of FASA's commercial item preference and the ability to modify those items could have been pursued. Instead, FASA implementation over the decades has focused on the mere adoption of COTS (or unmodified commercial off the shelf products) as the government did not really want to move much beyond the status quo.

Proactive Incremental Sustaining

In sustaining innovation, one can take a reactive or a proactive approach. Minimally sustaining is reactive. One is not yet disrupted, but competitive pressures are rising and an entity takes some reactive action. Another strategy is to address the prospects of that competition proactively. Ultimately, predictions about the future need to be made. A proactive incremental sustaining strategy is implemented though a future looking predictive planning process designed to do the minimum it requires to meet any perceived future threat to one's market or national security.

Whether this is a boardroom decision guided by a company's strategic planning process to allocate research and development (R&D) investment or DoD's PPBE, JCIDS and MDAP processes, a predictive and linear planned system is created to ensure that one does not spend too much money or resources on unnecessary innovation. This is a strategy that is implemented by market leaders who recognize the potential for competition on the horizon, but do not yet fear it. They only want to hedge against it.

While proactive incremental sustaining is a much better approach than reacting to market pressures, it is still drawn to a desire for a return to stasis. The whole process is considered somewhat wasteful in the sense that if only these bad new competitive actors would just leave us alone to our monopolies we could all live quietly and comfortably. But since we have to be on the watch for surprise, we will ensure that things are done right and rationally. This is a very incremental approach to innovation in both outlook and results. It is not limited by time but by process. We have all of the time in the world until we are truly disrupted (which cognitive dissonance suggest will never happen) so we need to take things step by step and slowly.

U.S. weapons procurement has primarily used a proactive incremental sustaining strategy since the establishment of the first 5000 series document in 1971. The incremental improvement of weapons systems initially designed in the 1970s has been the predominant focus of U.S. acquisition approaches toward the modernization of weapon systems for the last 50 years. Many of the same systems started during the Cold War are still the foundation of U.S. military forces—the Bradley Fighting Vehicle, M-1 Tank, Apache helicopter, F-15, F-16, and FA-18—albeit all incrementally upgraded. Ships, of course, have planned decades long lifetimes and receive incremental upgrades whenever they are in port for maintenance. For the last several decades, incremental upgrades—either through new contracted programs with the original contractor or conducted during depot maintenance of these items—have been the major source of defense innovation.

This is a minimalist strategy that corresponded to the lack of threats after the end of the Cold War and thus is a sustaining innovation strategy to maintain one's position in the market. Even new capabilities programs are usually planned incremental step changes from what came before. A proactive sustaining strategy has corresponded with a constraining oversight process focused on delivering capability to meet preordained estimated cost and technical goals. As has been continually learned, it is far easier to meet those goals if one limits risk—either technical or managerial.

The danger of pursuing a proactive sustaining strategy is that companies and governments can fool themselves through the planning process they are pursuing great advances in innovation. But in reality, they have created an extremely expensive strategy that primarily yields limited innovation productivity or rarely moves beyond the status quo. Those countries and firms that pursue innovation at a differing point in the innovation spectrum can potentially leapfrog the market leader who burdened with hubris and complicated processes could end up being left behind. There is a danger that a sustaining innovation strategy could continue in a national security context until these forces are finally tested on the battlefield and found wanting.

Time-Based Reactive

What does one do when one is already disrupted? Competition is not just on the horizon but is here and now bringing to bear something new that is threatening one's market, global or regional dominance. This dynamic can be seen in initial wartime innovation. If one is stuck in a process-based innovation strategy, the first thing to be done is to break the rules of the old system to rapidly meet any unexpected disruption. This has happened in every conflict in U.S. history: emergency acquisition authorities are put in place to buy and innovate at a faster scale where needs are immediate and time is of the essence (Nagle, 1999).

A time-based reactive strategy is different than a minimally sustaining reactive defense model. Innovation is driven by urgency. It is rapid and limited by time. Competition is no longer theoretical or emerging but is very real. A time-based emergency approach often generates new uses for modified existing technology. One might first need to use multi-million-dollar weapons to destroy drones that cost thousands. "Production Catch Up" or the ramping up of production of legacy weapon systems is initiated and then very quick capabilities programs are initiated to support combatant commanders in the field to address real shortcomings. The MRAP and counter-improvised explosive device (IED) programs of the mid-2000s using rapid acquisition authorities granted by Congress are prime examples of the more recent use of this type of innovation strategy.

Still, in the end, time-based reactive is limited by the desire to revert back to stasis. The widespread use of going around the existing system only lasts as long as the crisis and then is tossed aside. A sense of time and urgency will encourage new innovation to emerge but it is eventually incorporated back into either status or the predictive sustaining model.

Time-Based Proactive

Time-based strategies can also be proactive in anticipating future competition and disruption. This approach essentially uses artificial time constraints to drive advances in innovation. Rapid serial operational prototyping and rapid fielding as envisioned under Middle Tier Acquisition authority is one such proactive approach. A time-based proactive strategy can potentially be a revolutionary and disruptive model, but can also serve as a sustaining one. This approach is based on the time-based serial prototypes that were created by DoD in the 1950s, which evolved over several short cycles. Commercial equivalents were seen in the semiconductor industry's efforts to implement Moore's Law that drove 18-month advancements in integrated circuit design and production, as well as in agile software approaches used by Silicon Valley. Early Cold War–era weapons systems developments had an agile, time-fixed execution as depicted in Figure 7 by the history of the B-52. The B-52 could have foreshadowed a radically different future for U.S. defense acquisition, where DoD focused less on performance against prediction, and more on the speed of capability delivery and learning. DoD did not take that path, but Silicon Valley ultimately did. That the B-52 development looks remarkably like how Apple developed and produced the iPhone is not a coincidence.

Continuous quality improvement is the process-based analogue of serial operational prototyping. The Japanese auto industry's use of Deming's ideas and processes that centered on improving quality over time created significant quality changes in capabilities to the point that it completely disrupted the U.S. industry that had drifted into stasis. U.S. commercial industry began to adopt these ideas only after it was disrupted. A culture change was required in the factory and management around the concept of continuous process improvement, and ultimately the auto industry and much of the commercial manufacturing process was changed.

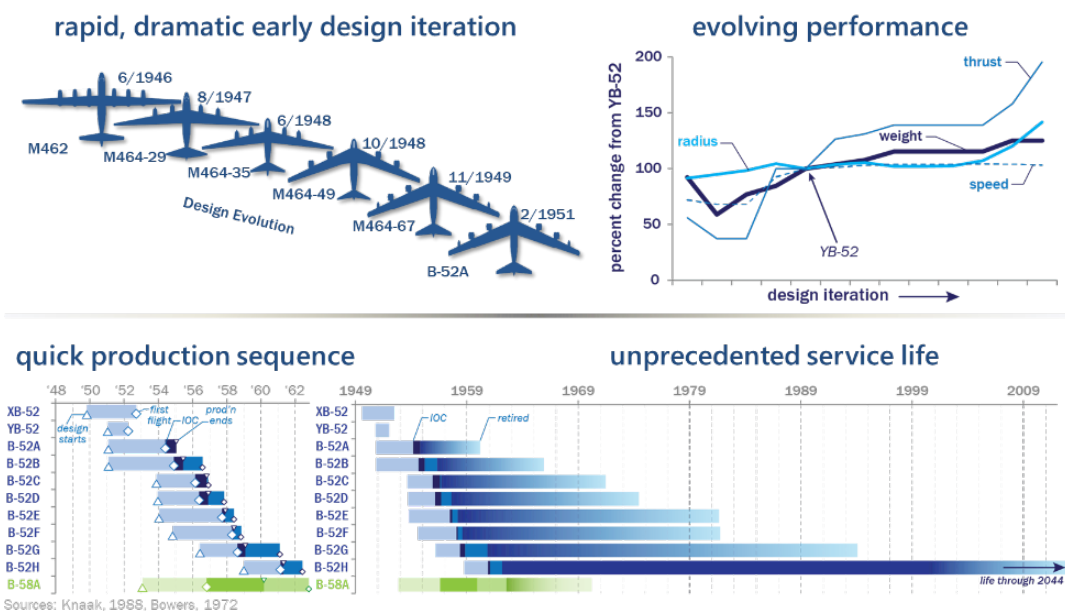

Figure 7. The B-52 and a Serial Operational Prototyping Strategy

Revolutionary Step Change

The concept of a revolutionary step change is introduced here to distinguish quality changes that perhaps don't qualify as disruptive. This is defined as a significant change in capability that may not be disruptive in the Christenson (1997) sense as it does not result in significant culture change, but is still a large jump in the quality of a capability. Revolutionary step changes in capabilities can occur through both predictive proactive sustaining and time-based methods, but will more likely to appear through a series of rapid time-based serial prototypes or serial changes in process.

One could have radical or revolutionary change within the sustaining innovation category. It is often difficult to do so because achieving such a significant step change in technological innovation is achieved almost by accident because originally a proactive sustaining approach was only designed to incrementally maintain one's place in the marketplace. It is possible for predictive models to actually get it right and be revolutionary by pushing the bounds of technology in 10-20 years' time. Ironically, that may have come from initial inaccurate perceptions of the evolving threat. Even if a predictive program does achieve such an outcome, it will likely not do so in accordance with its original predicted baselines of cost, schedule, or performance, as after a few years the adequacy of those predictions become increasingly deficient. Thus, if a new technology is delivered a decade or so later it is often seen as a failure despite some having achieved revolutionary step changes in capability.

Emergency reactive time-based approaches can also result in revolutionary innovation. A step change in military innovation occurred in intelligence, surveillance, data analytics, and sensor fusion to address post 9/11 national security threats designed to track down small independent combatant units in Afghanistan, Iraq, and Syria. These new innovative efforts were examples of how to enable near-term technological advantage on the battlefield, but they would not have likely been made except for urgent operational shortcomings. These are revolutionary in the sense that they while technologically significant did not require a significant change in culture or operations to incorporate and provided further battlefield advantage.

Most of the discussion up to this point has been about the United States as market leader both in commercial and defense. What if you are not a market leader and want to be the disrupter? The flip side of a sustainment innovation strategy is first catching up. This begins with a greenfield catch-up strategy that takes advantage of the state of the art made possible by the global diffusion of technology and knowledge. Greenfield catch up is what first Japan, China, the ASEAN nations, and now India have been doing for decades. The creation of a new facility, factory, or business can begin with the state of the art at the time of initiation. This can incorporate all of the lessons learned in producing past capabilities and can also consider new emerging approach to innovation in creating that capability to catch up. Disruption can then happen through a leap frog approach that once the new greenfield operation has been established can take advantage of time base innovation strategies. China's remarkable pace in military hardware appears to conform with this strategy (Greenwalt & Patt, 2021).

Disruption

Disruptive innovation up ends markets and balances of power. It not only requires a major technological or market offering change, but a change in culture and operations or business model. In Christenson's (1997) commercial analysis, this results in an easier to use, cheaper alternative that is more accessible and available to a larger population. This is likely not to come from the incumbent, who is more focused on sustaining innovation. In business, disruptive innovation comes from finding a cheaper way of doing things, which has not always been the case in the defense market. Disruption in this context comes from doing something faster, better, or cheaper and by doing so is so revolutionary that it forces all sides to change how they think about the market.

While disruptive innovation can change the market and culture or operations, the Christenson (1997) framework needs to be modified for defense. This would address a truly radical new revolutionary technology or capability to emerge, which is likely to be less accessible and perhaps more expensive than other alternatives, at least initially. The submarine, tank, aircraft carrier, nuclear weapons, and satellites were disruptive innovation candidates as defined by the need to change culture, but they do not meet the rest of the Innovator's Dilemma definition.

There are two types of disruption to consider. One is an order of magnitude better, faster, and cheaper capability than the existing solution. One area in defense that might qualify is the proliferation of cheap, unmanned drone development that has arisen in the Ukraine war and the Middle East. Asymmetric strategies such as cyber warfare, disinformation, and anti-access/area denial strategies may be cases of revolutionary innovation, but could also meet Christenson's disruptive criteria of cheaper, more accessible innovation likely to be initiated from outside the dominant culture.

A second disrupter is the never been done before moonshot that actually succeeds. These disruptive defense capabilities require a significant shift in outlook, process, tactics, and doctrine. They are not always cheaper, easier to use, or more accessible, but they change the rules of the game completely. There are two methods to achieve disruption, which are both predominantly time-based. The first is the adoption of the ruthlessness of the venture capital power law incentives, and the second is the development of government-sponsored revolutionary operational prototypes.

VC Power Law Model

The venture capital (VC) power law as outline by Sebastian Mallaby (2022) is a situation in the venture capital market where only a small number of investments are successful while the majority fail. These successful investments need to provide something like a 10X return to cover those other failed investments. To get that type of return, one needs to disrupt the existing market through major improvements in productivity at a fraction of the cost, develop something new that has never been done before, or both. This is what SpaceX did with its Falcon 9 and why it is a prime example of the ability of the VC power law model to drive disruptive innovation. Falcon 9 was developed for a tenth of the cost that NASA originally estimated it would cost if conducted under the traditional proactive incremental predictive model. It also ultimately delivered a more than a 10X gain in productivity as measured by the cost to launch a pound to space and it did it by doing something new—reusing bits of the launcher. Achieving this has completely disrupted the space market and is leading to other new advances in commercial satellite networks and distribution. This disruption fits neatly into Christenson's (1997) framework as doing something better and cheaper that changed the space culture and made it accessible to more people, but the VC model could equally be leveraged for the second method.

Time-Based Disruptive (Moon Shots)

As much as the private sector can be innovative and disruptive, some things can be too big or too risky for the private sector to do alone. Even the Falcon 9 was developed using NASA money. There is a reason these types of efforts are called moon shots, but the model that took America to the moon was refined in the 1950s and early 1960s in defense. It was during this time that DoD deployed the first nuclear power ships and submarines, the first jet aircraft, the first ICBM, the U-2, SR-71, and the first reconnaissance satellites. These efforts were time driven and for the most part took less than 5 years to deploy something that was operationally capable and usable. The Apollo program may be the best example of a “moon shot” but these efforts were designed to disrupt or revolutionize their environment. They each required a different way of thinking about the future.

This different way of thinking evolved from the early Cold War competition with the Soviet Union that incentivized the U.S. military to maintain World War II development emphases. This resulted in the creation of multiple disruptive new technologies. Innovation efforts conducted during the war, in the 1950s, and then in the subsequent space race with the Soviet Union in the 1960s had several things in common: a focus on time, rapid experimentation, multiple technological pathways, rapid operational prototyping, and a risk-taking culture that embraced creating something new and disruptive.

Disruptive innovation may be closer to the technological component that supports the concept of the Revolution in Military Affairs doctrine from the 1970s that originated in the Soviet Union and was the source of much interest in the United States after the Gulf War by Andrew Marshall in the Office of Net Assessment (Dombrowski & Ross, 2008). Future disruptive innovation in this context could potentially cover the potential use of artificial intelligence linked to autonomous systems or in the deployment of directed energy weapons. The current National Missile Defense system was essentially and still is an operational prototype. A U.S. Golden Dome would likely start out similarly and end up being highly disruptive if successful.

Conclusion: U.S. Defense Innovation Since WWII

Using this taxonomy, the history of U.S. innovation efforts can be assessed (see Figure 8). At some point in time, the United States has pursued or taken advantage of each of the innovation models, categories, and types. Unfortunately, there has been a marked tendency to creep back toward stasis and the status quo with corresponding countervailing efforts at using a predictive and process based sustaining innovation. To compete in the newly emerging global threat environment, DoD needs to pursue more disruptive, time-based defense innovations similar to the innovation pathways it pursued in WWII and the early Cold War.

The post-World War II period was a watershed moment for U.S. defense innovation. It didn’t have to be that way and could have very easily conformed to the pre-World War II pattern. Whether through serendipity, planning, luck, or foresight, the past cycle was broken, and the system did not return to stasis after the conflict. This period did not last long—at most 20 years—but it became the most innovative period in U.S. history and the source of some of the most significant military technologies still in use today.

The 1960s becoming a transition decade. In the aftermath of the Cuban Missile Crisis and the rise of arms control measures to try and manage conflict, military innovation entered a stasis period with a planned proactive incremental sustaining strategy adopted as a hedge against technological breakthroughs from the Soviet Union. The end of the Cold War saw even this sustaining strategy rolled back significantly. The Global War on Terrorism encouraged some emergency time-based reactive measures that were reversed once the conflicts in Iraq and Afghanistan ended. Sustainment type innovation strategies and U.S. dominance began to be tested in 2014 by the invasion of Crimea and Chinese militarization of disputed islands in the South China Sea. Congress reacted by providing the means to adopt a time-based disruptive innovation strategy through the expansion of Other Transaction production and rapid acquisition authorities, the strengthening of the commercial item preference, the establishment of Middle Tier Acquisition authority, and the creation of the software acquisition pathway. The last decade has only seen marginal usages of these authorities and little disruption.

Time Period	US Innovation Trends and Types
World War II	Defense: Emergency Time-Based Reactive, Time-Based Disruptive Commercial: CMI to Defense, Subsidized Retooling
Early Cold War (1945-1960)	Defense: Serial Time-Based Operational Prototype Disruptive Commercial: Innovation Statis, Sales Expansion to Meet Pent-up Demand
Late Cold War (1960-1990)	Defense: Beginning of Arms Control Statis and Minimally Sustaining Proactive Model Industrial Commercial: Statis and Decline then Emergency Time Based Reactive Once Disrupted Japan Challenge (1970s Proactive Quality Process) Emergency Reactive Silicon Valley: CMI from Defense, Serial Time Based Disruptive (Moore's Law)
Post-Cold War Pax USA (1990-2014)	Defense: Stasis (Peace Dividend), Minimally Sustaining Predictive GWOT: Emergency Reactive (MRAP/RAA) Industrial Commercial: Minimally Sustaining -- China Outsourcing Strategy Silicon Valley: Serial Time Based + VC Disruptive
US Hegemony Challenged (2014-2025)	Defense: Stasis and Expanded Evolutionary Predictive Creation of Time Based and Disruptive Alternatives (Production OTA/MTA/Software Pathway) Industrial Commercial: Emergency Reactive, Supply Chain Disruption, China Risk Reduction and Decoupling (Friend-shoring, Insourcing) Silicon Valley: Serial Time Based + VC Disruptive

Figure 8. History of U.S. Innovation Efforts

Defense innovation in the United States continues to primarily focus on predictive, process based, incremental sustaining innovation. To compete in a new Great Power competition, defense innovation needs to become more time based and disruptive, taking advantage of growing trends in the commercial innovation system through CMI. This will require a change in culture, mindset, and processes. The ingrained cultural resistance to disruptive new technologies and ways of doing business has to be addressed to achieve any traction on achieving the necessary changes to the industrial base and management regimes required to enable future disruptive and revolutionary step change defense innovation.

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Prometheus Unbound

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Abstract

The United States Navy was founded in 1775, just as the First Industrial Revolution started. Consequently, the U.S. Navy has matured in a vibrant, innovative technology environment throughout this and the three subsequent industrial revolutions. The U.S. Navy has consistently maintained an innovative, forward-leaning posture, repeatedly and progressively adopting innovative technologies into operational service. Ironclads, dreadnoughts, naval aviation, nuclear power, submarine-launched ballistic missiles, guided missiles, jet airplanes, and phased array and digital radars are the highlights of the U.S. Navy's skill at technology adoption.

While typically innovative and progressive, the U.S. Navy has entered a new, regressive phase, trailing its strategic maritime competitors in adopting technology innovations, like autonomous vehicles, quantum computing, hypersonics, and other groundbreaking maritime innovations.

This project assessed two centuries and three industrial revolutions of the U.S. Navy's innovative technology adoption practices. It merges those organizational learning and innovation adoption principles with leading modern organizational theorists and practical innovators into a single conceptual framework that uniquely applies to the United States Navy.

This novel conceptual framework merges current organizational learning frameworks and behavioral models with time-proven and successful U.S. Naval empirical practices. They explicitly define principal U.S. Navy organizational practices that are internally culturally acceptable, performance-proven, and not overly complex, creating, in effect, a road map, a leaders' guide, for future U.S. Navy technology adoption techniques and organizations for the 21st century.

Introduction

In the last 25 years the U.S. Navy has fielded exactly two classes of surface warships (LCS 1 & 2 class), one new combat aircraft (F-35), no new classes of submarine, and no new uncrewed air, surface, or undersea vehicles or ships. This lackadaisical pace has not been seen since the 25-year gap between the first American steamship sailed (Fulton) in 1814 and the Commissioning of the USS Mississippi, soon to be one of Commodore Perry's ships that opened Japan to trade, in 1839 (Bennett,1896).

Since 1839, the United States Navy has invented "Silicon Valley" rapid technology adoption practices an entire century and a half before there was a Silicon Valley. The U.S. Navy built 50 steamships before the American Civil War (Bennett, 1896). In 1861, the USS Monitor went from a paper model to a combat victory in six months. In 1881, the New Steel Navy fielded four revolutionary steel warships in less than a decade, followed by the U.S. Navy's first battleship in 1890 and simultaneous combat victories in the Atlantic and the Pacific oceans in 1898. Submarines entered American naval service in 1900. America's first dreadnought-style battleship, USS South Carolina, followed just 12 years later, in 1910. Naval aircraft were flying operational missions by 1914. By 1916, the U.S. Navy's Fleet was "Second to One," and then quickly became "Second to None" by 1934. The Monitor's ironclad Sailors of 1862 would not have recognized the American ships, submarines, and aircraft that fought in World War I, just 56 years later. Even after all that, the U.S. Navy fielded a blizzard of innovative ships, aircraft, and submarines until 2000. A turn-of-the-century sailor from 1900 would not recognize the U.S. Navy's turn-of-the-century Fleet in 2000, just as Bill Hewlitt and David Packard would not recognize the industry they created, Silicon Valley, just 53 years after it was first popularized in 1971. But a sailor from 1965, 60 years ago, would be perfectly comfortable in today's Fleet. Jet airplanes, nuclear submarines, air defense cruisers and destroyers, and nuclear-powered aircraft carriers remain in service today, many the same, if not similar, to those of the Vietnam War era.

What happened?

"*Prometheus is best known for defying the Olympian gods by taking fire from them and giving it to humanity in the form of technology, knowledge, and, more generally, civilization*" (Wikipedia, 2025). The U.S. Navy's leaders from 1836 through to 2000 were modern Prometheuses, creating organizations and processes that gifted the Navy knowledge and skills, thus creating abilities that revolutionized naval technology invention and fleet adoption practices. That began the golden age of American naval innovation.

What did those early leaders do to release Prometheus to the custody of the U.S. Navy?

Writing on military innovation today often conflates three related topics: *invention*, *adoption*, and *adaptation*. Closely affiliated with these is the complex term "*a Revolution in Military Affairs*," or RMA. *Invention* is precisely what it sounds like: inventing a new machine, process, or technology(O'Sullivan & Dooley, 2008). This paper focuses on *adoption,* the process of incorporating an invention into the established force structure of military service (Denning & Dunham, 2010). *Adaptation* is using existing, adopted technology in a new or unique way other than as envisaged initially (Lacey & Woods, 2007). *A Revolution in Military Affairs* is the term used to describe what happens when a suite of modern technologies, once invented, adopted, and adapted, fundamentally changes the nature of combat operations (Rogers, 1995). Maritime warfare is amid an RMA today due to the cumulative effect of new 21st-century technologies and the suite of maturing technologies from the late 20th century.

Peter Rosen's *Winning the Next War* profiles two core methods for introducing military innovation: during peacetime through personnel assignments and organizational changes and wartime innovations implemented through adaptation, operational, and doctrinal changes. He provides case studies supporting his thesis. The most significant changes address organizational and leadership issues, not technological factors (Rosen, 1991).

Adoption of an invention is not a speedy process. Studies have shown that commercial progression from invention to adoption can take between 30 and 40 years (Doraszelski, 2004). and such a scale is seen in the military and naval spheres. The first U.S. Navy–funded steam-powered ship sailed in 1807, but the first U.S. Navy steamship was not commissioned for another 29 years. The first self-propelled anti-ship torpedoes were invented in 1866, but their first tentative use in combat was not until 1894–1904, and their first effective combat use wasn't until World War I, 48 years later (O'Hara & Heinze, 2022). A range of factors in the invention/adoption process can accelerate or retard technology adoption in the naval sphere, and those will be enumerated later in this paper. During the fielding process, the conflating factors of invention, adoption, adaption, and RMA come into play.

In one of my prior contributions to the field, I cite the utility of engineering operational flexibility in the designs of warships and weapons systems, especially in the modern era, to hasten the adoption of emerging technologies and wartime tactical adaptations. My conclusions are based on historical examples of such utility from the Spanish Armada of 1588 to 2021. In every case, the principal challenge is organizational versus technical, and the principal obstacle is leadership (or lack of) to meet operational performance objectives, not the lack of engineering tools and rigor to articulate a better outcome (Lewis, 2022). Larrie Ferreiro, in *Bridging the Seas: The Rise of Naval Architecture in the Industrial Age, 1800–2000,* calls this necessary engineering rigor "the ghost in the machine," the underlying technical discipline and accompanying good engineering practices associated with adopting an innovative technology into the Fleet. The flash of brilliance of an invention (or determined act of invention, as you wish) must be followed by the complex, often tedious work of design, engineering, functionality, usability, sustainability, and all other factors that matter to both Sailors and naval leaders if they are to use a new technology to wage war at sea (Ferreiro, 2020).

Beyond the Navy, society, in general, has been changing rapidly, creating dominant technological effects that coincidentally started with the birth of the United States and the U.S. Navy and continue through today: the four industrial revolutions. These are defined as the first industrial revolution (1IR), the second industrial revolution (2IR; Lanteri, 2019), the third industrial revolution (3IR; Evron et al., 2023), and the current fourth industrial revolution (4IR; Lanteri, 2019). The 1IR includes the invention and adoption of steam and steam propulsion. The 2IR encompasses the invention and adoption of electricity, machinery, radio, internal combustion engines, and manufacturing systems. The 3IR started with the birth of computers, computer programming, networks, satellites, and the internet. Our current 4IR includes cloud computing, quantum computing, artificial intelligence, machine learning, and data analytics (Lanteri, 2019).

Denning and Dunham's revolutionary 2020 innovation taxonomy, *The Innovator's Way*, provides a robust methodology and a practical conceptual framework that provides a definitive, systematic approach to defining, organizing, and implementing the adoption process. Denning and Dunham define a prime innovation pattern (PIP) that, when executed, produces eight innovation practices divided into three phases (Denning & Dunham, 2010).

Phase I: The Main Work of Invention

1. Sensing
2. Envisioning

Phase II: The Main Work of Adoption

3. Offering
4. Adopting
5. Sustaining

Phase III: The Environment for the Other Processes

6 Executing
7. Leading
8. Embodying

Each of these attributes encompasses an operational definition. They can be indexed and assessed when comparing adoption cases from history by these attributes, then compared using the PIP rubric. This provides a common lexicon and measurement template for all U.S. Navy technology adoption events across all four industrial revolutions. All adoption activities, successful or not, can be parsed into one of these eight independent variables (Lewis, 2024).

The 2010 Denning and Dunham PIP tracks closely to other, later innovation adoption rubrics (Taylor & Hall, 2013), and implementation research methods (Peters et al., 2014) that stress sense-making, user communication, and user-provider interactions as necessary precursors to adopting innovative ideas and processes into an established community of practice.

Of applicability to this paper, Phase III "The Environment for the Other Processes" PIP attributes are (Denning & Dunham, 2010):

1. **Executing.** Requires domain-specific and conversational skills. Effectiveness depends on completing actions within a domain as promised in conversations.
2. **Leading.** "The point of innovation leadership is adoption and integration of new practices in a community, not sustaining the power of a leader." These include focus on followers, focus on outcomes, and observability of the outcomes produced.
3. **Embodying.** "The innovator's challenge is to get the members of a community to embody a new practice."

Part I: Leadership—Founding an Audacious New Navy

The United States Navy was disbanded after the Revolutionary War, and its management and functions were incorporated into the Department of War. This Cabinet post also administered the United States Army. For two decades, this arrangement worked well for the Navy's few warships and the tiny American Army. Piracy had always been a problem in the world's ungoverned seas. Still, a new, organized group of pirate leaders based on the North African coast, the Barbary Pirates, began to practice a highly organized form of piracy, more like a protection racket than simply randomly attacking passing merchant ships at sea. Ransoms were demanded to return ships and Sailors, and protection money was demanded to avoid future attacks—failure to pay generated targeted attacks and outrageous demands. By the early 1790s, unescorted and unprotected American cargo ships were being targeted. Congress authorized the building of warships to protect America's commercial Fleet (Smelser, 1959). With the nation's first warships came the first Naval Constructors. Naval Constructors were established to supervise the construction of the Navy's first six Frigates, authorized by Congress in 1794.

As the government's on-site technical authority, Naval Constructors were the first demonstrated PIP Phase III *executing* attribute, placed there by Secretary of the Navy Benjamin Stoddert, representing the *leadership* attribute through their eventual acceptance by the shipbuilding industry and the active-duty Navy, demonstrating *embodiment (Leiner, 2000).* This represents the first stage of Prometheus's gift: organizational learning through individual learning (Argote, 2021).

Neither American shipyards nor the Naval Constructors had ever built a warship, so they learned together. Of note, the ships were extraordinarily innovative in their design, as was to become evident to the world during the War of 1812. Joshua Humphries, the Chief Constructor, designed powerful preindustrial, technically innovative ships that were designed well beyond the minimal requirements of their stated counter-piracy missions (Toll, 2008) and, in so doing, set an innovative tone for thousands of future U.S. Navy ship designs. Prometheus became unbound.

In a pattern that was to repeat many times over the next two centuries, an ad hoc advisory process was created during the existential naval crisis of the War of 1812, which led Secretary of the Navy William Jones to establish a permanent Board of Naval Commissioners (the "Navy Board") in 1815 to advise the Secretary on complex Naval Matters (Albion, 1980). This represented a second preindustrial step in organizational learning, implementing both *active* and *latent* context that "forms the backdrop of organizational learning," where *active context* defines the members and tools that interact with the organization, and the *latent context* establishes design and duties (Argote, 2021). The Navy Board remained in existence until 1842, when it was overwhelmed by steam and new ordnance technology and was replaced by the Naval Bureau system.

Creating knowledgeable people is the first step in creating a learning organization. Those knowledgeable people can then create tools (Ferreiro's "Ghost in the Machine") to perform tasks to achieve the organization's mission. Once people are knowledgeable, moving them and their tools between organizations allows their knowledge to diffuse throughout the larger organizational entity. It is precisely the organizational learning cycle necessary to impart specialized knowledge across a growing organization.

This is how the U.S. Navy dealt with the rise of 1IR technologies. First, the Navy recognized its knowledge deficit. Then, it sought out people and organizations who had the knowledge and experience the Navy desired (i.e., industry). Finally, it created learning centers in the Navy to create knowledgeable Navy people, built tools, tasks, and organizations to support them, and then proliferated those people and their tools throughout the Navy (Lewis, 2024).

Naval Constructors learned to build warships alongside industry. Then, the Navy Board identified knowledge deficiencies, which generated Navy Schools and the Naval Academy, which, as we will see next, led to the creation of the Bureaus and the Naval Engineers.

Two environmental aspects of organizational learning are *exploration* and *exploitation* (see Figure 1). *Exploitation* maximizes the value of known knowledge and improves upon an established base of practice, information, and knowledge. For wooden sailing ships of the 18th and early 19th century, this was a rich and deep well of over four hundred years of experiential learning and operational knowledge (Lewis, 2022). Its complement, *exploration*, is the discovery of new possibilities and knowledge that can be applied to the situation (York, 2020). This was first used in the U.S. Navy by adopting Joshua Humphries' novel hull construction technique, allowing American frigates to carry more guns than any extant foreign frigate. That difference would almost always guarantee victory in single-ship combat (Toll, 2008).

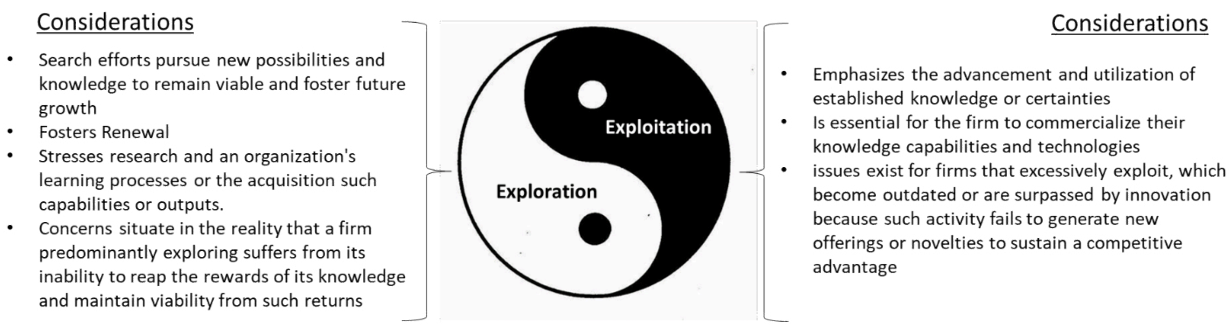

Figure 1: The Yin and Yang of Exploration and Exploitation of Organizational Learning (York, 2020)

As the 1IR suite of emerging innovative maritime technologies expanded, the need for more expertise in the U.S. Navy became an issue. A letter in 1835 from the Naval Commissioners to the Secretary of the Navy, cited in *The Steam Navy of the United States,* says it best:

> from their ignorance upon the subject of steam engines, they are in doubt whether [they have] given the necessary information . . . to make proper offers. They are satisfied that they are incompetent themselves and have no person under their direction who could furnish them with . . . information to form a contract for steam engines . . . the board begs . . . your authority for engaging some person who may be deemed competent. (Bennett, 1896)

In the context of organizational learning, the new *exploring* environment upset the established latent organizational context of the Navy. Hence, the Navy had to discover new tasks (skills) to be performed, had to find new people (members) to perform them, and had to develop new tools (naval engineering) for them to use during those tasks. All to overcome the changed environment created by the steam propulsion technology.

Freeing Prometheus proved to be more complex than just cutting chains!

The creation of the Bureaus also began a long-standing trend whereby the U.S. Navy preferred empirical design methods over rationalist design practices as defined by the computer scientist Frederick Brooks in *The Design of Design* (Brooks, 2010):

> **The rationalist** believes that man is inherently sound (and reasonable), subject to mistakes, perfectible by education. After the right education, maturing experience, and sufficient careful enough thought, a designer can make a flawless design. The design methodology task, then, is to learn how to reason a design into flawlessness.
>
> **The empiricist** believes that man is inherently flawed and subject repeatedly to temptation and error. Anything he makes will be flawed. The design methodology task, therefore, is to learn how to determine the flaws by experiment, so that one can iterate on the design. (Brooks, 2010, p. 106)

The Bureaus, as *exploring, experiential* learning organizations, assembled teams of highly qualified civilians and military engineers to learn the new technologies of the 1IR, developed new tools and new methods to implement them, and then set about designing and ordering innovative ships and weapons to adopt those new technologies into the Fleet, iterating with each version, model, or class as flaws and defects emerged.

Part II: Leadership—Resurrecting an Audacious Navy

In 1881, the election of President Garfield and the appointment of three extraordinary Secretaries of the Navy revolutionized the U.S. Navy's approach to technology adoption, just as the 2IR was starting. In many respects, the New Steel Navy's birth mirrored the Steam Navy's birth, in that little invention was involved. Apart from armaments, the entire endeavor was based on the diffusion of existing practices from commercial practice and other navies, notably England, for America's New Steel Navy technologies.

Consistent with past best U.S. Navy practice, Secretary of the Navy William Hunt formed an Advisory Board to prepare his modernization report to Congress, which then legislated the creation of a Naval Advisory Board that devised the eventual shipbuilding plan for the new Secretary of the Navy, William Chandler, to propose to Congress for funding. That plan resulted in constructing the foundational "ABCD" ships of the New Steel Navy (Wolthers, 2011). Congress legislated which technologies could be bought from foreign suppliers and which could not, providing a much-needed boost to fledgling 2IR domestic industries. By 1889, modern ship designs, armor, and shafting could be procured domestically, and modern ships could be built in government shipyards and commercial ironworks (Bennett, 1896).

This surge of effective leadership and organizational learning allowed Secretary of the Navy Benjamin Tracy to request funding for the U.S. Navy's first oceanic battleships in 1890, enabling the Navy to finally abandon its century-old mission of single-ship maritime interdiction, trade protection, and distant station operations to be replaced by a bona fide maritime dominance mission—a true American Fleet (Albion, 1980). Eight years later, it was a modern enough Fleet to decisively defeat the second-rate Spanish Navy during the Spanish-American War (Symonds, 2016), announcing America's entry onto the world stage as a significant maritime power.

At the dawn of the 2IR, Secretaries Hunt, Chandler, and Tracy led the transformation of the U.S. Navy from an obsolete, backwater service to a prominent position on the world maritime stage in less than two decades. As the Navy's material condition improved, significant organizational changes were required to continue the momentum they created.

In organization learning theory, this illustrates the ability of the United States to create a competitive advantage through its dynamic capability, which "*a*llows [an organization] to integrate, build, and reconfigure internal and external competencies to engage in a dynamic [operational] environment and provide competitive advantage" (York, 2020). This capability had been demonstrated intermittently during the previous century. However, the creation of the New Steel Navy in 1881 and the American combat victories in 1898 demonstrated a new coherent, sustained maritime dynamic capability. As we will see, the Navy would successfully execute that newly developed dynamic capability for a century until the start of the 4IR.

Close on the heels of the birth of the New Steel Navy in 1881 was Britain's 1905 adoption of the dreadnought-type of "all big gun" battleship as the new premier naval warship, with the first three U.S. Navy ships of that type being commissioned in 1910 (Friedman, 1985), lagging the Royal Navy, then the acknowledged maritime technology leader, by only five years.

Compared to the performance of the dominant Royal Navy, the U.S. Navy's new 1IR and early 2IR organizational learning process had accelerated the American technology adoption rate by a factor of five. Prometheus had been fully released, and the U.S. Navy began to run rampant.[1] This quantum leap in innovative technology adoption practices was the precursor to the U.S. Navy's mid–World War I objective of being "a Navy Second to One." In other words, second only to the Royal Navy (Weigley, 1973).

In just 29 years (1881–1910), the U.S. Navy progressed from being a small, technically backward, third-rate naval power to one aspiring to become the second most powerful Navy in the world (Cable, 1998). This contrasts with the 68 years the Colonial and 1IR Navy took to achieve similar growth in force structure and stature between 1794 and 1865. This second progressive move forward by the U.S. Navy took less than half the time of the first, principally due to improvements in the U.S. Navy's Phase III PIP leadership attributes and effective organizational learning practices. The Navy's profound leadership and organizational changes during that time were the key enablers to its rapid growth in combat power and capability.

After it was founded in 1921, the Bureau of Aeronautics (BuAer) fielded 62 different models of naval aircraft by 1941, including 22 fighter models and 20 seaplane designs. Even though dive bombers were introduced only in the mid-1930s, the U.S. Navy fielded eight unique designs in the six years before the 1941 Japanese attack on Pearl Harbor (Lewis, 2023). Compare that to current U.S. Navy performance: one new aircraft model since 2000. Although the U.S. Navy's naval aviation branch did not exist as an organization until 1921, the naval aviation force that fought and won in the Pacific Theater in 1941–1945, just 20 years later, demonstrated sophisticated aircraft designs and practical combat skills against an equally skilled and capable maritime peer competitor. That level of performance was not gained in one rationally derived, preplanned, orchestrated, and coordinated leap; it was learned through dozens of small, rapid, incremental, empirical improvements executed by a capable learning organization led by empowered leaders and staffed with enlightened and mission-focused members and a growing Argote-based active engineering toolset (Symonds, 2016). Naval aviation matured empirically, not rationally, according to Brooks's definitions.

The organization that the Navy built in the 1IR and early 2IR served them well going into a period of high innovation and technological changes (Kuehn, 2008):

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[1] A comparison to today's maritime competitive landscape should give the reader immediate pause.

The Navy was already organized in a fashion that encouraged operational innovation. They had a relatively flat organizational hierarchy and a tradition of frank communication between its constituent organizations. Managerial control was spread out . . . among several organizations. The sometimes-depressing effect of strong executive leadership on new ideas from the "rank and file" was alleviated to some degree by the healthy collaboration and sometimes competition between the General Board and OpNav . . . to ensure that a powerful CNO did not unduly influence the General Board's advice.

Lastly, the 2IR cemented a viable and vital relationship with industry regarding innovative technologies. As with steam in the 1830s, neither submarines nor aviation had a predecessor technology or product from which to draw Navy expertise. The Navy had to go to industry because industry was the only source of applicable knowledge, skills, and abilities (KSA).

The Navy had not fundamentally changed warship propulsion since the introduction of steam in the 1830s, so the development of nuclear-powered ships in the early 1950s was a change that the U.S. Navy met with a new leader and a new organization. Similarly, the Doolittle Raid on Tokyo in 1942 introduced the Navy to a new long-range maritime strategic strike mission, which it fully adopted after World War II. However, extending that to strategic missiles was utterly new (Reynolds, 1968). Launching maritime strikes from submarines using rockets was an even greater stretch, so, again, a new leader and organization were selected to champion and then adopt these into the Fleet (Sapolsky, 1972).

Lastly, after multiple failed attempts to bring new, computer-controlled radar technology to the Fleet, another new leader was found, and a new organization was created to adopt this innovative technology into the Surface Navy's Fleet of cruisers and destroyers (Wildenberg, 2024). The U.S. Navy discovered what is now known as the Lean Startup Model, first proposed by Steve Blank.

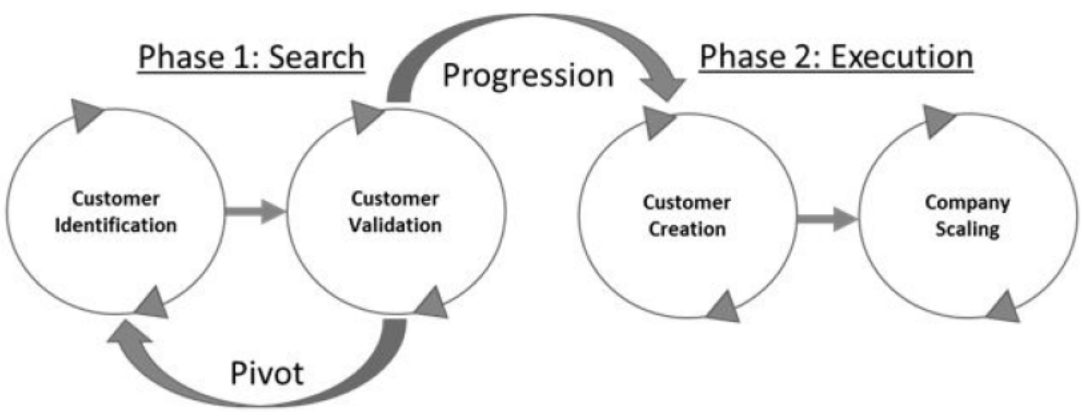

Figure 2: The Customer Development Model (Blank, 2013)

This is the practice of focusing on the customer before defining the product. It conforms with Brooks's model of empirical design and Denning and Dunham's PIP Phase I and II processes of sensing, envisioning, offering, and adopting.

The vexing technologies of the 3IR required the U.S. Navy to refine their already proven novel approach to organizational learning, one that presaged Blank's model, today's build-measure-learn (BML) lean startup learning model later popularized in the Boyd observe, orient, decide, act (OODA; Woods, 2013) and the Deming plan-do-check-act rubrics (York, 2020). These processes seek to produce a minimum viable product (MVP), which is then iterated through resultant empirical cycles of learning to deliver a series of incrementally improved products in rapid succession (Borotini et al., 2021; Eisenmann et al., 2011; Reis, 2020):

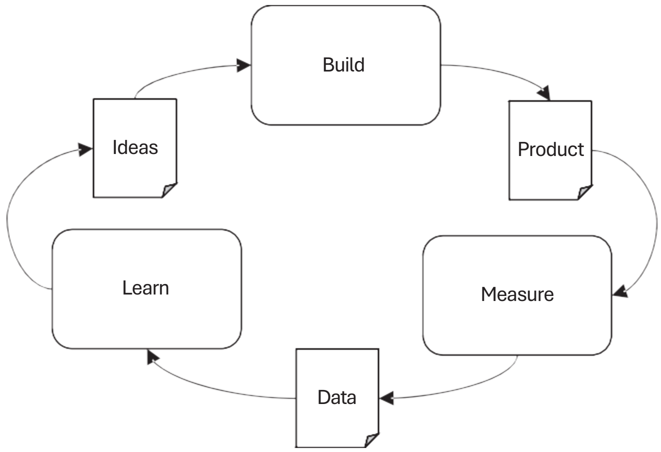

Figure3: Lean Startup's BML Cycle and Learning Actions

In 1955, the USS Nautilus, SSN 571, reported herself "underway on nuclear power." (Rockwell, 2022). Between 1954 and 1961, just seven years, the U.S. Navy commissioned 11 *classes* of nuclear submarines, 22 boats in all, including two classes of an entirely new type of submarine, a ballistic missile submarine. "The Navy explored the entire design space: conventional hulls, albacore hulls, twin screws. Single screws, one reactor, two reactors, water-cooled reactors, and sodium-cooled reactors. Fast and less-fast boats" (Lewis 2022). The Navy also built the first-ever nuclear-powered cruiser and aircraft carrier in the same period.

The USS Nautilus was a true MVP, and the 22 boats that followed were examples of BML practices applied in the very technically challenging, entirely new operational environment of nuclear-powered submarines. Similar operational learning behaviors were demonstrated for the 1956 Polaris program, where the Polaris A1 submarine-launched ballistic missile (SLBM), deployed in USS George Washington, SSBN 598, was an MVP (Sapolsky, 1972), and the 1968 Aegis Program, where USS Ticonderoga, CG 47, the first Aegis cruiser, was also an MVP (Wildenberg, 2024).

Using a specialized portfolio-oriented organizational structure for all three innovative technology adoption projects was critical to their success. This precisely evoked prior U.S. Navy empirical practices for the first six Frigates in 1794, the Ironclad Board that delivered three different ironclad ships in 100 days, the Naval Advisory Board that produced the four different "ABCD" ships in a decade, and the creation of the Bureau of Aeronautics in 1921 that delivered 62 different models of aircraft in 20 years. The Navy Nuclear Power Program (NNP), The Strategic Systems Program (SSP), and the Aegis Program (PMS 400) continued that unique and prescient U.S. Navy organizational rubric into the 3IR. All three implemented Argote's innovative, fact-based learning organizational culture and structure.

Part III: Prometheus Chained

In 1947, at the end of the 2IR, the United States decided to unify the armed forces into a single Department of Defense. The new structure codified the informal, ad hoc leadership and advisory groups formed before and during World War II (Albion, 1980).

This dramatically changed the U.S. Navy's Phase III PIP role in technology adoption by introducing an intermediate, higher-level decision-maker between the Secretary of the Navy and the President and Congress. Another leadership and decision-making layer, and a new, inexperienced one at that, was inserted into an existing, successful maritime technology adoption process, disrupting it.

The new Department of Defense started its organizational learning and innovative maritime technology knowledge at zero (i.e., 1794 in the context of this paper) while "supervising" a supremely progressive, technologically sophisticated maritime organization with 153 years of maritime technology and organizational learning, as presented here. Argote's organizational learning model of migrating knowledge into the new organization by moving people and tools into it was negated because few U.S. Navy people were assigned to the new Defense Department, and the new organization did not use the Navy's existing engineering toolsets. The details of the new structure are beyond the scope of this work, but its learning behaviors in the maritime domain, distinct from the U.S. Navy's, have been clearly demonstrated to be destructive in the extreme.

By the 1960s, the Defense Department had fully embraced the then-new, rationalist Product Development Model, which focuses on the product first and then shifts to selling the product to the customer (Blank, 2020).

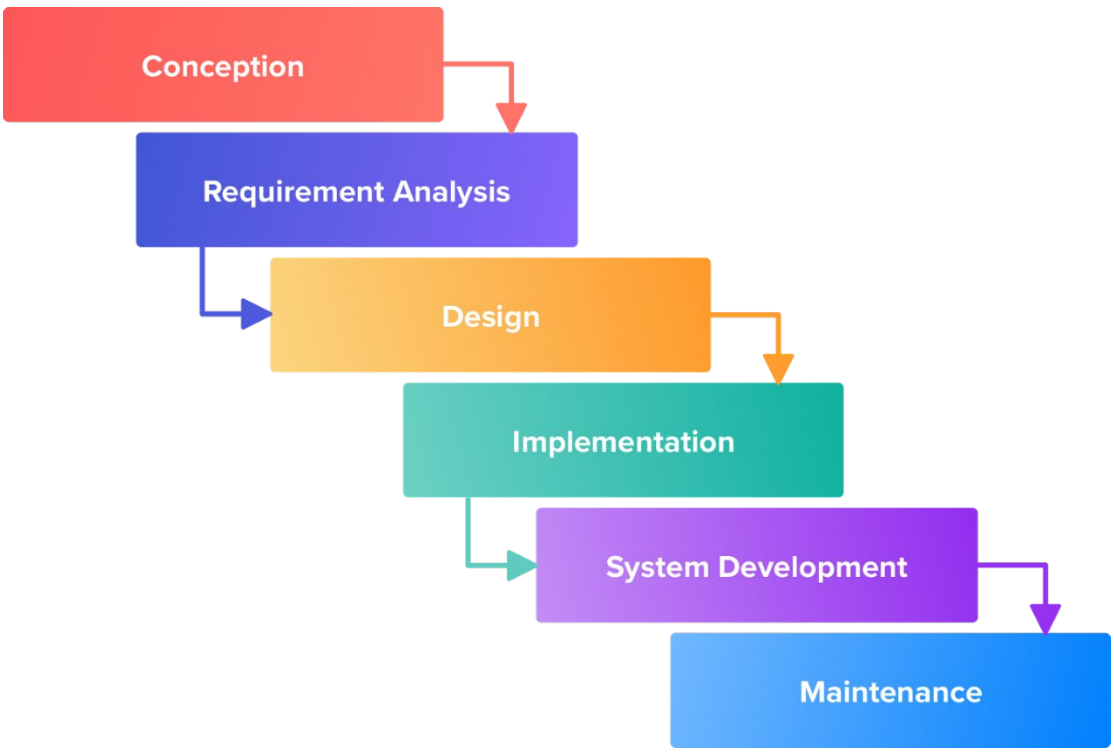

Figure 4: The Product Development Model

This model, reflecting Brooks's rationalist approach to design, assumed that designers, engineers, and scientists were perfect, fully understood the problem, and could thus deliver a perfect product. Failures were ascribed to the customer's failure to appreciate the perfection of the design.

Blank's euphonious epiphany (and later by Reis and many others) was that existing customers do not inherently accept innovative technology. Even less so when it is delivered whole and unchangeable. Moreover, technology developers do not know what customers want or will accept. Customers know what they use today and may not understand the utility of innovative technology without preparation and discovery (Blank, 2020). As one wag recently quipped, “Well, nobody wanted an iPad until they saw an iPad” (Murray, 2024).

That is also the premise of Phase II of Denning and Dunham’s PIP discussed earlier. Simply inventing an innovative technology is insufficient to bring it to market (or, in our case, Fleet operation); a high level of adoption preparation and customer awareness is required to adopt a new product successfully. PIP Phase III is an essential element of success. That is also the essence of Brooks’s empirical design method, Blank’s Customer Development Model, and today’s BML models: designers and engineers are flawed and have imperfect knowledge. So, they develop imperfect products that must be iterated to improve them. Prometheus must be unbound; knowledge must be proliferated.

Of note, the PIP Phase III attributes are absent from the Product Development Model and the Department of Defense’s implementation. Leadership, executing, and embodying are replaced by procedure, analysis, and direction, leading, as it soon became apparent, to dysfunctional organizational behaviors.

While the new Department of Defense had negligible impact on the U.S. Navy’s innovative technology innovation work for more than 15 years, the arrival of a new Secretary of Defense in the Kennedy administration changed that relationship. Robert S. McNamara came into his new job as a card-carrying Brooks rationalist. He led a “Whiz Kids” team that would fix the Defense Department and the Defense industrial base (Oliver & Toprani, 2022). It became almost impossible to field an *exploring* technology; nonetheless, the current 4IR U.S. Navy technology and engineering organizations have proven themselves skilled at introducing *exploiting* technologies into existing 3IR platforms as part of a viable and effective *exploitation* process in lieu of adopting thwarted 4IR replacement technologies.

	Vintage	Replacement 4IR Platform	Replacement 4IR Vintage	Replacement Outcome	Duration of the 3IR Platform (In Years)
SSN-688 Los Angeles Cass Submarine	1970	SSN-774 Submarine	1998	Adopted (But 688s are Still in Service)	54 plus
FFG-7 Frigate	1973	Littoral Combat Ship	2007	Adopted, curtailed at 22 Ships	42
FFG 7 Frigate	1973	FFG 62 Frigate	2022	In Design and first hull under construction	42
F-18 Strike Fighter	1974	F-35	2001	F-35 Curtailed, (But F-18s Still in Service)	50 and still in service
F-18 Strike Fighter	1974	MQ-25	2018	Not Adopted	Replacement Failed
CG 47 Cruiser	1975	CG(X)	2008	DDG 51 Flight III Upgrade, instead (But CG 47s are Still in Service)	49 and still in service

DDG 51 Aegis Destroyer	1981	DDG-1000	2000	Cancelled. Three ships commissioned	Replacement Failed
DDG 51 Aegis Destroyer	1981	DDG(X)	2020	Under Consideration	43 and still in production
SSN 774 Virginia Class Submarine	1998	XLUUV	2017	Not Adopted	26 and still in production
P-8 Maritime Patrol	2003	MQ-4	2021	Adopted	18

Figure 5. Thwarted 4IR *Replacement* Technologies

What Does "Good" Look Like in the 4IR? The most successful innovative technology adoption in the 4IR U.S. Navy is "Task Force 59." Started in September 2021 by the U.S. Navy's Fifth Fleet, based in the Persian Gulf, the unique *empirically* defined Customer Development Model organization adopted a BML strategy to introduce 4IR drone and artificial intelligence (AI) technology into that Fleet's operations as quickly as possible. Like the Ironclad Board, submarines, BuAer, and other U.S. Navy cold-start innovative technology organizations, TF 59 went directly to industry for innovative technology (Helfrich, 2023).

TF 59 built a new learning organization following Linda Argote's model: picking new people who learned about drones and AI, then developed new tools and tasks to field those innovative technologies. The result is a proper 4IR learning organization that has fielded a compelling suite of 4IR technologies that successfully addresses a genuine Fleet operational concern in less than two years (Helfrich, 2023). The U.S. Navy's Fifth Fleet PIP Phase III leadership and leadership methods operated in the finest traditions of the 2IR and 3IR Navy.

As of this writing, the U.S. Navy and the Department of Defense are 25 years into the 4IR. At this point in the 2IR (1894), the U.S. Navy had broken the shackles of their post–Civil War Dark Ages, fielded a New Steel Navy, and iterated it once to build a battleship Fleet. At this point in the 3IR (1974), the U.S. Navy had adopted nuclear power, fielded strategic ballistic missiles, jet airplanes, and guided missiles, and started the adoption process for software-defined radars. Only in the 1IR do we see no progress in adopting innovative technologies by 1800; Fulton's first steamship was still seven years into the future. Must the U.S. Navy repeat the same lag in adopting 4IR technologies as they did for adopting 1IR technologies?

In his prepared Congressional Statement in April 2018, Eric Schmidt said that "even the most senior leaders described responsibilities being so intricately nested across the organization that a sense of true ownership proved elusive to them. Early on, I reached a fundamental conclusion that has been borne out over time: DoD does not have an innovation problem; it has an innovation adoption problem" (Schmidt, 2018). Schmidt's clearly stated vital point was that leadership was ineffective, resulting in failed adoption events.

Conclusions

The 4IR has not been kind to the U.S. Navy. Its performance today most closely follows the pattern of the new U.S. Navy during the 1IR, where an organization that is unskilled at adopting innovative technology struggles to learn how to manage *exploring* technologies. As compensation, it becomes adept at enhancing the existing force structure by *exploiting* innovative technologies. For the 1IR, steam engines are added to sailing ships. Shell and rifled guns are installed on wooden sailing ships. Propellors replace paddlewheels on wooden steamships. Only the crisis of war opens the path to adopting ironclads, an *exploring* technology. However, as soon as the crisis passed, the U.S. Navy returned to its pre-war force structure. The 4IR U.S. Navy exhibits these same 1IR regressive, conservative, hesitant, self-doubting, and cautious behaviors. New radars are added to old ships. Old airplanes get limited design refreshes. Tired hulls, airframes, and propulsion plants are extended in service because no modern replacements are being built. The U.S. Navy has lost its technology adoption knowledge, skills, and abilities in the fourth industrial revolution. Prometheus is truly bound again. U.S. Navy leaders, exercising leadership, must change organizations, change people, and unbind Prometheus to bring the U.S. Navy into the 21st century and return them to being "A Navy Second to None."

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An Exploration of Methodologies Used to Measure Technology Maturity in Department of Defense Non-ACAT 1 Programs

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Abstract

In response to the lack of a codified or standardized methodology for assessing technology maturity during an Analysis of Alternatives for potential material solutions in Department of Defense (DoD) programs under the Acquisition Category (ACAT) 1 threshold, the purpose of this explorative qualitative study was to identify, analyze, and compare different methodologies currently used by acquisition professionals in non-ACAT 1 programs. Typically valued at over $3 billion, ACAT 1 programs experience heavy service and congressional oversight and have mandated Technology Readiness Assessments (TRAs) to determine technology maturity but account for less than 40% of the total DoD program budget. Technology maturity is an imperative metric required for conducting a comparative analysis of potential material solutions. Since neither a formal Analysis of Alternatives (AoA) nor a TRA is statutorily required for programs under the ACAT 1 threshold, the omission of any standardized AoA or TRA on the majority of acquisition programs allows for increased risk in cost, schedule, and performance overruns, all potentially resulting in increased taxpayer costs and decreased readiness for the DoD.

This study aimed to identify commonalities among methodologies and ultimately provide a set of best practices for measuring technology maturity for future alternative analysis by collecting and analyzing interview responses from DoD acquisition professionals responsible for conducting AoA in non-ACAT 1 programs.

Background

As new threats emerge in the global landscape, facing competition with peer and near-peer competitors emphasizes the need for the United States to modernize its forces and infrastructure while simultaneously facing a decrease in its domestic industrial capacity (Wostenberg, 2021). The modernization of forces requires an unprecedented reliance on technological innovation and adoption that currently outpaces the DoD acquisition framework (Blank, 2024; Clark, 2024). Despite numerous recommendations on acquisition reform from both government and private organizations, the DoD continuously finds its major defense acquisition programs (MDAPs) on the Government Accountability Office’s High-Risk List, signaling to Congress “programs and operations that are vulnerable to waste, fraud, abuse or mismanagement, or in need of transformation” (Government Accountability Office [GAO], 2024, header). Following numerous reform efforts over the past 50 years, the Government Accountability Office (GAO) consistently reports that most MDAPs experience cost increases and schedule delays due to numerous issues, including inaccurate and inconsistent assessment of technological components of the overall program (GAO, 2021a, 2021b).

Individual military departments manage those programs falling under the ACAT 1 threshold, identified as ACAT 2 or ACAT 3. While significant research has been conducted studying the performance of ACAT 1 programs, both the GAO and DoD Inspector General’s Office (DoDIG) have identified similar issues with ACAT 2 and 3 programs within each department, finding a lack of oversight and control for cost, schedule, and accountability (U.S. Department of Defense Inspector General [DoD IG], 2019). Many, if not all, of these programs possess an element of technology as part of the overall acquisition. However, determining technological readiness is at the individual department's discretion. With a lack of guidance at the DoD level, each department is left to determine its own best practices and adopt methodologies to assess technological readiness.

Problem Statement

The United States Department of Defense (DoD) is the nation's largest federal agency, whose annual budget is larger than all other federal agencies combined (Congressional Budget Office [CBO], 2024). Despite having an annual budget of $816.7 billion in 2023, almost 47% of the federal government's discretionary spending outlays (DoD, 2022), the DoD has consistently remained on the GAO High-Risk List, indicating program vulnerability to waste, fraud, abuse, or mismanagement (GAO, 2024). Over 60% of the DoD's programs fall under the Major Defense Acquisition Program (MDAP) threshold of a total cost of $3 billion and do not require the same level of oversight or adherence to codified assessment procedures as MDAPs (DoD, 2020). As new threats in the global landscape emerge and evolve, the DoD's programs will become increasingly reliant on technology, and accurate readiness assessments of that technology will be critical. The lack of any standardized or codified technology readiness assessment on most acquisition programs allows for increased risk in cost, schedule, and performance overruns, potentially resulting in increased taxpayer costs and decreased readiness for the DoD (GAO, 2019).

Research Question

What current methodologies are used by personnel to assess technology maturity in DoD non-ACAT 1 programs?

Methodology

Technology maturity can be ambiguous, often defined by the organization conducting a technology maturity assessment. Technology maturity assessments can be loosely defined and executed, ranging from simple observations to complex calculations. DoD acquisitions, whose execution is heavily regulated by organizational guidance, are often also complex and enduring processes. The lack of available accurate consolidated execution data for DoD ACAT 2 and 3 programs prohibits the efficient evaluation of any technology maturity assessment methodology and a comparison of methodologies. As such, the goal of this research was to utilize interviews to identify methodologies used in these programs as the first step in a greater effort in research to ultimately evaluate their use, similar to the significant efforts taken regarding ACAT 1 programs. The methods identified were compared, and the frequency of the total and frequency of use by individual services was calculated. Additionally, each identified methodology was compared to existing DoD regulations, and academic research focused on that methodology, if any exists, to conduct triangulation.

Population

The population for this research consisted of personnel who currently or previously participated in the technology maturity assessment process as part of DoD ACAT 2 and 3 programs. Due to organizational limitations of researching personnel actively participating in these programs within the DoD, the researcher excluded any personnel actively participating within programs in the DoD and sought individuals with previous acquisition program experience. From previous experience as a student at DAU and researching the organization, the researcher identified DAU as a significant single source of potential sample participants due to their mission faculty composition. DAU faculty would satisfactorily represent the population as it provides training and consists of faculty from all military branches.

The researcher identified interviewees based on the eligibility criteria below via a pre-interview questionnaire:

1. Currently or previously assigned to a DoD acquisition position or involved in a DoD acquisition program.
2. Assigned to a DoD non-ACAT 1 program.
3. Wholly or partially responsible for assessing the technological maturity of a potential solution for a non-ACAT 1 program.

Sampling and Sampling Procedures

With an initial sample set identified, the researcher used a purposive sampling strategy to identify those he would contact with interview offers. As Campbell et al. (2020) described, purposive sampling can improve the study's rigor and the trustworthiness of the data and results since the sample is more closely matched to the research objectives. By examining the accompanying demographic data collected via the pre-interview questionnaire, the researcher ensured a broad representation of participants based on experience, branch of service, and acquisition program roles. For example, the data may be biased if only participants who served in U.S. Navy acquisition programs were selected.

Qualitative case study research typically involves three to ten participants, but there is no specific requirement for the number of participants so long as research findings reach saturation (Creswell & Creswell, 2023). However, with over 170 technology maturity assessment methods identified (Parolin et al., 2024), it would be impossible to account for every potential use of these methods on ACAT 2 and 3 programs, given the research design and scope. The research applied judgment in selecting the best representative candidates to ensure sufficient representation and maximum possible saturation. The pre-interview questionnaire also allowed the researcher to calculate the frequency of listed assessment methodologies without interviewing participants; this data could be presented external to the interview analysis.

Instrumentation

This study used three instruments and three data collection methods. The first instrument was the researcher, who aggregated the data from the second and third instruments and conducted triangulation of that data with other sources, including DoD acquisition regulations and academic research. The researcher analyzed each case independently and cross-analyzed the collective cases based on the responses from the second and third instruments.

The second instrument used in this research effort was a pre-interview questionnaire to determine which DAU faculty personnel qualified for follow-up interviews. In addition to the three previously stated questions, the instrument included questions on DoD acquisition experience, acquisition training, and current employment status. Additionally, if applicable, the instrument presented preliminary questions on the participants' experience with technology maturity assessments and Analysis of Alternatives processes. These questions intend to facilitate purposive sampling and ensure adequate participant representation of the population. The questionnaire was delivered via Qualtrics, and answers would be parsed using Qualtrics filters.

The questions on the pre-interview questionnaire included the following:

1. Are you currently or have you previously been in a DoD acquisition position or involved in a DoD acquisition program?
2. How many years of DoD acquisition experience do you currently have?
3. In which DoD service were you primarily involved?

4. Have you received formal DoD acquisition training?
5. Have you received formal DoD training to conduct an Analysis of Alternatives?
6. Have you received formal DoD training in assessing technology maturity?
7. Are you currently a DoD civilian or uniformed military personnel (active or reserve)?
8. What is your current DoD grade level?
9. What is your current military rank?
10. Within your acquisition experience, have you ever been assigned to a DoD non-ACAT 1 program?
11. Within your acquisition experience, have you ever been partially or wholly responsible for assessing the technological maturity of a potential solution?
12. For the specific experience in #14, did the program prescribe a method or process for assessing the technology maturity of the solution alternatives?

Not all questions in the questionnaire required answers to submit, but only those participants who fully completed the questionnaire were considered for follow-up interviews.

The third instrument selected for this research effort was a semi-structured interview to collect greater details on the responses from the chosen participants' pre-interview questionnaires. In addition to gathering background information, interviews can be used to tap into an individual's expert knowledge. These interviews aimed to gather factual material and data, such as descriptions of processes, specifically technology maturity assessments. Researchers often use semi-structured interviews in policy research to delve deeply into a topic and understand the answers provided (Harrell & Bradley, 2009). Interviews were primarily conducted over virtual meeting applications like Microsoft Teams or Zoom. Recordings of the meetings were saved and sanitized to remove participants' names. Participants were notified before recording that their identities would remain anonymous, and each was assigned a number for reference and coding purposes. Each participant was offered a copy of their transcript to confirm accurate transcription. The semi-structured interview questions focused on the overall research effort question and included the following:

1. What methods were used to assess the technological maturity of the solution alternatives?
2. Was the outcome of the program considered successful?
3. Was the solution alternative with the highest assessed technological maturity selected?
4. What reason/rationale was provided for selecting a solution alternative with a comparatively lower maturity level?
5. What methodologies would you recommend for assessing the technological maturity of potential solutions during an Analysis of Alternatives for DoD non-ACAT 1 programs?

Data Collection

To accurately understand the research question proposed in this study, the researcher sought to locate themes from acquisition personnel with experience assessing technology maturity for DoD ACAT 2 and 3 programs. Lester et al. (2020) outline a seven-step plan for preparing, coding, and analyzing data for a qualitative approach utilizing thematic analysis.

Each of the three instruments used in this research effort had a different initial medium for collection. The pre-interview questionnaire data was managed and stored utilizing the

Qualtrics online application. Participant responses were manipulated and parsed within this application based on researcher needs. Various export report formats are available for incorporation into the larger data corpus stored in ATLAS.ti, a qualitative data analysis software application. The virtual interview sessions were recorded via virtual meeting applications like Microsoft Teams or Zoom. These applications provided an audio file and a verbatim transcription of the recording in text format, also stored in ATLAS.ti. For analysis, the text file was incorporated into the larger corpus. The applicable DoD regulations and academic research were available as various text files from online sources and available to the researcher at any time. The researcher created initial codes with the data collected and began coding and categorizing utilizing the ATLAS.ti application.

Limitations and Protocols

Three major limitations in this study could be addressed in future research efforts. First, this qualitative study collected data via interviews with DAU employees. While not confirmed, it was assumed that none of these individuals were active participants in DoD acquisition programs. The relevancy of the data the individuals provided could be considered; DoD personnel actively involved in DoD acquisition programs could provide more relevant data on current technology maturity assessment methodology. Future research could collect data from DoD personnel active in acquisition programs pending DoD approval. Second, the interviewees' ACAT 2 and 3 program data was purposefully omitted to protect the anonymity of the participants. As such, this data was not validated within service-specific acquisition systems or the DoD Defense Acquisition Visibility Environment (DAVE) information system. Pending DoD approval, future research could collect and/or validate ACAT 2 and 3 program data within these systems. Lastly, the lack of previous government and academic research on ACAT 2 and 3 program performance prohibited further analysis of the effectiveness and comparison of technology maturity assessments. Further research, both qualitative and quantitative, would serve as the foundation of this body of knowledge.

The interviews aimed to gather factual material and data, such as descriptions of processes, specifically technology maturity assessments. An Institutional Review Board (IRB) approved the interview questions. Participants were notified before recording that their identities would remain anonymous, and each was assigned a number for reference and coding purposes. Each participant was offered a copy of their transcript to confirm accurate transcription. Additionally, no DoD acquisition programs were listed by name in the data collection to maintain program performance and participant anonymity.

Results

From the initial solicitation email, 61 individuals completed the pre-interview questionnaire. Of those 61, 14 met the eligibility criteria and provided their contact information. One participant met the eligibility criteria but declined to be contacted. With the 14 individuals identified, the researcher emailed each willing participant individually to schedule the virtual interview. Of the 14, eight individuals provided replies to schedule the interviews. Inductive qualitative research usually uses theoretical sampling based on the researchers' perspectives and interpretations (Jain, 2021). However, Leedy and Ormond (2019) point to an iterative data collection and analysis process, sometimes called the *constant comparative model*. As the researcher analyzed the original content of the recorded interview sessions, new concepts were introduced and required further research via the document analysis effort. As more data was collected on these new concepts, new connections began to form with existing concepts and themes. As Leedy and Ormrod (2019) recommended, several initial, broad categories were identified to assist in coding. With the iterative process adopted, these categories were refined to themes and subsequently coded to smaller and more distinct units within the themes, allowing the researcher to focus on target document analysis and associating repeated units within the theme. Identifying these themes and units provided the foundational data needed to answer the research question of this study. With the interview transcripts loaded into ATLAS.ti, four initial categories became prevalent for coding.

The initial coding categories are identified in Table 1.

Table 1. *Initial Coding Categories*

Theme	Code	Description
Types of Technology Assessment Methods	TYP	Referenced types of assessments used in DoD acquisition programs
Constraints on Technology Assessments	CON	Factors affecting execution of assessments
Technology Assessment Influences	INF	Organizations, factors, and/or elements that influence assessments
Third Party Assessments	3PA	Organizations conductings/factors affecting third party assessments

Based on the interview questions, all eight interviewees provided data on the methods of technology maturity assessment, as this was a direct question. This was the only question that resulted in a 100% response, and as such, *Types of Technology Assessment Methods* was identified as the first initial coding category. Specific methods identified were nominated as subsequent themes and units.

Following the initial analysis, while not a direct question, interviewees provided data on the factors that influence technology maturity assessments within DoD acquisition programs. These factors were attributed to why an assessment may or may not be conducted and the factors that influence its results. As such, *Constraints on Technology Assessments* and *Technology Assessment Influences* were identified as the second and third initial coding categories. Specific factors identified were nominated as subsequent themes and units.

Interviewees provided data on third parties or organizations external to the acquisition program members conducting technology maturity assessments. *Third-Party Assessments* were identified as the fourth and final initial coding category, and specific organizations and the factors affecting the execution of the third-party assessments were nominated as subsequent themes and units.

With the initial categories identified, subsequent subordinate themes and units within the transcripts could be coded and assigned to the initial categories. With the use of ATLAS.ti, these themes and units were identified and supplemented with data obtained from the document analysis performed by the researcher. This data was added to ATLAS.ti and coded accordingly. The interviewees' extensive knowledge and experience provided enough data to explore the primary themes further. They revealed commonality regarding the significance of incorporating customer input into assessments and the factors that prohibit or influence executing assessments, including cost, time, and lack of knowledge. Additional connections between these themes and subthemes were explored, constructing a basis and foundational level of knowledge for further research.

The final coding and relationship structure is shown in Figure 1.

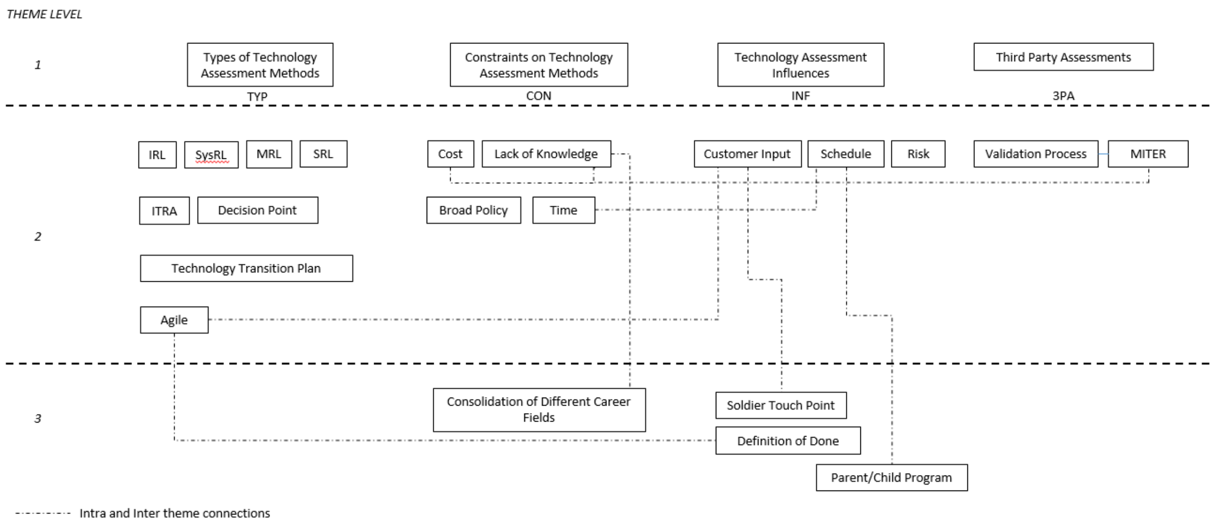

Figure 1. Coding and Relationship Structure

Figure 2 depicts the frequency of sub-themes within each initial theme category.

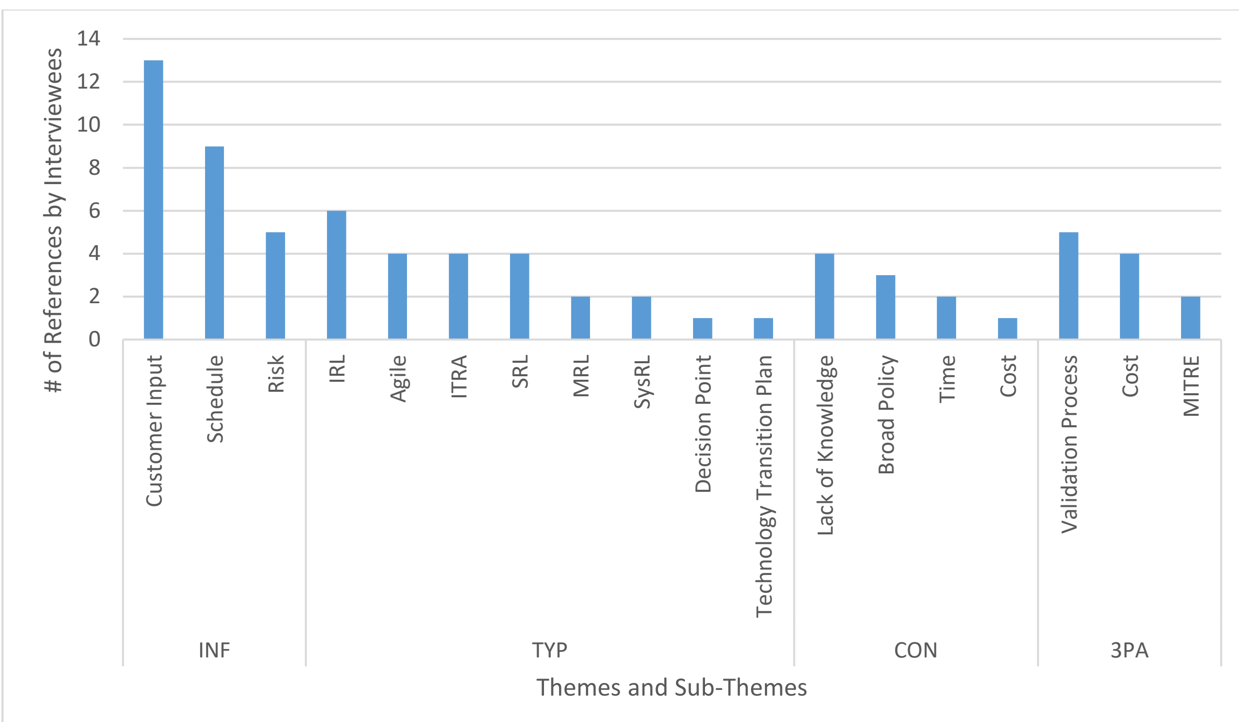

Figure 2. Theme and Sub-Theme Frequency

Discussion and Conclusion

The Literature Review revealed many assessment methodologies, specifically citing Parolin et al. (2024), whose research identified and compared 170 distinct assessment tools. Many of these methods, as noted by other researchers (Cauthen et al., 2022; Rea, 2022; Silberer et al., 2023), currently only provide theoretical frameworks for assessments and have yet to be applied to real-world situations such as DoD acquisition programs. The Literature Review also revealed repeated recommendations by the GAO (2022b, 2023b) for the DoD to adopt more comprehensive and encompassing assessment methods in acquisition programs. While the Literature Review yielded numerous methods, the interview data supporting the research question revealed eight distinct methods, only one recounted as used in a DoD non-ACAT 1 program. The Agile method, codified in 2001 (Beck et al., 2001), was emphasized by the DoD, specifically in software development, via the Adaptive Acquisition Framework (DoD, 2022a). While the DoD has no policy mandating Agile, the GAO has recommended that the DoD adopt Agile practices across all of its acquisition pathways (GAO, 2023a). A central tenet of the Agile method is iterative input and feedback from the end user. The interview data revealed the emphasis placed on *Customer Input* to satisfy User Acceptance and Definition of Done, both principles within the Agile process. While this method is potentially more resource-intensive and only feasible in some acquisition program types, it showcases the DoD's transition to a greater focus on incorporating user input into maturity assessments. The high frequency of *Agile* and *Customer Input* themes within the data reflects this organizational transition.

The lack of experiential data for actual usage of technology maturity assessment methodology in DoD non-ACAT 1 programs suggests constraints in executing assessments in these programs. This theme is further supported by the interviewee data, which provides specific instances of constraints affecting assessment execution. There is an evident literature and research gap on how these constraints affect non-ACAT 1 programs despite these programs being affected by the same constraints. The interviewee data suggests an inability of the DoD to create a policy broad enough to cover the range of acquisition programs at the non-ACAT 1 level, and a lack of policy potentially suggests a lack of priority for these assessments at both the DoD and individual service levels. This theme is supported by the repeated recommendations from the GAO to the DoD to account for the cost and time of conducting accurate and thorough assessments (GAO, 2020). The lack of a DoD mandate requiring these assessments could account for the lack of research and analysis of their subsequent constraints.

Although each interviewee's service affiliation, tenure, and acquisition experience differ, the four common themes provided relevance regarding assessing technological maturity in DoD non-ACAT 1 programs; as shown in Figure 2, the interconnectedness of these themes signifies the relationships these factors play in executing these assessments. Despite the wide range of acquisition programs within the DoD and the variety of methodologies available for implementation, many of these factors are present regardless of that diversity.

This research suggests little to no framework for conducting technology maturity assessments at the DoD level for non-ACAT 1 programs. The existence of any framework for conducting assessments at the service level within the DoD was not prevalent within the Literature Review; subsequent frameworks and/or policies may exist within lower functional levels of individual services but could not be verified within this research effort. The benefits of executing accurate and relevant technology maturity assessments and assessments whose scope extends beyond strict technology maturity are supported by government and academic research. Likewise, the results of inaccurate and irrelevant assessments are cited by interviewee data, supported by government and academic research, but still need to be aggregated in a manner suitable for further analysis.

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