SYM-AM-23-109

Proceedings

of the

Twentieth Annual Acquisition Research Symposium

Wednesday, May 10, 2023 Sessions
Volume I

Acquisition Research:
Creating Synergy for Informed Change

May 10–11, 2023

Published: May 1, 2023

Disclaimer: The views represented in this report are those of the author and do not reflect the official policy position of the Navy, the Department of Defense, or the federal government.

Approved for public release; distribution is unlimited.

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

The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Defense Management at the Naval Postgraduate School.

To request defense acquisition research, please contact:

Acquisition Research Program
Department of Defense Management
Naval Postgraduate School
E: arp@nps.edu
www.acquisitionresearch.net

Copies of Symposium Proceedings and Presentations; and Acquisition Sponsored Faculty and Student Research Reports and Posters may be printed from the **NPS Defense Acquisition & Innovation Repository** at **https://dair.nps.edu/**

Table of Contents

SYM-AM-23-109

Proceedings
of the
Twentieth Annual
Acquisition Research Symposium

Wednesday, May 10, 2023 Sessions
Volume I

Acquisition Research:
Creating Synergy for Informed Change

May 10-11, 2023

Published: May 1, 2023

Disclaimer: The views represented in this report are those of the author and do not reflect the official policy position of the Navy, the Department of Defense, or the federal government.

THIS PAGE INTENTIONALLY LEFT BLANK

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

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

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

Vice Admiral David H. Lewis, USN (Ret.) took the helm as the Naval Postgraduate School Chair of Acquisition in 2021 and led the Acquisition Research Program (ARP) in the Graduate School of Defense Management to connect NPS with leaders and policymakers in the acquisition community. Lewis graduated from NPS in 1988 with a Master of Science in Computer Science and returned to campus to replace the founding Chair of Acquisition, Rear Admiral, USN (Ret.) Jim Greene, who retired.

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

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

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

Lewis's extensive experience in shipbuilding has given him a unique understanding of the full acquisition lifecycle. He has delivered ships as a program manager and program executive officer, then later sustained and modernized them as a fleet engineer and systems commander.

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

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

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

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

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

KEYNOTE SPEAKER: DR. WILLIAM A. LAPLANTE, UNDER SECRETARY OF DEFENSE FOR ACQUISITION AND SUSTAINMENT (A&S)

Honorable Dr. William A. LaPlante Senate, serves as the Under Secretary of Defense for Acquisition and Sustainment (USD(A&S)). In this role, he is responsible to the Secretary of Defense for all matters pertaining to acquisition; contract administration; logistics and materiel readiness; installations and environment; operational energy; nuclear, chemical, and biological defense; the acquisition workforce; and the defense industrial base.

Prior to this appointment, Dr. LaPlante served as President and Chief Executive Officer of Draper Laboratory, a research and development company specializing in advanced technology solutions in national security, space exploration, health care, and energy. Previously, he was senior vice president and general manager at MITRE National Security, where he oversaw the operation of two federally funded research and development centers and the U.S. Department of Commerce's National Institute of Standards and Technology.

Dr. LaPlante served as the Senate-confirmed Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics from 2014 to 2017, where he aligned that Service's $43 billion acquisition enterprise budget with the Air Force vision and strategy. During his tenure, he forged a path forward on critical Air Force acquisition programs such as the B-21 long range strike bomber, while realizing nearly $6 billion in "should-cost" savings in other programs. Prior to this position, Dr. LaPlante spent 26 years at Johns Hopkins University Applied Physics Laboratory (APL), ultimately leading the Global Engagement Department where he was responsible for all of APL's work supporting offensive strike military capabilities. He also served as a member of the APL's Executive Council.

Dr. LaPlante has been a member of several scientific boards and commissions focused on maintaining national security, including the U.S. Strategic Command Senior Advisory Group, Naval Research Advisory Committee, and Defense Science Board. He joined other national experts as a commissioner on the congressionally-mandated Section 809 Panel, which performed a comprehensive review of Department of Defense acquisition policies and provided improvement recommendations, many of which became law.

Dr. LaPlante holds a doctorate in mechanical engineering from the Catholic University of America, a master's degree in applied physics from The Johns Hopkins University, and a bachelor's degree in engineering physics from the University of Illinois.

PANEL 1. THE NEED FOR RECAPITALIZATION AND SURGE CAPACITY: IMPLICATIONS FOR THE DEFENSE ACQUISITION SYSTEM

Wednesday, May 10, 2023	
9:05 a.m. – 10:15 a.m.	**Chair: Hon. David Berteau**, President & CEO, Professional Services Council ***Defense Acquisition Trends 2023*** Greg Sanders, Center for Strategic and International Studies **Panelists:** **Cynthia Cook (Ph.D.),** Director, Defense-Industrial Initiatives Group and Senior Fellow, International Security Program, CSIS **Matthew Zimmerman,** Acting Deputy, Joint Program Executive Office Armaments and Ammunition **Christine Michienzi,** Senior Technology Advisor for the Undersecretary of Defense (USD) for Acquisition and Sustainment (A&S) **William C. Greenwalt,** Nonresident Senior Fellow, American Enterprise Institute (AEI)

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

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

Matthew Zimmerman— Mr. Zimmerman became the Acting Deputy Joint Program Executive Officer (JPEO) for the Joint Program Executive Office Armaments and Ammunition (JPEO A&A) in January 2023. In this role, he provides executive leadership to efforts developing and procuring leap-ahead munitions that increase the joint Warfighter's combat power while ensuring a responsive munitions industrial base. He also provides oversight for the life cycle management and sustainment of Army weapon systems, munitions and equipment from research and development through test and evaluation, acquisition, logistics, fielding, and demilitarization. He oversees a civilian workforce of ~500 civilians and manages a $5B+ annual budget.

Christine Michienzi—Dr. Christine (Chris) Michienzi is an ST in the Office of the Secretary of Defense. She is the Chief Technology Officer for the Deputy Assistant Secretary of Defense (DASD) for Industrial Policy and for the Undersecretary of Defense (USD) for Acquisition and Sustainment. She provides technical expertise and strategic guidance to the DASD and USD on critical defense industrial base issues and mitigations in acquisition and sustainment technology areas such as critical chemicals, hypersonics, microelectronics, and strategic systems.

William C. Greenwalt—William C. Greenwalt is a nonresident senior fellow at the American Enterprise Institute (AEI), where he focuses on the expansion of America's defense industrial base and defense management issues. Issues include technology-transfer reform, defense acquisition and procurement reform, technology policy and innovation, and the civil-military integration of US and allied commercial and defense industrial bases. Dr. Greenwalt is also a founder of the Silicon Valley Defense Group.

Defense Acquisition Trends 2023: A Preliminary Look

Greg Sanders—is a Fellow in the International Security Program and Deputy Director of the Defense-Industrial Initiatives Group at CSIS, where he manages a research team that analyzes data on U.S. government contract spending and other budget and acquisition issues. In support of these goals, he employs SQL Server, as well as the statistical programming language. Sanders holds a master's degree in international studies from the University of Denver, and he holds a bachelor's degree in government and politics and a bachelor's degree in computer science from the University of Maryland. [gsanders@csis.org]

Abstract

The past year of contracting has faced multiple external influences: ongoing Covid-19 responses and supply chain disruptions, increasing inflation, and large-scale U.S. support to Ukraine given the Russian invasion of Ukraine. Despite all this, FY 2022 defense contract spending shows marked continuity with contract spending growing 0.1% after accounting for inflation. OTA spending has fallen further as commercial contracts have taken over as the mechanism of choice for responding to Covid-19. There are signs of greater adoption contracts with economic price adjustments or shorter time periods, but as of FY 2022 these shifts remained small scale. More surprisingly, spending on ordnance and missiles fell, suggesting that the acquisition system is still ramping up to recapitalize drawdowns by the United States and allies.

What is DoD Buying?

The continuity between FY2021 and FY2022 contract spending is striking given Russia's February 2022 invasion of Ukraine, the inflation in the larger economy, and ongoing supply chain challenges. Contract spending grew from $387.1 billion to $414.4 billion in current dollar terms, a 7.1% increase that after accounting for inflation represented 0.1% real growth (Office of Management and Budget, 2023).[1]

A key factor enabling this continuity is that while Ukraine has been given $45 billion in current dollars of U.S. aid, with much of that aid transferred in FY 2022, most of the arms transferred came in the form of defense drawdowns. Because drawdowns transfer items already in stock there was a need to transport them to Ukraine, but they did not have to be purchased as products. However, these transfers still had important implications for the acquisition system, as the Department of Defense planned to replace the stocks with equivalent or successor systems in addition to taking further steps, where necessary, to strengthen production capacity strained by the unanticipated surge in demand. At time of writing, the United Staets reports obligations of $432 million for Ukraine Mission Support, although this total underestimates spending (*Ukrain Mission Support Report*, 2023).[2]

---

1 This report uses the methodology employed in a range of CSIS reports on federal contracting. For over a decade, the Defense-Industrial Initiatives Group (DIIG) has issued a series of analytical reports on federal contract spending for national security by the government. These reports are built on Federal Procurement Data System (FPDS) data, which is downloaded in bulk from USAspending.gov, and, for other transaction authority data, from SAM.gov. DIIG now maintains its own database of federal spending, which includes data from 1990–2021. This database is a composite of FPDS and DD350 data. All dollar figures are in constant FY 2022 dollars, using Office of Management and Budget (OMB) deflators. This report accounts for inflation using Office of Management and Budget deflators for the entire economy. Use of different deflators, for example those for federal outlays or defense outlays specifically, suggests larger real growth, though regardless of measure there was substantial inflation in FY 2022. For additional information about the CSIS contracting data analysis methodology, see https://github.com/CSISdefense/Lookup-Tables.

2 DoD contracts are subject to a 90-day reporting delay and beyond that the latest reported contract start at time of writing was in September of 2022. In addition, in past conflicts National Interest Action Codes have a fairly strict definition of what is included under them, for example not including many of the transactions that took place in Afghanistan or Iraq under codes for the respective conflicts (Sanders et al., 2020).

As shown in Figure 1, the DoD has managed to maintain its buying power in inflation adjusted terms. Product spending increased by 1% to $209.14 billion, a comparable level to FY 2018. The peak product spending in FY 2020 was driven in good part by a substantial contract for the F-35, large contracts for major defense acquisition programs are often experience spikes and troughs rather than steady year-on-year growth (Jang et al., 2021). R&D spending grew by 0.9% to $34.1 billion dollars, the seventh year of real growth. Unlike products and services, R&D avoided a decrease from FY 2020 to FY 2021. Finally, services contracting fell by 1.0% to $170.6 billion.

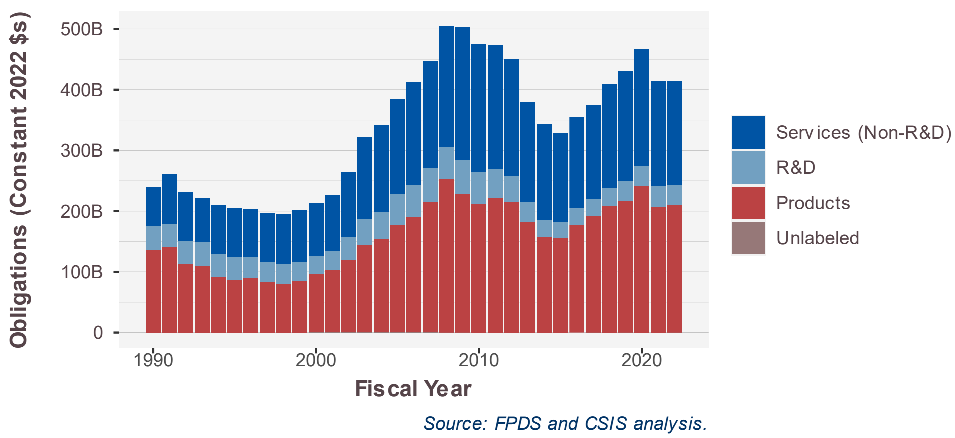


Figure 1. Defense Contract Obligations by Product, Service, and R&D, FY 1990–FY 2021

When considering contract spending by platform, as shown in Figure 2, FY 2022 spending shows one strikingly counterintuitive result: the largest decline was in ordnance and missile spending. That category fell to $23.5 billion, a 13% decline, a result that will merit closer inspection given the demand for both munitions to backfill U.S. and allied stocks as well as ongoing research in hypersonic missile. Much of this can be attributed to obligations for the guided missile product category fell from $6.6 billion to $5.1 billion. Some of this change included normal whipsaws in project funding, with the Trident II spending rising from $1.7 billion in 2020 to $3.1 billion in 2021 before falling to $2.5 billion in 2022. However, other shifts are more perplexing. Largely within the guided missile product category, obligations for the Guided Multiple Launch Rocket System dropped from $1.81 billion in FY 2021 to $1.27 billion in FY 2022.

The second largest decline was in the other R&D and knowledge-based portfolio, which fell by 10% to $41.6 billion despite the 1% rise in R&D spending overall. This implies that much of the R&D spending was in categories clearly tied to a category of platform. The largest areas of growth were more intuitive. Space systems increased by 18% to $11.3 billion. While space spending is widely believed to have significant spending tied to classified contracts, space has been an ongoing are of interest both in cutting edge research and in supporting a range of established DoD capabilities including global positioning system and communication satellites. The second largest increase was in missile defense, which rose by 7% to $13.8 billion. That level is still below the recent peak of $21.4 billion in 2020, but is consistent with an increasing strategic emphasis on air and missile defense driven in part by the demonstration of Russian missile attacks against Ukraine, including the regular target of power facilities and civilians.

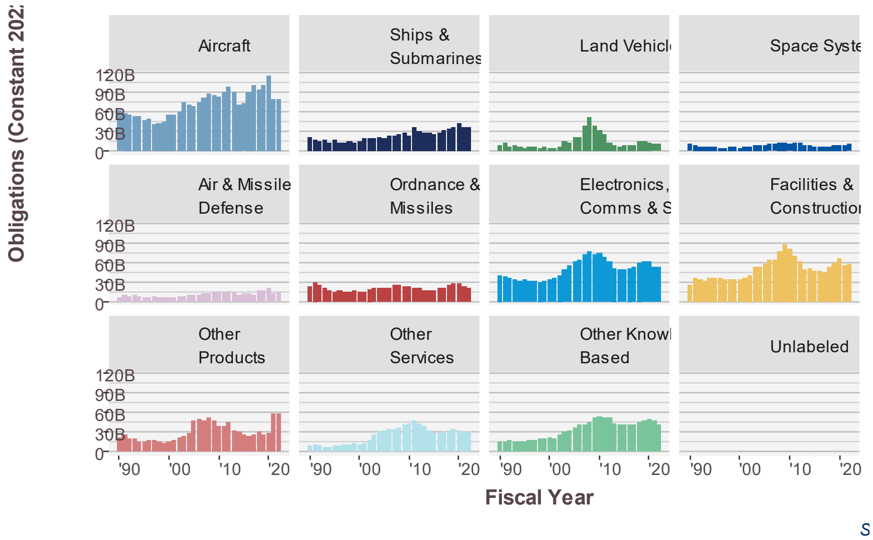
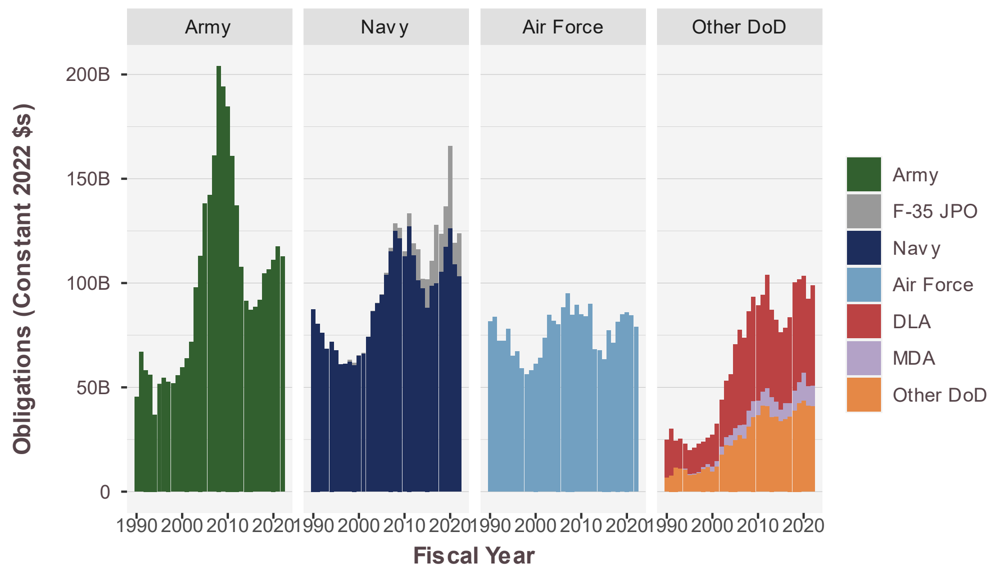


Figure 2. Defense Contract Obligations by Platform Portfolio, FY 1990–FY 2022

When considered by the contracting agency, as shown in Figure 5, the largest changes happened below the military department level. Spending on the F-35 continues to fluctuate. That program, due to the placement of the Joint Project Office (JPO) is entirely reported under the Navy despite the F-35A also being a leading acquisition priority for the Air Force. Spending for the F-35 major defense acquisition program, whipsawed up to $20.7 billion, a 97% increase over FY 2021 but still below the nearly $40 billion spent in FY 2020. These changes are a result of the uneven distribution of major contracts rather than major changes of plan for this program.

The military departments have all dropped slightly due to the effect of inflation, Army falling 4% to 1$12.7 billion. However, the overall share going to the Army may lead one to overestimate spending on traditional Army platforms such as land vehicles and vertical lift. Instead, starting in FY 2021 COVID-19 response has is responsible for more than a quarter of Army spending. The Army spent $31.6 billion in FY 2021 and $23.6 billion in FY 2022 on drugs and biological products. In FY 2022, the Army spent $4.6 billion on medical and surgical instruments. When excluding the F-35, Navy spending fell by 5% to $103.1 billion. Finally, the Air Force fell by 6.6% to $79.0 billion, although the Air Force, which includes Space Force spending, is suspected to be responsible for the largest proportion of the classified budget.

Growth was concentrated instead in the Defense Logistics Agency (DLA), which experienced a 15% increase to $48.2 billion in FY 2022. A cursory examination of product and service codes reported by DLA did not show a clearcut source for this growth, the agency does spend on medical supplies in a heightened manner since FY 2020 and also may be showing the effects of supporting the sustainment necessary for support to Ukraine and European reassurance initiatives. The Missile Defense Agency also grew, but only by 4% to $9.8 billion. The remaining other DoD agencies in aggregate fell by 1% to $40.9 billion.

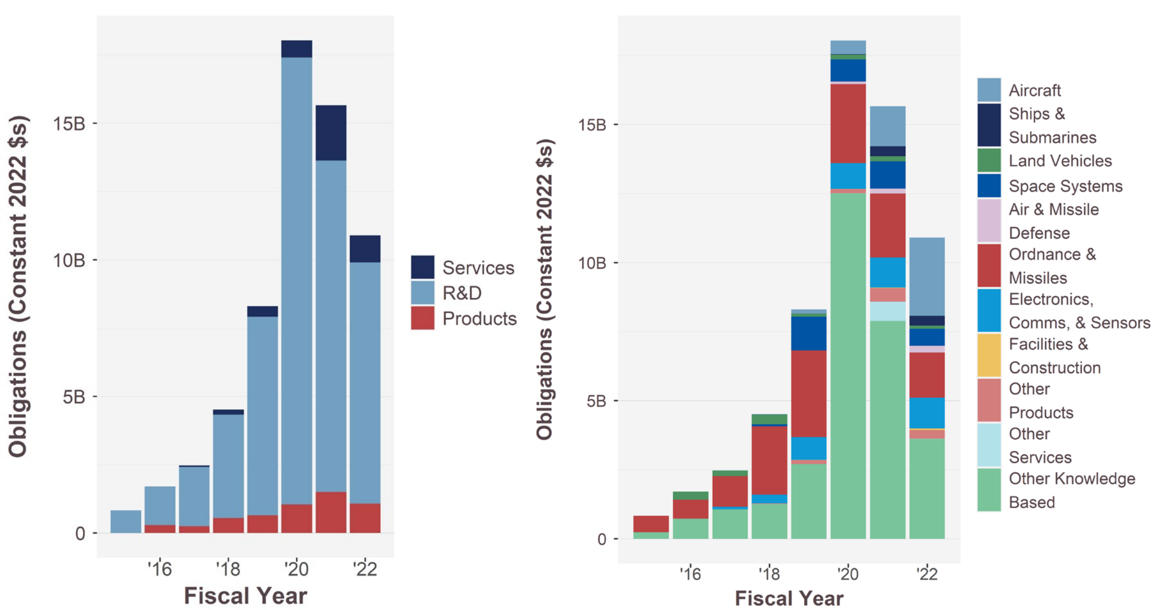


Source: FPDS and CSIS analysis.

Figure 3. Defense Contract Obligations by DoD Component, FY 1990–FY 2021

Use of Non-Traditional Acquisition Approaches

While contract R&D spending has experienced steady contracting growth, the picture is different when including other transaction authority (OTA) arrangements. That contracting approach grants great flexibility and is targeted towards non-traditional vendors as well as any vendors have made substantial internal investments in their offering to the DoD (McCormick & Sanders, 2021). The large FY 2020 spike in of Figure 4 can be traced in part to the Army's role in the federal response to the COVID-19 pandemic.



Source: FPDS and CSIS analysis. *Source: FPDS and CSIS analysis.*

Figure 4 Defense OTA obligations by product, service R&D area and portfolio, FY 2015-FY 2022

OTAs proved their worth in their ability to rapidly support Operation Warp Speed and that spending accounted for nearly half of OTA expenditures in FY 2020 and a significant portion of FY 2021 (Schwartz & Halcrow, 2022). In the lower graph COVID-19 related spending is largely contained within other knowledge-based services. As that rapid response effort wraps up, OTA R&D spending has faded as well.

However, while ordnance and missiles have been a consistent use case for OTAs, the war in Ukraine has not led to a surge in activity. Instead spending on ordnance and missiles dropped to $1.6 billion in FY 2022, a 29% decline.

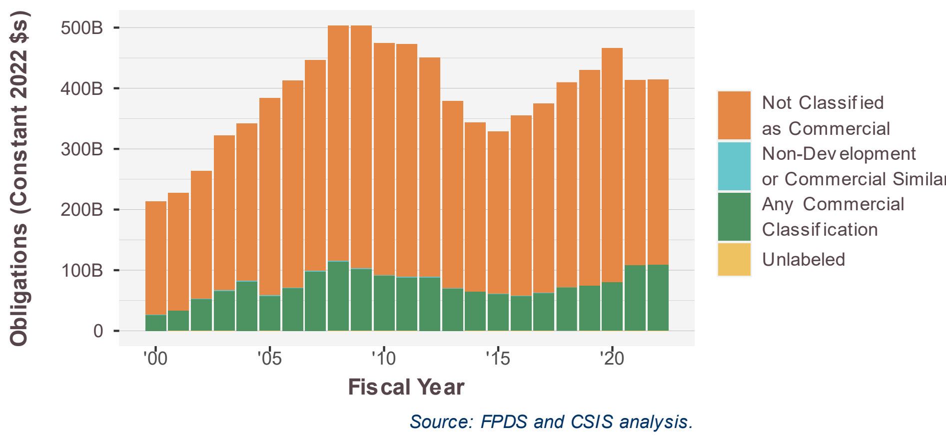


Figure 5. Defense Contract Obligations Categorized as Commercial

While OTA use has declined from its initial pandemic surge, use of commercial items grew dramatically in FY 2021 and sustained that larger market share in FY 2022, rising 1.2% to $109.0 billion. For the past two fiscal years at least 26% of DoD contracting has used commercial procedures, the highest proportional share of this century, although FY 2008 had $114.1 billion in commercial obligations, a slightly higher absolute spending level.

As shown in Figure 6, the Army and the Defense Logistics Agency (DLA) have been the primary users of commercial items and services. Echoing the FY 2020 spike in OTA spending, the growth in commercial contracting was largely driven by the Army spending discussed above.

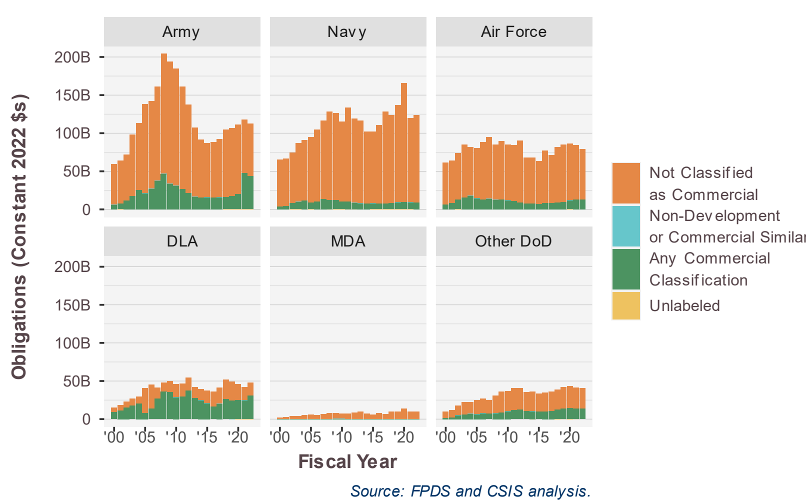


Figure 6. Defense Contract Obligations Categorized as Commercial

Competition

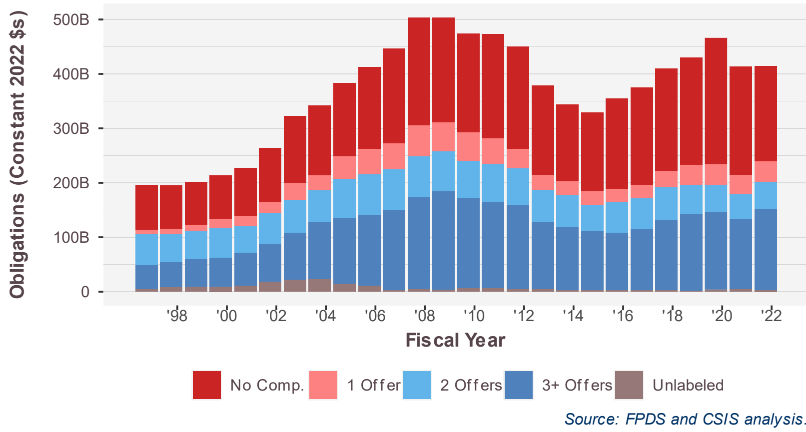


Figure 7. Competition Spending by Number of Offers, FY 1997–FY 2022

The share of contract obligations originally subject to competition has fluctuated notably in recent years. From FY 2021 to FY 2022, the value of contracts competed with three offers or more rose by 16% to $149 billion. This increase contributed to the share of obligations that were competed with two or more offers rising from 42% to 48%, the highest level since FY 2015. This increase is in line with Biden administration emphasis on competition (Office of the Under Secretary of Defense for Acquisition and Sustainment, 2022). That said, the changes in recent years regarding the level of competition are more affected by the composition of purchases than any given competition promotion policy.

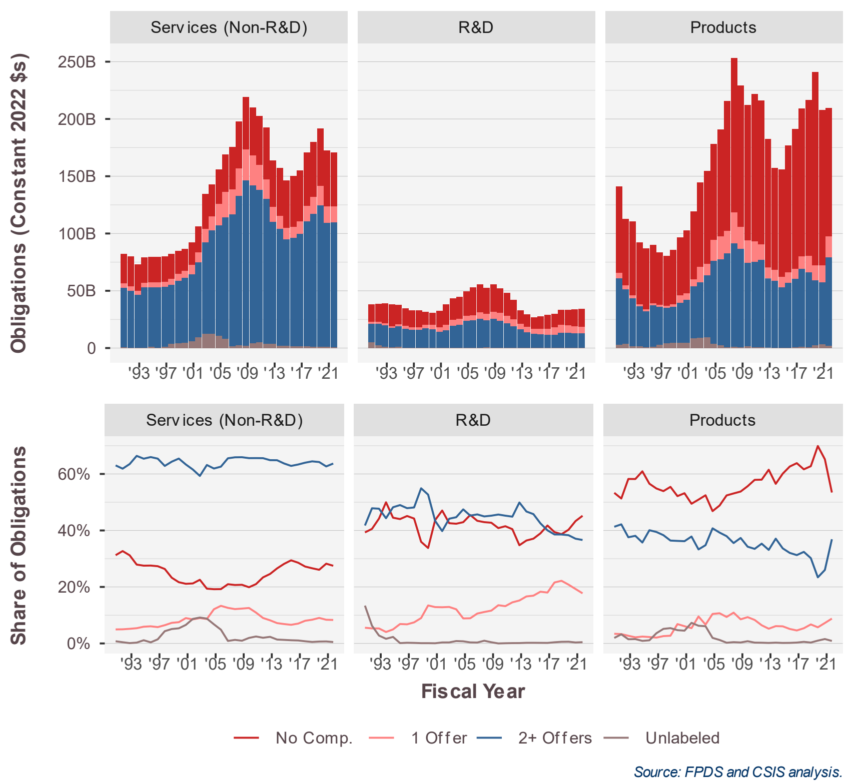


Figure 8. Competition Spending and Share by Product, Service, and R&D, FY 1991–FY 2022

As shown in Figure 8, the average level of competition varies greatly between products, services, and R&D. In the rightmost column and least competed are defense products, because much of the spending goes to weapon systems that the developing vendor has exclusive rights to produce. During the Trump administration, a drive to purchase existing weapon systems contributed to falling share of contracts subject to competition (Jang et al., 2021). In FY 2022 the value of contracts for defense products competed with two or more offers, rose from 26% to 37%. This led to the larger increase in competition noted above. It was driven not by a sudden surge of competition for weapon systems but instead by increasing competition for other products related to Covid-19 response.

Services, shown in the leftmost column, have been fairly stable in the extent of competition, even as total spending rose and fell. However, in the middle, R&D contracts shows a troubling trend of increasing competition with a single offer starting after FY 2005 and peaking in FY 2019 at 22% of defenses R&D spending. Single offer competition can indicate weakness in the industrial base, as it can indicate that a contracting officer hoped for competition but that multiple vendors did not find it worth their effort to bid. The rate of single offer competition defense R&D competition has begun to fall losing out to contracts awarded without competition which accounted for 45% of defense R&D spending in FY 2022, the highest level since FY 2006.

Responding to Inflation

The 7% GDP inflation seen in past year meant that inflation has been a concern to a degree not seen since the early 1980s which peaked even higher at 13.6% in the summer of 1980 (*Consumer Price Index (CPI) Databases*, n.d.). That inflationary period also coincided with hikes in defense outlay that had begun in FY 1979 and meant that contract spending could keep pace and gave contracting officers flexibility to maintain scope (Sanders & Holderness, 2022).

The steady state spending in FY 2022 suggests that today's environment is similar, although risk is not evenly distributed throughout the industrial base. Last year, to analyze potential sources of risk, CSIS looked at the distribution of pricing mechanism and duration by vendor size as shown in Figure 11. For industry, risk is highest in firm-fixed price contracts which, by default, are static in the face of changing external market conditions. That said, this risk is mitigated by contracts with shorter durations, which may still be subject to a period of high inflation but not the accumulated effects of multiple years. Small and medium vendors are most exposed to firm-fixed price contracts that last more than a year; in FY 2021 this made up 38% and 43% of their prime obligations respectively. The rate for large and big five contractors, 31% and 26% respectively, still holds real risks but is mitigated by the greater reliance for many of these contractors on cost-based contracting which generally has more mechanisms to reflect unexpected changes during contract implementation.

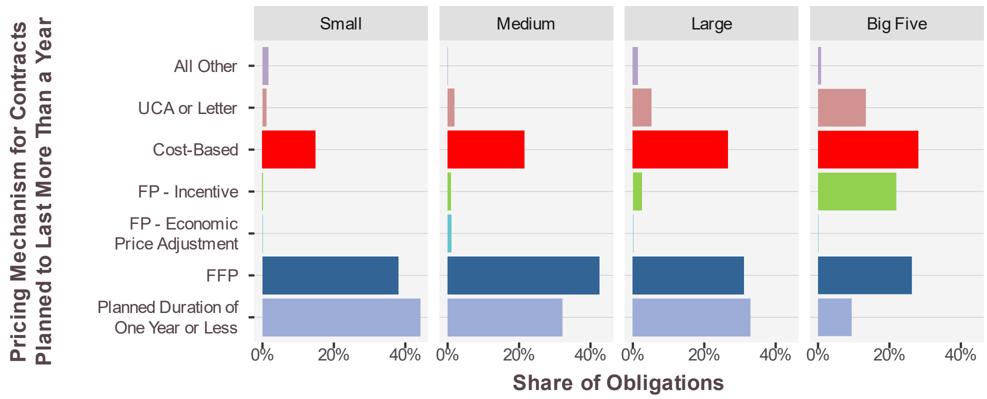
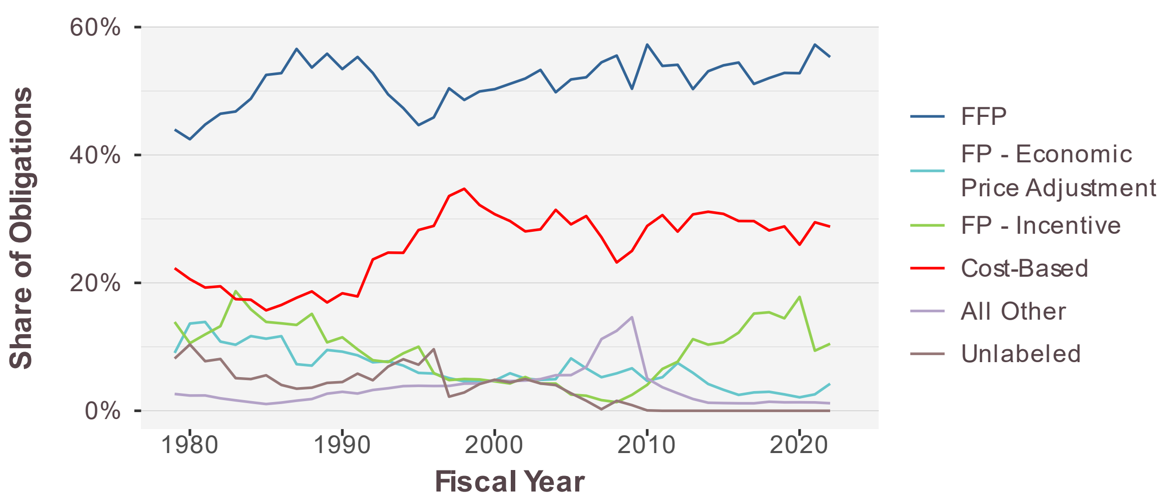


Figure 9. Share of Defense Contract Obligations by Pricing Mechanism and Planned Duration, FY 2021

There is a mechanism in fixed-price contracting that is deliberately designed to address risk from changing prices, namely economic price adjustments. As shown in Figure 10, in FY 2021, contracts using economic price adjustments as their primary pricing mechanism accounted for 2.6% of DoD prime contracts. After the last bout of inflation, that share routinely exceeded 10% through FY 1986. Then and now those numbers understate the use of any form of fixed-price economic price adjustment, as such mechanisms will often be a small part of a larger contract to address a specific known risk, such as fuel costs. However, even with imperfect reporting, the trends in use can still provide an important clue as to the larger use of such mechanisms. In FY 2022, the obligations for contracts primarily using this mechanism rose 65% to $17.5 billion, which increased the overall usage rate from 2.6% to 3.1% of DoD contract obligations. The baseline usage rate back in FY 1979 was notably higher, already reaching 9.1%. This suggests that while use of the pricing mechanism is on the rise today, it is unlikely to reach past peaks and that in keeping with DoD statements there have not been widespread adjustments of existing contracts to incorporate economic price adjustment mechanisms (LaPlante, 2022).



Source: Federal Procurement Data System (FPDS) and CSIS analysis.

Figure 10. Historical Contracting Mechanisms, FY 1979–FY 2022

Another possible mechanism for reducing the risks of inflation would be to reduce the planned duration of contracts and task orders. This would be an inherently slow shift, as 50% of contracts obligations in FY 2022 have an initial ultimate duration of at least two years or more and thus this will slowly work their way through the system. As seen in Figure 11, fast duration contracts did become more common from FY 2021 to FY 2022, growing by 20% to $37.2 billion.

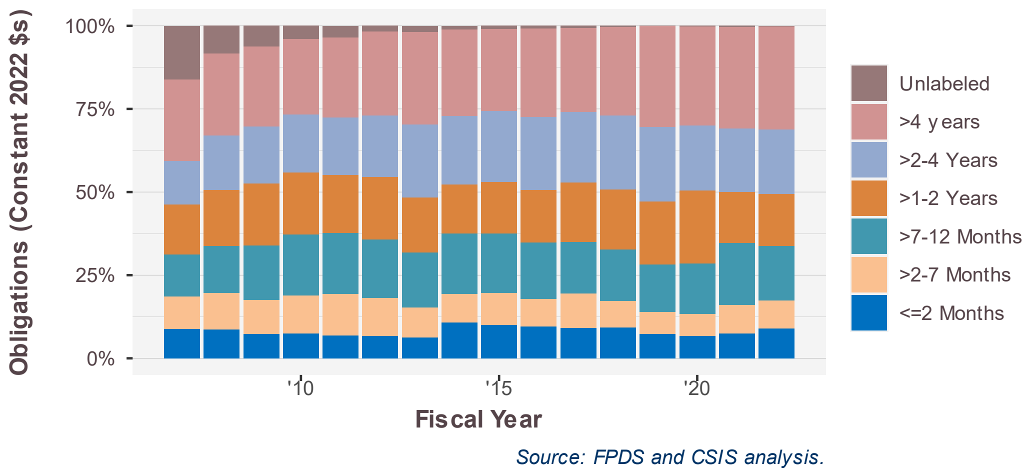


Figure 11. Share of Defense Obligations by Initial Contract or Task Order Ultimate Duration, FY 2007–FY 2022

However, this did not reflect a larger trend to shorter contracts, as the total obligations to contracts with initial unmodified duration of a year or less fell by 2% to $140 billion, despite the strong growth of quick turn contracts. In FY 2021 and FY 2022 obligations to contracts lasting a year accounted for 35% and 34% of all contract spending, respectively. This is notably higher than the 28% rate that prevailed in both FY 2019 and FY 2020, but still below the recent peak of 38% in FY 2011 and FY 2014. Taken together this suggests that if inflation is an ongoing concern there is room for further shortening of contract terms, but that it is too soon to say if such a sustained shift is occurring.

Addressing Limits to Production

In recent years, acquisition reform efforts focused on innovation and rapid prototyping and transfer of new systems to operators in time to maintain technology superiority. However, the war in Ukraine is a more industrial conflict, U.S. and allied transfers are often technologically superior to Russian equivalent systems, but production capacity has increasingly been an area of focus. Congress has voted to authorize wider use of multi-year procurement which is a vital tool for building this capability. Multi-year procurement gives industry greater certainty that their investments in expanding a factory or training new workers will not prove to be redundant several years later when the immediate crisis is past.

Because of the necessity for Congressional authorization, it is not surprising new permissions granted in the 2023 National Defense Authorization Act (NDAA) have not led to increases in the FY 2022 data included in Figure 12. Instead, it is useful to look at FY 2022 levels as a baseline and an example of what to expect by looking at the often cyclical rates of multi-year authority employment in ships and submarines and lane vehicles. That said, acquisition experts also raised concerns as to the quality of multi-year reporting earlier in the century, which may merit additional investigation.

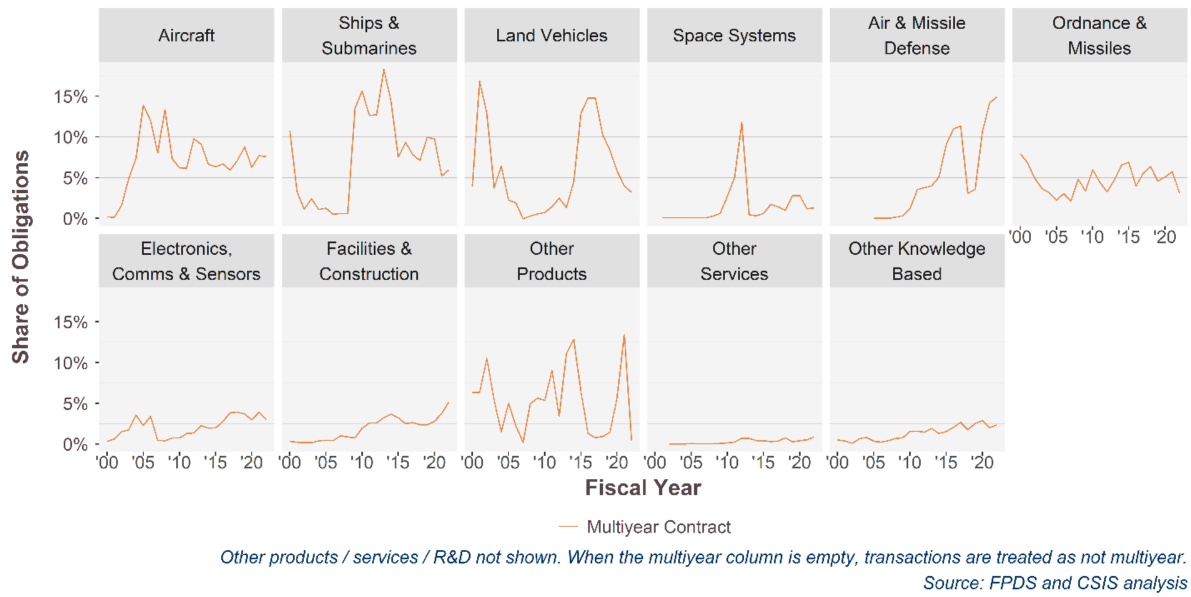
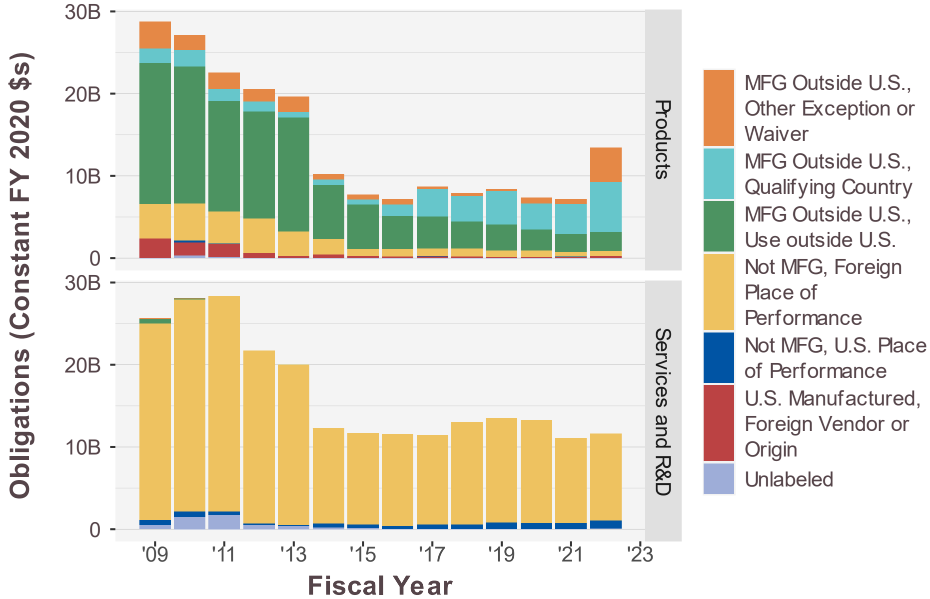


Figure 11. Share of Contract Obligations Employing Multiyear Procurement by Platform, FY 2000–FY 2022

Usefully given the relevance of air and missile defense to the war in Ukraine, multi-year contracting has a growing role for that portfolio, reaching 15% of spending in that category in FY 2022. By comparison, ordnance and missiles presently devotes only 8% of obligations in that portfolio to multi-year contracting. Based on the example of other sectors, the reliance of the ordnance and missiles sector on multi-year contracting could easily double. That said the limitation on the rate of increase in implementing the 2023 NDAA will be shaped not just by the DoD's ability to move swiftly on contracting, but also the long lead times for standing up or expanding production activities.

Another possible way to increase capability is to look to other nations to fill gaps in U.S. industrial capacity. As Figure 13 shows, the DoD heavily relied on international production during the more intense periods of the wars in Iraq and Afghanistan, primarily for use outside the United States, as is shown in green. In more recent years, acquisition of products from abroad has turned to ally-shoring from countries with reciprocal defense procurement arrangements with the United States that thus are qualifying countries depicted in light blue. The biggest surprised in FY 2022 is the $4.2 billion for products manufactured outside the United States that is driven by purchase of commercial goods, including fuels.

These jumps for largely commercial goods are not yet an example of international production to help fill gaps that relate to weapon systems. The growth does not necessarily represent an increasing comfort with international vendors and manufacturing. Instead, a key factor is the rising U.S. content requirements, a process started under the Trump administration and continued by the Biden administration. As a result of these changing thresholds, products need more U.S. content to count as a U.S. good. Thus, a product that counted as United States in origin in FY 2016 may no longer qualify in FY 2022.



Source: FPDS and CSIS analysis.

Figure 12. Contracts with Foreign Vendor or Origin for Products and Services, FY 2009–FY 2022

Conclusions

Contract obligations kept up to inflation, even when using a comparatively high measure.

In nominal terms, contract spending grew from $387.1 billion to $414.4 billion, a growth rate of 0.1% when applying a 7% inflation adjustment. The Office of Management and Budget's estimates that inflation for federal outlays in general and defense outlays in particular are both lower than that overall chained GDP inflation rate, so it is safe to say that spending is steady or growing depending on the preferred measure.

OTAs, commercial acquisition authorities, and efforts to increase competition have all been applied to the DoD's COVID-19 response.

The DoD response to COVID-19, led by the Army, has employed a range of acquisition approaches that were cultivated to ease the adoption of new technology, often from outside the traditional defense ecosystem. As these responses mature, efforts move from OTAs to traditional contracts employing commercial contracting approaches. This change was already in progress from FY 2020 to FY 2021, with the notable change in FY 2022 being a shift to increasing competition.

The acquisition system is adjusting to inflation, but primarily through higher topline spending.

Product, service, and R&D obligations each had growth rates within roughly plus or minus 1%. This suggests relatively stable spending patterns compared to the shift to product spending that happened under the prior administration. While the rise in nominal spending is the most important trend, there were notable shifts in contracting approaches that reduce risks to industry from inflation: a 65% increase to $17.5 billion in obligations for contracts primarily using fixed-price economic price adjustment contracts and 20% growth to $37.2 billion in obligations for contracts taking two months or less. However, these substantial increases are not enough to hit historic ties or change how the typical dollar is spent in a $414 billion acquisition enterprise.

Through FY 2022 efforts to support the war in Ukraine and build productive capacity are not primarily being exercised through defense contracts and OTAs. Presidential drawdown authority for existing stocks and funding under the Defense Production Act Tittle III are both not included in the data of this report and represent are both being used in bold and innovative ways to address this challenge. However, from a strict acquisition system spending perspective, the money has not yet arrived through contracts and OTAs. Even before accounting for inflation, missile and munition obligations fell from $22.0 billion to 20.5 billion.

References

Consumer Price Index (CPI) Databases: U.S. Bureau of Labor Statistics. (n.d.). Retrieved April 13, 2023, from https://www.bls.gov/cpi/data.htm

Jang, W. J., Sanders, G., & Holderness, A. (2021, December 2). *2021 defense acquisition trends: Topline DoD trends after a half decade of growth*. https://www.csis.org/analysis/2021-defense-acquisition-trends-topline-dod-trends-after-half-decade-growth

LaPlante, W. (2022, October 19). *Responses to questions: Senator Warren letter dated October 5, 2022*. https://www.warren.senate.gov/imo/media/doc/Letter%20-%20Dr%20LaPlante.pdf

McCormick, R., & Sanders, G. (2021). *Trends in Department of Defense other transaction authority (OTA) usage*. 51.

Office of Management and Budget. (2023). *Table 10.1—Gross domestic product and deflators used in the historical tables: 1940–2028*. The White House. https://www.whitehouse.gov/omb/budget/historical-tables/

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2022). *State of competition within the defense industrial base* (p. 30). U.S. Department of Defense. https://media.defense.gov/2022/Feb/15/2002939087/-1/-1/1/STATE-OF-COMPETITION-WITHIN-THE-DEFENSE-INDUSTRIAL-BASE.PDF

Sanders, G., & Holderness, A. (2022). *Inflating the risk? Contracting in the face of inflation*. https://www.csis.org/analysis/inflating-risk-contracting-face-inflation

Sanders, G., Hunter, A., Ruedlinger, J., Pandya, S., Ridings, M., Causwell, A., & Wang, X. (2020, April 17). Overseas contingency operations contracts after Iraq: Enabling financial management research and transparency through contract labeling. *Proceedings of the Seventeenth Annual Acquisition Research Symposium*. Acquisition Research: Creating Synergy for Informed Change, Monterey, CA. https://dair.nps.edu/handle/123456789/4230

Schwartz, M., & Halcrow, S. (2022). *The power of many: Leveraging consortia to promote innovation, expand the defense industrial base, and accelerate acquisition*. 49.

Ukraine Mission Support Report. (2023, April 6). SAM.Gov | Databank | Contract Data | Static. https://sam.gov/api/prod/databank/v1/reports/static/download?fileName=SAM_IAE%20Ukraine%20Mission%20Support&fileType=xlsx

PANEL 2. EXPLORING NEW FRONTIERS IN SPACE ACQUISITION

Wednesday, May 10, 2023	
10:30 a.m. – 11:45 p.m.	**Chair: Howard Pace,** Professor of the Practice, Acquisition Management, Naval Postgraduate School **Discussant: James H. Newman,** Chair, Space Systems Academic Group, Naval Postgraduate School ***DOD Acquisitions for Space Depend on Prioritizing Warfighter Needs to Maintain Strategic Advantage*** Desiree Cunningham, U.S. Government Accountability Office Burns C. Eckert, U.S. Government Accountability Office Brian Fersch, U.S. Government Accountability Office ***Schedule and Cost Estimating Analysis for LEO Satellite Constellations*** Brian Gladstone, Institute for Defense Analyses Patricia F. Bronson, Institute for Defense Analyses

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

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

James H. Newman—Chair of the Naval Postgraduate School Space Systems Academic Group, Dr. James H. Newman is a veteran of four space shuttle missions, including a critical mission to repair the Hubble Space Telescope. Newman graduated from La Jolla High School, San Diego, California, in 1974; he received a Bachelor of Arts degree, cum laude, in Physics from Dartmouth College in 1978, a Master of Arts degree and a Doctorate in Physics from Rice University in 1982 and 1984, respectively. In March 2006, Newman was detailed to the Naval Postgraduate School in Monterey, California, as a NASA Visiting Professor in the NPS Space Systems Academic Group. Newman left NASA in July 2008 to accept a position as Professor, Space Systems at NPS to continue his involvement in teaching and research, with an emphasis on using very small satellites in hands-on education and for focused research projects of national interest.

DOD Acquisitions for Space Depend on Prioritizing Warfighter Needs to Maintain Strategic Advantage

Desirée E. Cunningham—is a Senior Analyst at the U.S. Government Accountability Office, specializing in national security space and DoD major acquisitions. She has worked in this issue area for more than 14 years, reporting and making recommendations on a variety of DoD and space-related topics including national security space launch, the Mobile User Objective System, the F-35 Joint Strike Fighter, space command and control, and other programs. [cunninghamd@gao.gov]

Burns C. Eckert—is a Senior Analyst at the U.S. Government Accountability Office, specializing in space and software acquisitions, with brief annual forays in the Ford-Class Aircraft Carrier program. In 15 years at GAO, she has supported evidence-based reviews and recommendations across many subject areas, including extensive work in Iraq and Afghanistan earlier in her career. Burns is a graduate of the LBJ School of Public Affairs at the University of Texas, Austin (MPAff) and the University of Edinburgh, Scotland (MA Divinity). [eckertb@gao.gov]

Brian Fersch—is a Senior Analyst at the U.S. Government Accountability Office, specializing in cyber, software, and C4ISR acquisitions. Prior to joining the GAO in 2019, he spent 16 years with the DoD in various positions, including PEO C3I&N Special Programs CFO, AFLCMC Technical Director for Electronic System Cost and Program Analysis, and with the Air Force and Army service cost agencies. Fersch's current interests include non-kinetic warfare, C2, communications architectures, AI, and digital literacy. [ferschb@gao.gov]

Abstract

Congress has often expressed concerns about the DoD's ability to acquire innovative solutions that could serve the warfighter, particularly in software-intensive solutions, such as those that support the space domain. A further challenge is the DoD's adoption of Agile software development principles and its efforts to focus on warfighter needs. Our paper focuses on the GAO's work examining the DoD's approach to supplementing its space situational awareness (SSA) capabilities with commercial data; procuring the Space Command and Control (C2) system; and how the DoD's Software Acquisition Pathway focuses on warfighter engagement as well as outcome-based metrics to assess development progress.

Why This Matters

As the number of threats and objects in the space environment grows, timely and accurate data about these objects are crucial to understanding and managing commercial and military activities in space. The Department of Defense (DoD, 2020) has stated that space is vital to our nation's security, prosperity, and scientific achievement. The DoD also emphasizes that space is a contested environment due to the increasing number of threats to its satellites. For example, the DoD has reported that countries such as China and Russia have developed and demonstrated capabilities designed to contest or deny U.S. access to, and operations in, space.

With both the DoD and commercial companies growing their presence in space, the objects in space that can pose a threat to space assets is also growing rapidly. The DoD needs systems to help manage those objects—but struggles to build them. Since 2000, the number of cataloged space objects has jumped from about 10,000 to nearly 50,000. To command and control U.S. space assets, including maintaining the object catalog, the DoD needs supporting software-intensive systems. However, despite long-standing requirements and years of development work, the department still struggles to deliver effective systems that fully meet warfighters' needs and help them decommission legacy systems like the Space Defense Operations Center (SPADOC).

Background

Over the past 5 years, commercial and military activities in space have grown considerably, and continued growth is expected in the future. We reported in September 2022 that technological advancements allow for more affordable satellites and dramatic decreases in the cost to launch satellites, improving the potential to deploy large constellations of satellites that cover the entire globe (GAO, 2022d). We also reported that some experts cited the potential for 58,000 additional active satellites to be launched by 2030. Today, activities in xGEO are focused on scientific missions and exploration of the moon and other celestial bodies, but activity in xGEO is also expected to increase.

In addition, the amount of debris and other inactive objects in space is substantial. According to a Defense Intelligence Agency (2022) report, the primary risk to spacecraft in orbit is from the 600,000 to 900,000 space objects between 5 millimeters and 10 centimeters in size, many of which are not tracked in the DoD's Satellite Catalog (referred to in this paper as the catalog). The catalog is a database of information about specific space objects, including the objects' estimated size, location, and movements. Taken together, this information represents the DoD's current capability to archive, integrate, disseminate, and exploit SSA data obtained from detection, tracking, and identification.

Using such data enables DoD operations in space and helps mitigate risks to U.S. space assets, through command and control systems. Space command and control is the ability for military commanders to make timely, strategic decisions, take tactical actions to meet mission goals, and counter threats to U.S. space assets. Despite promising starts and some capabilities delivered, the Air Force's last three programs to improve space command and control capabilities over the past three decades have ended significantly over budget and behind schedule, with key capabilities going undelivered. The Department of the Air Force's current effort—Space Command and Control (Space C2)—is a software-intensive program that plans to deliver deferred requirements from past programs as well as to develop and field new advanced capabilities through an Agile strategy.

Our recent work found that the DoD has made efforts to modernize its software acquisition and development approaches for these systems over the past several years. However, we also highlighted that the DoD continues to face challenges in executing these approaches and rapidly delivering software to users (GAO, 2022c, 2022b, 2021b). The Defense Science Board and Defense Innovation Board, in 2018 and 2019 respectively, also found deficiencies in software development and acquisition practices within the DoD, such as outdated acquisition processes and challenges with rapidly delivering software to users. Their reports made 17 recommendations to the DoD to help address these deficiencies. Problems in software acquisition can result in DoD weapon programs delivering needed capabilities late, over-budget, or not at all.

SSA Key Takeaways: Prioritizing Warfighter Needs to Maintain Strategic Advantage

The GAO's prior and ongoing work in these areas point to a need to prioritize warfighters' requirements and continuously engage them in developing and acquiring space capabilities.

- **The DoD Faces SSA Challenges and Is Taking Steps to Address Them.** The DoD faces a number of challenges obtaining data needed for the SSA mission, a mission that Space Force identifies as foundational to all space operations. Specifically, Space Force and USSPACECOM officials identified current and anticipated challenges obtaining SSA data in the evolving space domain. These include space becoming increasingly congested; ground-based sensor coverage varying by location, limiting SSA data collection; limits on sensor capability for xGEO objects; and the DoD's ability to maintain SSA in light of adversary capabilities. The DoD is taking steps to mitigate these challenges, including incorporating additional sensors with primary missions other than SSA, developing new tactics, techniques, and procedures, reassessing SSA needs and updating requirements document, acquiring new SSA systems, and experimenting with commercial SSA data.

- **Space Force Has Not Fully Evaluated How Commercial SSA Data Could Meet Mission Needs.**
    - **Commercial companies provide a variety of SSA capabilities.** Commercial SSA companies use sensors such as telescopes and radars to collect data on objects in space. The type of sensor used determines the type of data it can collect. Although the SSA companies we talked to are using similar sensing technologies as the DoD, they do offer some advantages to the DoD; some companies have deployed sensors across the globe, and in some cases, in locations that the DoD would not be able to do so because of political or security concerns. For example, one of the companies we interviewed has access to over 300 sensors on five continents, with many assets located in the southern hemisphere where the DoD has limited sensor coverage. In addition, most of the DoD's ground-based radars can only track objects larger than 10 centimeters in diameter in LEO and objects about 1 meter in diameter in GEO.[1] However, one company's commercial sensors can track objects as small as 2 centimeters in diameter, about the size of a marble.
    - **DoD documents prioritize the use of commercial space capabilities when possible.** See Table 1 for a summary of DoD strategies establishing the department's intent to use commercial capabilities.

Table 1: Department of Defense Strategies Related to the Integration of Commercial Space Capabilities (*GAO Assessment of DOD Information*, n.d.)

Document title and owner	Summary of guidance
2020 *Defense Space Strategy*, DoD	The 2020 *Defense Space Strategy* identifies commercial innovation as cornerstone enablers of the strategy's lines of effort to outpace potential adversary threats. The strategy references commercial companies as an integral partner in achieving collective space security.
2022 *National Defense Strategy*, DoD	The 2022 *National Defense Strategy* places increased emphasis on commercial integration to leverage technological advancements and enable emerging capabilities. Further, the document directs the DoD to repurpose decision systems using innovations in both the commercial and military sectors to make smarter technology investments; leverage experimentation to solve problems; generate more flexible military capability requirements; and rapid experimentation, acquisition, and fielding.
2022 *Commercial Integration Strategy Overview*, USSPACECOM	The *Commercial Integration Strategy Overview* sets forth the framework for how USSPACECOM will collaborate, integrate, and partner with the U.S. commercial industry. The strategy sets priorities and synchronizes commercial integration efforts so that USSPACECOM can mitigate capability gaps, improve space architecture resiliency, and gain and maintain a technological and operational advantage over adversaries.

[1]Apart from the other DoD sensors, the Space Fence is a ground-based radar that tracks objects as small as 1–2 centimeters in LEO.

In addition to the previously mentioned strategies , the DoD also updated its Space Policy Directive 3100.10 in 2022 to assign responsibility for DoD space-related activities in accordance with national and DoD policies (*Space Policy*, 2022). This Directive states that "consistent with national security requirements, commercial systems, services, and technologies will be used to the maximum practical extent, and commercial capabilities will be modified to meet those requirements when doing so is more cost-effective and timely for the US government."

- **DoD acquisition and evaluation of commercial SSA data has been limited.** The DoD acquires a small amount of commercial SSA data primarily to meet its protect and defend mission through the JTF-SD Commercial Operations Cell (JCO).[2] This USSPACECOM initiative is focused on purchasing commercial SSA data in support of the command's mission to protect and defend U.S. space assets. According to Space Force officials, as of May 2022, the JCO was buying commercial data for a few hundred objects of interest to the JTF-SD. According to company representatives we interviewed, Space Force purchases of SSA data for the JCO have been on an ad-hoc or monthly basis. However, the Space Force requested funding to buy commercial data in its budget request for the first times in fiscal years 2022 and 2023. According to a memorandum of understanding between Space Force and USSPACECOM, Space Force is planning to provide approximately $20 million to the JCO for commercial SSA data purchases in fiscal year 2023 and a total of approximately $110 million for fiscal years 2023 through 2027. According to a Space Force official, this funding covers a limited subset of SSA missions—namely, SSA for the protect and defend mission.

    i. Although the commercial data purchased by the JCO is currently of limited use to the 18th and 19th Space Defense Squadrons for conducting their SSA mission, the Space Force is testing new capabilities in a few ways. For example, 18th Space Defense Squadron operators told us that they have browsed through the Unified Data Library (UDL) to see what type of commercial SSA data it contains and they have observed some of the Joint Task Force-Space Defense Commercial Operations Cell's Sprint Advanced Concept Training events. Also, the 19th Space Defense Squadron is evaluating commercial and academic capabilities to improve SSA in xGEO.

        1. The Space C2 program is the Space Force's latest effort to modernize a system that gathers data from sensors, transmits these data to a repository, and processes the data to enable commanders to make timely decisions, take action, and counter threats.[3] However, we reported in December 2021 that the DoD has spent decades trying to modernize this system, and it is still trying to do so (GAO, 2021c). The 18th and 19th Space Defense Squadrons are waiting for the Space Command and Control program, discussed later, to deliver SSA capabilities.

---

[2]The government acquires licenses to use commercial SSA data in accordance with the Federal Acquisition Regulation, DFARS, and any specifically negotiated licenses, as mentioned above. Throughout this section, when we state that commercial data is acquired or purchased, what is being purchased is a license to use the commercial data, not the commercial data itself. See generally DFARS § 252.227.7013 (n.d.) and DFARS § 252.227-7014 (n.d.).

[3]Congress established the Space Force in 2019 as a military department within the Air Force. See National Defense Authorization Act for Fiscal Year 2020 (2019).

3. **Space Force Lacks a Plan on How to Use the Unified Data Library With SSA Systems.**

- **Space Force has fielded the UDL and continues to develop new capabilities.** The Space Force began development of the UDL as a research and development effort in 2018 for $150,000. In 2019, the Space Force awarded a contract to continue the UDL development and fielded an initial operational system in 2022.[4] In April 2022, the UDL received a 3-year Authority to Operate by the Air Force, accrediting the system to be used operationally at the unclassified, secret, and top-secret levels. According to a contractor representative, agencies outside of the DoD and the Space Force are using the UDL to store other types of data; it is primarily a cloud-based repository of SSA data, with 85% of the data being SSA-related as of November 2022. In addition, the UDL can connect directly to sensors and store sensor data automatically. In April 2022, data from the Space Fence radar were directly uploaded and made available to the classified UDL, establishing the UDL's first direct sensor connection. This demonstrates the UDL's ability to connect to a sensor in the DoD Space Surveillance Network, which includes all of the DoD's SSA sensors.[5] Since April, the UDL has connected to an additional sensor at the classified level and several other sensors at the unclassified level.
- **SSA systems are not using the UDL in operations, and Space Force does not have a plan to address existing challenges and determine how to use the UDL.** Although the UDL is used as a repository for commercial and DoD SSA data, the DoD's SSA C2 systems—SPADOC and the Correlation, Analysis, and the Verification of Ephemerides Network (CAVENet)—are largely not taking data from the UDL. The 18th and 19th Space Defense Squadrons rely on these SSA C2 systems to perform their mission functions, such as assessing potential collisions and maintaining custody of space objects. These systems use the DoD's SSA data in the catalog to carry out these functions, but not commercial SSA data from the UDL.
    i. According to Space Force officials, the Space Force is currently testing ways to put commercial data into a common internal format for the UDL so that it can better integrate with existing C2 systems. This effort requires the ability to calibrate and monitor the quality of data from non-DoD sources to ensure they are safe and accurate for use in Space Force missions. Such a capability would mark a "paradigm shift," according to the officials. Also, the Space Force recently began a trial period for the first full path using data from the UDL for integration with 18th and 19th Space Defense Squadrons. Specifically, this trial is incorporating data from four Air Force Research Laboratory sensors through the UDL that are not otherwise able to connect with these C2 systems and are not part of the Space Surveillance Network. According to Space Force officials, the UDL connection to these non-traditional sensors, which are owned by the government, is intended to pave the way for eventual machine-to-machine commercial data

[4]Development continues on the UDL, with total contract value exceeding $280 million as of February 2023.

[5]The Space Surveillance Network is a collection of radars and ground- and space-based optical telescopes that tracks more than 27,000 satellites and pieces of orbital debris for the catalog.

integration into the DoD's SSA systems. The Space Force is using the data coming from these sensors to conduct SSA during the trial period, which began in January 2023 and was ongoing as of February 2023. While this is a good first step, the Space Force still needs to consider what further steps to take to determine how to use the UDL in SSA operations.

1. Creating a plan to integrate the UDL into Space Force operational systems, such as SSA and Space C2 missions, would better ensure operators had access to the full suite of DoD and commercial data to execute these critical national security missions.

Space Command and Control Key Takeaways: Addressing Challenges to Meet User Needs

The DoD intends for Space C2 to consolidate operational level command and control capabilities for DoD space assets into an integrated system for operators and decision makers. A consolidated set of capabilities will

- Allow operators to comprehensively identify and monitor threats to U.S. space assets,
- Identify possible courses of action to respond to threats,
- Communicate course of action to decision makers, and
- Direct action to respond to threats.

The overall design of the Space C2 program is for data to be gathered from sensors, placed into a data repository, and then be available for various applications to process and provide timely information to space operators and commanders. The program had been working to develop this design through Agile principles and by entering the Software Acquisition Pathway.

The GAO's prior work identified several challenge areas that have led to persistent delays in meeting key program requirements:

Management Challenges. In 2019, we identified three management challenges for Space C2: (1) absence of a formal acquisition strategy, (2) no formal system architecture, and (3) limited enterprise management authority (GAO, 2019). Of these, the lack of an approved acquisition strategy remains the most persistent challenge—the program continues to work from a draft strategy. We recommended Space C2 develop a comprehensive acquisition strategy and the program has not yet close that recommendation. Without an approved acquisition strategy, Space C2's plan to meet requirements and manage program risks does not have buy-in within the DoD and has not shown that it fully addresses all aspects of program development.

Technical Challenges. The primary challenge we identified in 2019 was the complexity of requirements Space C2 must meet (GAO, 2019). This complexity is two-fold: the program plans to develop systems that are technologically complex and then integrate those systems. This finding echoes years of prior GAO work on the DoD's efforts to replace SPADOC. In 1989, we found that the Air Force's attempts to modernize SPADOC were highly complex and technically risky, resulting in acceptance of a system that was marginally useful (GAO, 1989). In 2006, we found the Combatant Commanders' Integrated Command and Control System deferred capabilities, resulting in risks to future operations if key systems like SPADOC were not replaced (GAO, 2006). In 2011, we reported that the Joint Space Operations Center Mission System faced multiple technical risks, including data and system integration resulting from the program's complexity, and technological maturity (GAO, 2011).

Workforce Challenges. In 2019, we highlighted workforce challenges that stem of the availability of staff with expertise in Agile software development (GAO, 2019). Given Space C2's planned Agile approach, that the DoD had not yet issued acquisition guidance on software-intensive programs, and that DoD officials pointed to a lack of qualified software developers in the department at that time, Space C2 was taking a risk.

Reporting Challenges. In our most recent report in December 2021, we found that annual reporting Space C2 provides to Congress is limited because it lacks contextual information that would highlight program changes (GAO, 2021c). For example, Space C2 changed its description of the capabilities it planned to provide without explaining why or how the program made this change. Including such detail would provide a more complete picture of the status of the Space C2 program.

The GAO has work ongoing to examine the program's annual report as well as the effects of the challenges we identified. At this point in time, questions remain regarding steps the DoD and the Space C2 program office may take to address some of these challenges. Space operators and commanders are still waiting on core Space C2 capabilities, particularly those that will help decommission SPADOC. We anticipate publishing our report later in 2023.

Software Acquisition Pathway Key Takeaways: Prioritizing Warfighter Needs to Maintain Strategic Advantage

In October 2020, the DoD released DoD Instruction 5000.87, *Operation of the Software Acquisition Pathway*. This pathway is for the timely acquisition of custom software capabilities developed for the DoD. The Software Acquisition Pathway emphasizes frequent, ongoing collaboration between the program office, software developers, and the software user community. To ensure collaboration among these communities, the Software Acquisition Pathway integrates modern software development practices—such as Agile—that rely on continuous feedback between these communities as well as regular assessments of new capabilities.

The Software Acquisition Pathway also requires key documents, including:

Capability Needs Statement. A high-level description of mission deficiencies that the development effort is to address and other attributes that provide information to define software solutions as they relate to the overall threat environment. The program office and end users or user community are responsible for drafting this statement, which the sponsor—the organization that identifies and advocates for needed end user capabilities and associated resources—approves. Programs should review the statement at least annually to determine if updates are warranted.

Product Roadmap. A high-level visual summary that maps out the vision and direction of software solutions over time. It describes the goals and features of each software delivery. The program office and sponsor develop and maintain the roadmap.

User Agreement. A commitment between the sponsor and program manager for continuous user involvement and assigned decision-making authority in the development and delivery of software capability releases. The program office is responsible for developing this document in coordination with the sponsor; the program and sponsor co-sign the agreement.

Value Assessment. An outcome-based assessment of mission improvements and efficiencies realized from the delivered software capabilities, and a determination of whether the outcomes have been worth the investment. The sponsor, program office, and user community are to perform Value Assessments at least annually to inform program decisions. The Value Assessment is the formal, recurring feedback mechanism for each program acquired through the Software Acquisition Pathway. The sponsor and program office should negotiate the timing and frequency of the Value Assessment and document that schedule in the User Agreement.

These elements of the Software Acquisition Pathway, especially the emphasis on frequent, collaborative software delivery and feedback relationships are, according to DoD policy and guidance, grounded in Agile and other modern practices for software development. According to Software Acquisition Pathway guidance, implementing these practices helps the DoD use technological innovation to sustain the U.S. military advantage.

Challenges With Outcome-Based Metrics and Incorporating User Perspectives

Our prior reporting on programs either on or using aspects of the software pathway found that identifying outcome-based metrics and incorporating user perspectives has been challenging for the DoD (GAO, 2021c, 2022a). Programs we reviewed have metrics to assess their own software development processes and performance but did not yet have metrics that describe if programs are achieving intended operational outcomes. Additionally, we identified that some program metrics and reporting could be enhanced by consistently incorporating user perspectives on the operational benefits associated with program efforts. DoD Instruction 5000.87 states that Value Assessments are to be outcome-based. In our March 2021 report on key terms in program evaluation, we defined outcomes as the desired results of a program; therefore, outcome-based metrics would measure those desired results (GAO, 2021a). Supporting guidance for the Software Acquisition Pathway also describes the importance of outcome-based metrics for programs to understand the mission improvements or efficiencies that newly developed capabilities provide and directs that programs use those results as the basis for the Value Assessment.

What the GAO Recommends

The GAO has made nine recommendations to the Air Force to establish a process and plan to ensure that it prioritize warfighter needs to maintain our strategic advantage. Recommendations from each of the reports we mention can be found at www.gao.gov by searching for the report number.

How the GAO Did This Study

The House Armed Services Committee's report 117-118 accompanying a bill for the National Defense Authorization Act for Fiscal Year 2022 contains a provision for the GAO to review planned procurement of commercial SSA data (H.R. No. 117-118 at 276, 2022). The provision also asked for an overview of the Unified Data Library (UDL), a DoD cloud-based, online data repository intended to improve the collection, sharing, and accessibility of SSA data. This report (1) describes the challenges the DoD faces in identifying and characterizing objects in space, (2) assesses the extent to which the DoD uses commercial SSA data, and (3) assesses the development status of the UDL and how the DoD is using it.

To answer these objectives, we reviewed relevant documentation such as the DoD's 2022 *Defense Space Strategy*, the 2022 U.S. Space Command's (USSPACECOM) *Commercial Integration Strategy Overview*, an Air Force report to congressional committees entitled *Commercial Space Domain Awareness Services* and the RAND Corporation (2022) *Commercial Space Capabilities and Market Overview 2022* report (Department of the Air Force, 2021). Additionally, we interviewed officials from agencies with SSA responsibilities, including Space Force units and USSPACECOM. We also interviewed and collected information from a non-generalizable sample of 10 out of approximately 50 commercial companies. We selected these companies based on whether they had a contract with the DoD regarding SSA and the type of SSA data they provided the DoD.[6] We also interviewed contractor representatives responsible for the UDL. Additional details on the report's methodology are in Appendix I.

To summarize our past work on Space C2 and the Software Pathway, we reviewed earlier reports, available publicly at www.gao.gov.

References

Defense Federal Acquisition Regulation Supplement, § 252.227.7013, Rights in Technical Data – Noncommercial Items (n.d.).

Defense Federal Acquisition Regulation Supplement, § 252.227-7014, Rights in Noncommercial Computer Software and Noncommercial Software Documentation. (n.d.)

Defense Innovation Board. (2019, May 3). *Software is never done: Refactoring the acquisition code for competitive advantage*.

Defense Intelligence Agency. (2022, March). *Challenges to security in space: Space reliance in an era of competition and expansion.*

Defense Science Board. (2018, February 14). Design and acquisition of software for defense systems.

Department of the Air Force. (2021, January). *Commercial space domain awareness services.*

DoD. (2020, June). *Defense space strategy summary*.

GAO. (1989, April 10). *Space defense: Management and technical problems delay operations center acquisition* (GAO/IMTEC-89-18).

GAO. (2006, July 6). *Defense acquisitions: Further management and oversight changes needed for efforts to modernize Cheyenne Mountain attack warning systems*. (GAO-06-666).

GAO. (2011, May 27). *Space acquisitions: Development and oversight challenges in delivering improved space situational awareness capabilities*. (GAO-11-545).

GAO. (2019, October 30). *Space command and control: Comprehensive planning and oversight could help DOD acquire critical capabilities and address challenges* (GAO-20-146).

GAO. (2021a, March). *Program evaluation: Key terms and concepts* (GAO-21-404SP).

GAO. (2021b, September 30). *DOD software acquisition: Status of and challenges related to reform efforts* (GAO-21-105298).

GAO. (2021c, December 22). *Space command and control: Opportunities exist to enhance annual reporting* (GAO-22-104685).

GAO. (2022a, March). *Defense acquisitions: Cyber command needs to develop metrics to assess warfighting capabilities* (GAO-22-104695).

GAO. (2022b, June 8). *Weapon systems annual assessment: Challenges to fielding capabilities faster persist* (GAO-22-105230).

GAO. (2022c, June 14). *Business systems: DOD needs to improve performance reporting and cybersecurity and supply chain planning* (GAO-22-105330).

GAO. (2022d, September 29). *Large constellations of satellites: Mitigating environmental and other effects* (GAO-22-105166).

GAO assessment of DOD information (GAO-23-105565). (n.d.).

H.R. No. 117-118, at 276 (2022).

National Defense Authorization Act for Fiscal Year 2020, Pub. L. No. 116-92, §§ 951-961, (2019). (Codified at 10 U.S.C. § 9081(a)).

RAND Corporation. (2022). *Commercial space capabilities and market overview*.

Space policy (DoD Directive 3100.10). (2022, August 30).

[6]Results from non-generalizable samples cannot be used to make inferences about a population.

Schedule and Cost Estimating Analysis for LEO Satellite Constellations

Patricia F. Bronson, Ph.D.—Patricia Bronson is a Research Staff Member at the Institute for Defense Analyses (IDA), specializing in cost estimation and resource planning for major weapon systems. Prior to joining IDA in 2006, she was an Operations Research Analyst for the Cost Analysis Improvement Group within the OSD. Her work products inform investment decisions by senior leadership. Before that, Bronson spent several years as a system engineer working on various national programs such as the Department of Energy's Civilian Radioactive Waste Management Program and the American Red Cross blood-banking information management system [pbronson@ida.org]

Brian G. Gladstone— is a Research Staff Member at the Institute for Defense Analyses (IDA), with expertise in operations research analysis, resource analysis, cost analysis of Major Defense Acquisition Programs, cost analysis of operation and sustainment costs, acquisition policies, industrial base matters, and evaluating corporate costs. He previously worked as an Analyst in the Office of the Under Secretary of Defense for Acquisition, Technology, & Logistics and the OSD Office of Cost Assessment and Program Evaluation in the Pentagon. He holds an MS in chemical biology from Harvard University and a BS from the University of California, Los Angeles. [bgladsto@ida.org]

Abstract

Following the lead of commercial satellite service companies, the Department of Defense (DoD) is developing new Low Earth Orbit (LEO) megaconstellations to improve the resilience and agility of military space systems. Megaconstellations can have hundreds of satellites in multiple orbital planes ranging from 500 kilometers to 1,200 kilometers in altitude. Additional replenishment satellites are maintained on the ground, ready to launch to replace satellites lost due to planned de-orbits, reliability issues, or attrition due to natural or manmade causes. DoD planning purposes demand a clear understanding of the cost implications for developing, procuring, and operationalizing a LEO-based megaconstellation's ground system and satellites, including initial launch and replenishment costs. This paper describes robust and simple parametric cost models, with reasonable explanatory and predictive power, that we developed to estimate the costs of these megaconstellations using data from 12 LEO government and commercial constellations.

Introduction

Commercial and government space sectors see significant utility in large networked satellite constellations in low earth orbit (LEO). Networked satellites hold the promise of providing near real-time global communications, access to the internet, and remote sensing. The Department of Defense (DoD) is currently procuring one such constellation, called the Tranche 1 Transport Layer (T1TL), through the Space Development Agency (SDA). According to the SDA, the three prototype agreements combined are worth approximately $1.8 billion and will "establish the foundation for Tranche 1 Transport Layer (T1TL), a mesh network of 126 optically interconnected space vehicles (SVs) that will provide a resilient, low-latency, high-volume data transport communication system, and be ready for launch starting in September 2024" (DoD, 2022).

> SDA's Transport Layer is envisioned, modeled, and architected as a constellation varying in size from 300 to more than 500 satellites in LEO ranging from 750km to 1200km in altitude. With a full constellation, 95% of the locations on the Earth will have at least two satellites in view at any given time, while 99% of the locations on the Earth will have at least one satellite in view. This will ensure constant world-wide coverage around the globe. The constellation will be interconnected with Optical Inter-Satellite Links (OISLs)

> which have significantly increased performance over existing radio frequency cross links. LEO orbits in conjunction with OISLs will reduce path loss issues but more importantly offer much lower latencies, which are deemed critical to prosecute time sensitive targets in today's wartime environment. (*Transport*, n.d.)

As part of a program review of the SDA's transport layer, and with the realization that megaconstellations in LEO are likely to proliferate, we developed an unbiased multivariate linear regression model[1] to cost the design, test, procurement, and launch of entire satellite constellations. In addition, we present a model to estimate replenishment costs as a function of satellite reliability and the number of LEO orbital planes in the constellation.

Methodology

Many sources of data were referenced to obtain the satellite program data listed below, including:

- Selected Acquisition Reports, and briefings from the SDA, the Space Force, Missile Defense Agency, and Office of the Secretary of Defense (OSD; for DoD satellites)
- President's Budget and Service/Agency Budget Justification, Federal Procurement Data System (FPDS), Defense Acquisition and Cost Information System (DACIS), Government Accounting Office reports (for U.S. government satellites, the DoD, National Aeronautics and Space Administration (NASA), and the National Oceanographic and Atmospheric Administration (NOAA)
- News and trade articles or other open sources of information (Wiki, Gunther's Space Page)

Relevant and available commercial and government space programs from the last three decades also were included in the dataset.

The following constellations of LEO satellites were used in our linear regressions for cost modeling:

- Iridium
- Iridium 2nd Gen
- Orbcomm
- Midcourse Space Experiment/Space Based Visible (MSX/SBV) sensor
- Space Based Space Surveillance (SBSS)
- Globalstar
- Globalstar 2nd Gen
- OneWeb
- COSMIC
- COSMIC-2
- Starlink
- Space Tracking and Surveillance System (STSS)

Data we collected:

- Satellite or constellation name
- Orbital configuration (LEO, MEO, HEO [low, medium, and high Earth orbit] altitudes)

[1] Standard method for regression modeling. The model uses least squares and has all of the assumptions embedded therein.

- Mission (SATCOM/Other)
- Commercial/other
- Generation (1st/2nd)
- Program/company information
- Program cost
- Program start and end dates
- Contract cost
- Contract number
- Contractor/builder
- Contract award date, end date, or period of performance (POP)
- Other milestone dates (i.e., Milestone B, Preliminary Design Review, Critical Design Review, Available for Launch [AFL] date, Initial Operational Test and Evaluation [IOT&E] complete date)
- Number of satellites in the constellation
- Constellation launch dates
- Mass (kg)
- Operational lifetime
- Ground station (descriptions, development schedule, cost, contractor, etc.)
- Time (years) to launch of first mission-capable satellite as a proxy for development time
- Time to complete launching the constellation

Calculations:

- Mass * Orbital Altitude * Number of Satellites (MAN) is a synthetic variable used in our linear regressions, based on the physics of putting a constellation in its operational orbit.

Regressions: Independent variables considered:

- Satellite generation
- Number of satellites in the constellation
- Mission (SATCOM/Other)
- Commercial/other
- Generation (1st/2nd)
- Mass (kg)
- Time (years) to launch of first mission-capable satellite as a proxy for development time
- Year first mission-capable satellite launched
- Lifetime (years)
- Orbital altitude (km)

We modeled total constellation cost using multiple linear regression techniques with various combinations of logical independent variables selected (from Table 1), along with a synthetic variable, MAN, that is going to be correlated with the total "work," in a physics sense, to get the constellation in its operational orbit:

- Mass (kg) * Orbital Altitude * Number of Satellites in the Constellation (MAN)

The resulting equations were evaluated using statistical parameters, and the robustness of the methodology was evaluated by determining how much data could be excluded from the regression while maintaining both a good fit of the remaining data and a strong prediction of the data that were excluded. In this paper, we discuss the simplest and best equation, as defined by these measures.

We also developed a replenishment cost model for LEO satellite constellations as a function of the number of orbital planes in the constellation, an assumed reliability of the satellites (where reliability equals 1- the number of satellites that need to be replaced annually/number of satellites), and a premium for high-priority launches. Launch vehicle costs were based on inflation-adjusted Falcon 1 and Falcon 9 rocket launch costs in open-source literature.

Schedule Analysis

Figure 1 depicts the amount of time it took to launch the first satellite for 22 programs. Year 1 is the year of program initiation, and the last year illustrated is the year of the first launch of a *mission-capable* space vehicle. Space vehicles are organized by increasing mass, with the lightest vehicles appearing at the bottom of the chart. Satellites with different orbits (e.g., LEO, MEO, Geosynchronus Earth orbit [GEO], and Sun-synchronous orbit [SSO]) are included in the dataset and labelled on the vertical axis next to mass. The green bars in Figure 1 represent commercial programs, whereas the blue bars are government/military and scientific. The rust-shaded bar in the background represents the average development time ranging between +/- 1 SD.

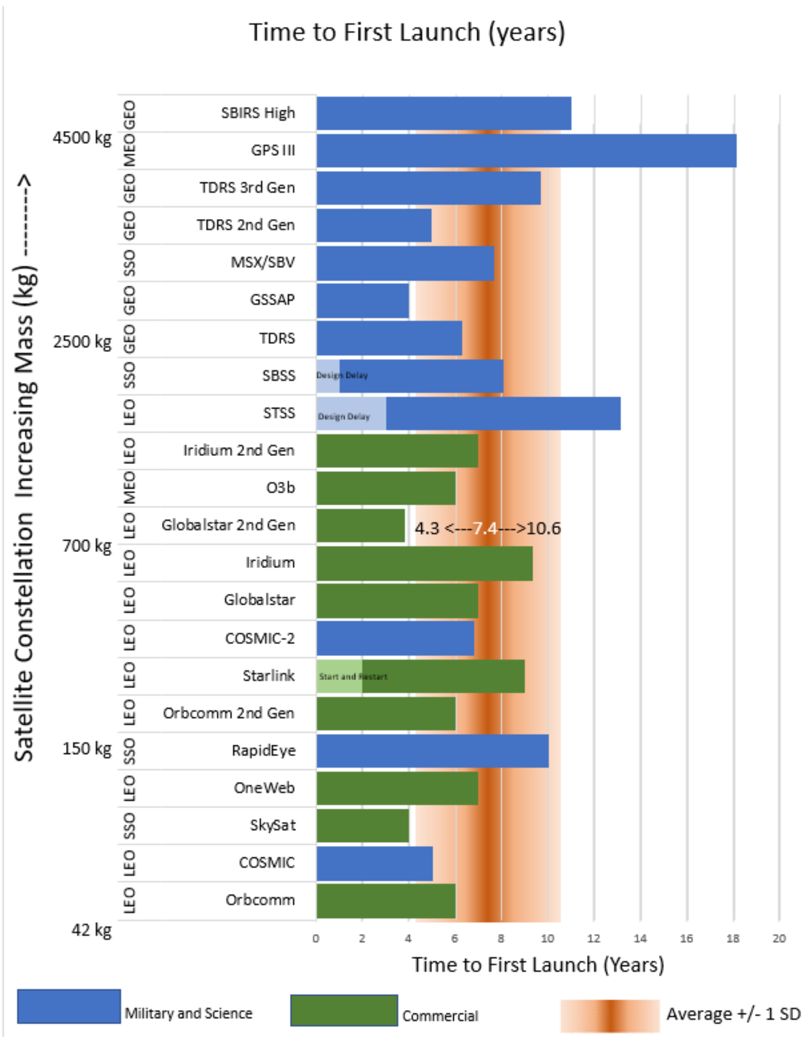


Figure 1. Historical Commercial and Government Space Development Schedules

Figure 2 compares the development times for the 22 constellations shown in Figure 1 and the subsets of 11 commercial, 6 DoD, and 13 LEO constellations. The average development time for all 22 systems in Figure 1 is 7.4 years. The average development time for the 13 LEO constellations is 7.2 years.

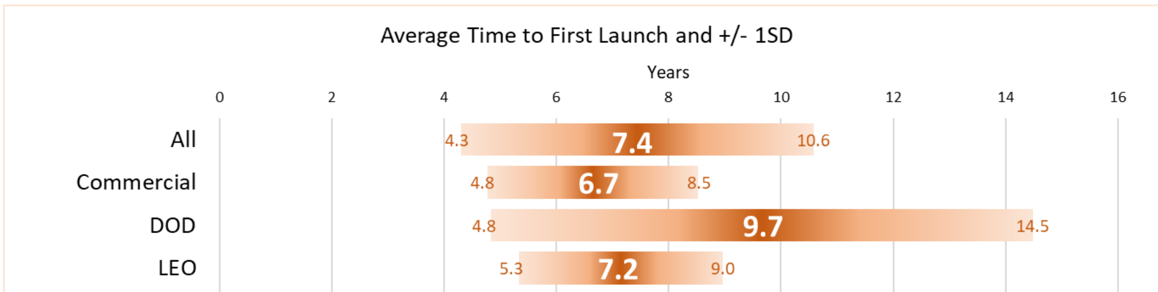


Figure 2. Average Time to Launch the First Mission-Capable Satellite

Cost Analysis

Table 1 shows the cost data collected for 12 LEO constellations. Commercial, military, and scientific constellations are represented. All costs are in $ million calendar year 2022 ($M CY 2022). We used the time from the program start (or contract award in its absence) to the launch of the first *mission-capable* satellite as a proxy for development time.

Table 1. Cost Data for LEO Constellations

Constellations	Generation	Number of satellites	SATCOM	Commercial	Mass (kg)	Time to first launch (years)	Year of 1st launch	Lifetime (years)	Orbital Altitude (km)	Cost (CY22 $M)
COSMIC	1	5	0	0	70	5.0	2006	5	700	111
COSMIC-2	0	6	0	0	278	6.8	2019	5	710	233
Orbcomm	1	28	1	1	42	6.0	1995	4	661	514
Globalstar 2nd Ger	0	24	1	1	700	3.8	2010	15	1,410	934
SBSS	1	11	0	0	1,031	7.1	2010	7	630	1,167
MSX/SBV	1	1	0	0	2,700	7.6	1996	26	898	1,514
STSS	1	2	0	0	1,000	10.1	2009	12	1,350	2,342
Globalstar	1	52	1	1	450	7.0	1998	8	1,410	2,976
Iridium 2nd Gen	0	81	1	1	860	7.0	2017	13	780	3,202
OneWeb	1	428	1	1	147	7.0	2019	7	1,200	4,011
Iridium	1	98	1	1	689	9.3	1997	8	780	7,488
Starlink	1	1,737	1	1	260	7.0	2018	6	550	10,400

We conducted regression analysis with this data as described in the methodology section. Dummy variables were used for the generation of the constellation (1 for first, 0 for second), those that were SATCOM (1 for SATCOM, 0 for other), and those that were commercial (1 for commercial, 0 for other.) The single best performing equation, however, excluded all variables except the proxy for the development schedule and the product of mass, orbital altitude, and number of satellites in the constellation (MAN).

Table 2 shows the regression results that we obtained with the equation that had the best statistical parameters and most statistically significant of the independent variables. The equation is a function of the time to first launch (development time) and the physics-based synthetic variable that is the product of satellite mass, orbital altitude, and the number of satellites in the constellation.

The resulting cost estimating relationship (CER) in CY22 $M is

$$CER = Development\ Time * 213 + MAN * 3.78 * 10^{-5}$$

where MAN is the physics-based synthetic variable mass*altitude*number of satellites.

Table 2. Best Regression Result

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.96							
R Square	0.92							
Adjusted R Square	0.81							
Standard Error	1303							
Observations	12							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	2	1.93E+08	9.64E+07	5.68E+01	7.86E-06			
Residual	10	1.70E+07	1.70E+06					
Total	12	2.10E+08						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
MAN	3.78E-05	5.60E-06	6.76E+00	4.98E-05	2.54E-05	5.03E-05	2.54E-05	5.03E-05
Time to first launch (ye	2.13E+02	6.17E+01	3.45E+00	6.20E-03	7.56E+01	3.51E+02	7.56E+01	3.51E+02
RESIDUAL OUTPUT								
Actual	*Predicted Cost (CY22 $M)*	*Residuals*	*Standard Residuals*					
111	1075	-9.63E+02	-8.10E-01					
233	1495	-1.26E+03	-1.06E+00					
514	1308	-7.94E+02	-6.67E-01					
934	1708	-7.74E+02	-6.51E-01					
1167	1778	-6.10E+02	-5.13E-01					
1514	1719	-2.05E+02	-1.72E-01					
2342	2259	8.34E+01	7.02E-02					
2976	2741	2.36E+02	1.98E-01					
3202	3548	-3.46E+02	-2.91E-01					
4011	4350	-3.38E+02	-2.84E-01					
7488	3986	3.50E+03	2.95E+00					
10400	10893	-4.93E+02	-4.15E-01					

Figure 3 shows the predicted versus actual cost values using the CER above. The regression results are displayed as blue dots with vertical standard error bars.

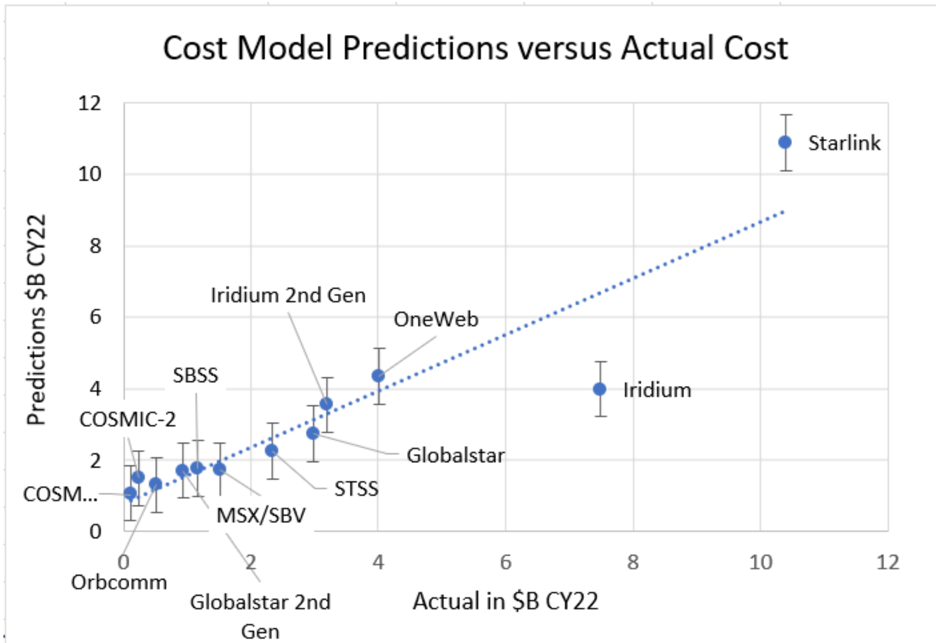


Figure 3. Sensitivity Analysis

The robustness of the methodology was evaluated by determining how much data could be excluded from the regression while maintaining both a good fit of the remaining data and a strong prediction of the data that were excluded. Figure 4 shows the regression results excluding the top three data points (left) and the lower six data points (right). Both the regression and variables for each “degraded” model below remained significant. However, excluding the highest cost constellations from the regression on the left led to a model that was less predictive for higher cost constellations. For the right-hand chart, the methodology still leads to a reasonable predictive model for the five lower points that were excluded from the regression.

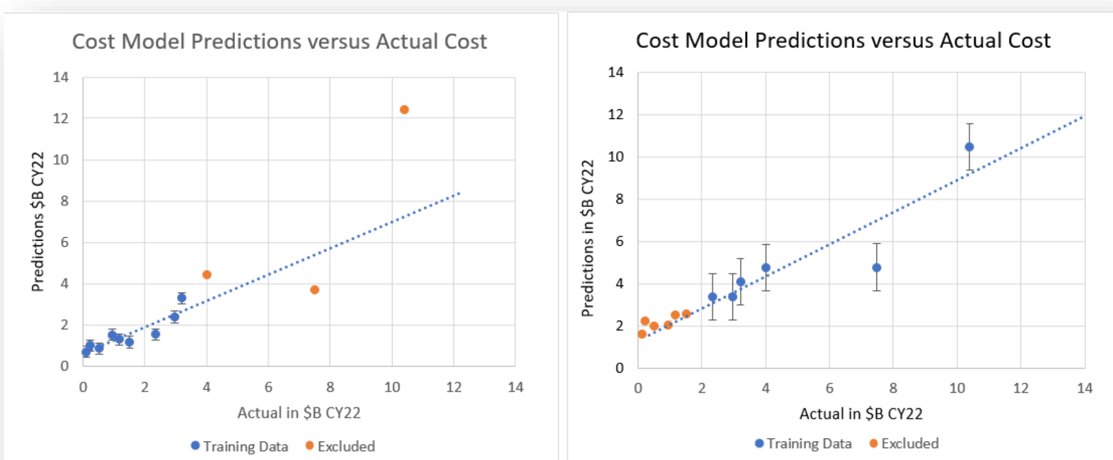


Figure 4. Sensitivity Analysis

Replenishment Costs

In order to maintain operational readiness of LEO constellations, additional replenishment satellites will be maintained on the ground, ready to replace satellites lost due to planned de-orbits, reliability issues, or attrition due to natural or manmade causes.

We developed a replenishment cost model to estimate the cost of maintaining LEO constellations in multiple orbital planes as a function of satellite reliability and launch priority.

The model calculates launch costs for the annual replenishment of an orbital plane using a series of launch vehicles that have different payload weights and cost. It then selects the launch vehicle configurations that provide the lowest cost under two conditions. When the replacement time is not critical (low priority), the rocket launch costs are allocated to the replenishment satellites by weight (sharing the cost of the launch with other satellite programs). Conversely, when the replacement time is critical (high priority), the replenishment satellites incur the full cost of the launch, oftentimes with a launch vehicle that has additional unused capacity. Next, the model adds the cost of the replenishment satellites and multiplies that cost by the number of orbital planes.

Figure 5 shows the annual replenishment costs for a 126- (500 kg, $13 million each) constellation in six orbital planes as a function of reliability (1-the number of satellites that need to be replaced annually/number of satellites). The figure demonstrates how replenishment costs are driven by the cost of the replenishment satellites and how launch priority affects it.

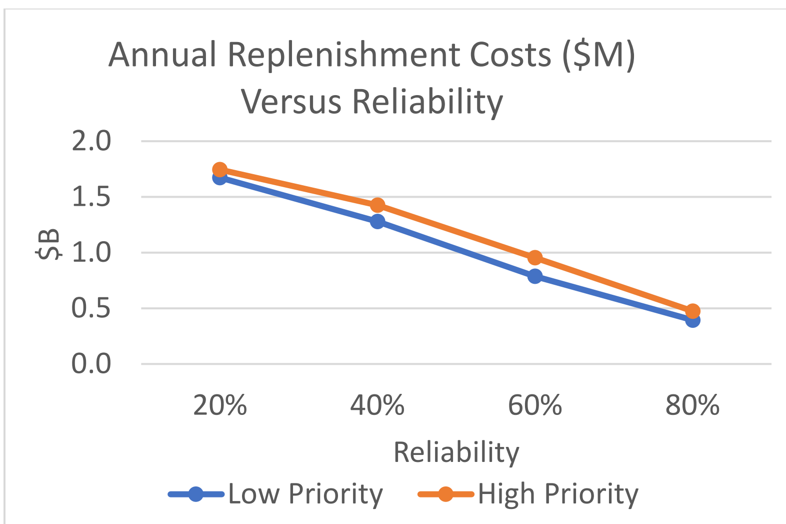


Figure 5. Annual Replenishment Cost as a Function of Reliability

Poor reliability increases replenishment costs if constellation performance is to be maintained.

Planned Constellations Telesat Lightspeed and T1TL

In 2016, Telesat announced it would launch an LEO constellation of 120 (about 800 kg) satellites, at an altitude of about 1,000 km, distributed in six orbital planes. Telesat (n.d.a) launched an experimental LEO satellite in January 2018. The number of satellites has changed over the years as Telesat looks for investors. Currently, Telesat Lightspeed is planning to have 198 satellites (including 10 spares), is estimated to cost $5 billion (but will likely cost 5–10% more; Forrester, 2022), and will be launched in 2025 (9 years from the beginning of development).[2]

Meanwhile, in February 2022, the U.S. Space Force awarded contracts totaling $1.8 billion to three development teams for their T1TL LEO constellation. The first launch is scheduled for October 2024, about 2.7 years after the contracts were awarded. The T1TL constellation comprises 126 (approximately 500 kg) satellites to be deployed at an altitude of 1,000 km into 6 orbital planes.

Both T1TL and Lightspeed provide an exceptional opportunity to test the predictive power of the Constellation CER discussed in this paper. Figure 6 shows our model predictions for the Lightspeed and T1TL constellations superimposed on the training data. Keep in mind there are no actual values for these constellations, so horizontal lines represent the possibilities. It will be interesting to see how these two satellite constellation programs execute.

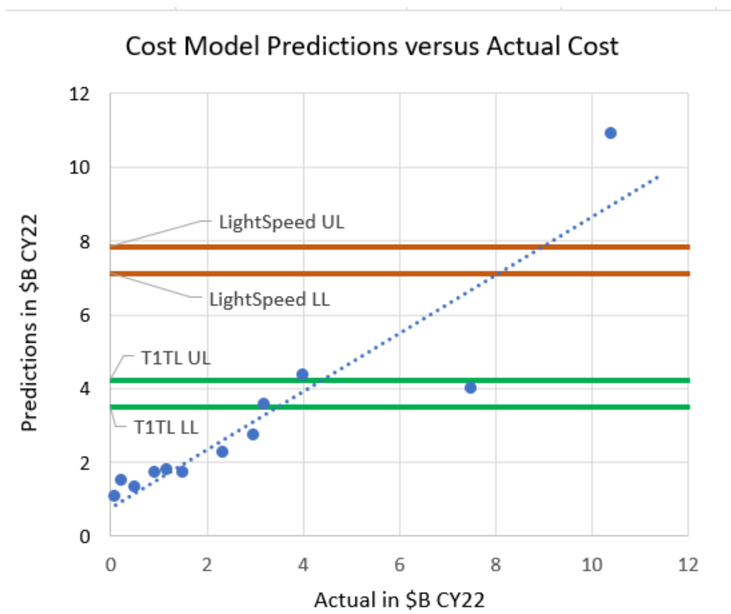


Figure 6. CER Predictions for Lightspeed and T1TL

Summary

Understanding the cost and schedule implications for developing and procuring a LEO-based megaconstellation's ground system and satellites, including initial launch and replenishment costs, is essential for DoD planning purposes. This paper describes robust and simple parametric cost models, with reasonable explanatory and predictive power, that we developed to estimate the costs of these megaconstellations.

The average development time for the 22 LEO, MEO, and HEO constellations identified in this study is 7.4 years, with a +/-1 standard deviation range from 4.3 years to 10.6 years. The average time for the 13 LEO constellations is 7.2 years, with a +/- 1 standard deviation range from 5.3 years to 9.0 years.

[2] $5 billion includes satellites, ground facilities, launch vehicles, and software platforms (Jewett, 2022).

Using regression analysis, we developed a cost estimating relationship (CER) for LEO megaconstellations based on historical cost and schedule data from 12 commercial, military, and research satellite constellations launched over the last 30 years. The CER is based on two independent variables: (1) the development time, and (2) the physics-based, synthetic variable MAN (Mass (kg) * Orbital Altitude * Number of Satellites in the Constellation). This is a measure of the “work” needed to get the constellation into its operational orbit.

A replenishment cost model was developed for LEO constellations placed into six orbital planes based on a function of reliability. It demonstrates how poor reliability leads to high replenishment costs.

This method can provide quick and reasonably accurate cost estimates for megaconstellations.

References

BlackJack Architecture Demo. (n.d.). https://www.dacis.com/programs/detail.lasso?id=249399&SearchBy=id.

Brown, G., & Harris, W. (2000, May 19). *How much do satellites cost?* HowStuffWorks. https://science.howstuffworks.com/satellite10.htm#:~:text=A%20typical%20weather%20satellite%20carries,million%20%5Bsource%3A%20GlobalCom%5D

The cost of building and launching a satellite. (n.d.). https://globalcomsatphone.com/costs/

DACIS: Contracts. (2007, September 27). *Aerojet taps SGI for SBIRS ground station servers, displays*. (2007, September 27).https://www.dacis.com/contracts/detail.lasso?id=516307&Integrated_Contracts

De Selding, P. (2022, May 6). *Telesat: New Lightspeed design, now 198 satellites but capex still at $5B, returns to export-credit agencies for review*. https://www.spaceintelreport.com/telesat-new-lightspeed-design-now-198-satellites-but-capex-still-at-5b-returns-to-export-credit-agencies-for-review/

Defense Acquisition and Cost Information System. (n.d.). https://www.dacis.com/

DoD. (2022, February 28). *Space development agency makes awards for 126 satellites to build tranche 1 transport layer*. https://www.defense.gov/News/Releases/Release/Article/2948229/space-development-agency-makes-awards-for-126-satellites-to-build-tranche-1-tra/

Federal Procurement Data System. (n.d.). https://www.fpds.gov/fpdsng_cms/index.php/en/

FORMOSAT 7. (n.d.). https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/formosat-7

Forrester, C. (2021, December). *Telesat slips launch of Lightspeed*.

Forrester, C. (2022, August 8). *Telesat: Still no word on Lightspeed budget*. Advanced Television. https://advanced-television.com/2022/08/08/telesat-still-no-word-on-lightspeed-budget/

Foust, J. (2021, April). *Telesat completing financing for Lightspeed constellation*. https://spacenews.com/telesat-completing-financing-for-lightspeed-constellation/

Geosynchronous Space Situational Awareness Program. (n.d.). Defense Acquisition Management Information Retrieval System.

GPS III. (2018, December). Selected acquisition report.

Gunter’s space page. (n.d.). https://space.skyrocket.de/

Harrison, D. C., & Chow, J. C. (1996). The space-based visible sensor. *Physics*. https://www.semanticscholar.org/paper/The-Space-Based-Visible-Sensor-Harrison-Chow/3549cb4eee627705f5a413164a7f72419d153298

Henry, C., & Berger, B. (2018, September 12). Amid concerns, OneWeb gets vague about constellation’s cost. *Space News*.

Iridium-NEXT. (n.d.). *Satellite library*. https://spaceflight101.com/spacecraft/.

Jewett, R. (2022, May 6). *Telestat downsizes Lightspeed constellation plans*. Via Satellite. https://www.satellitetoday.com/business/2022/05/06/telesat-downsizes-lightspeed-constellation-plans/

Mellow, C. (2004, September 1). *The rise and fall and rise of iridium*.
Next Generation Operational Control System. (2016). *Selected acquisition reports*.
Next Generation Operational Control System. (2018). *Selected acquisition reports*.
Next Generation Operational Control System. (2019, December). *Selected acquisition reports*.
NG OPIR GEO & Polar. (n.d.). https://www.dacis.com/programs/detail.lasso?id=247617&SearchBy=id
NOAA readies for cosmic 2 satellite launch. (n.d.). https://www.noaa.gov/media-release/noaa-readies-for-cosmic-2-satellite-launch
Northrop Grumman. (2021, November 10). *Satellite to play critical role in tracking and targeting enemy missiles*.https://news.northropgrumman.com/news/releases/northrop-grumman-completes-hypersonic-and-ballistic-tracking-space-sensor-critical-design-review
Peterson, M. (n.d.). *Midcourse space experiment: Introduction*. https://www.globalsecurity.org/space/systems/msx.htm
SBIRS low, STSS. (2001, October). Defense Acquisition Executive Summary. Defense Acquisition Management Information Retrieval System.
SBSS (Space-Based Surveillance System) - Satellite missions. (n.d.). eoPortal Directory. https://www.eoportal.org/satellite-missions/sbss
SkySat. (2016, July 26). https://www.eoportal.org/satellite-missions/skysat
Smith, M. (2020, June). *NOAA claims significant cost reduction for polar weather satellites.* https://spacepolicyonline.com/news/noaa-claims-significant-cost-reduction-for-polar-weather-satellites/
Space Based Space Surveillance SAR. (2007).
Space Based Space Surveillance SAR. (2010).
Space Network Ground Segment Sustainment. (n.d.). https://www.dacis.com/programs/detail.lasso?&ID=241182&GlobalSearch=TDRSS%20Ground%20Segment
Starlink: An overview. (n.d.). https://satellite-constellations.com/index.php/starlink/
Swinhoe, D. (n.d.). *Telesat to decrease size of upcoming Lightspeed satellite fleet by a third, satellite operator shrinking planned LEO constellation by 100 satellites amid supply chain issues*.
Telesat. (n.d.a). Telesat Lightspeed LEO network. https://www.telesat.com/leo-satellites/
Telesat. (n.d.b). In *Wikipedia*. https://en.wikipedia.org/wiki/Telesat
Todd, D. (2013, January). SSTL awarded 12-satellite Formosasat-7 contract. *Science*. https://www.seradata.com/sstl-awarded-12-satellite-form/
Tracking and data relay satellite system. (n.d.). https://en.wikipedia.org/wiki/Tracking_and_Data_Relay_Satellite_System
Tracking Data Relay Satellite. (n.d.). https://www.dacis.com/contracts/detail.lasso?id=638789
Transport. (n.d.). https://www.sda.mil/transport/
Various President’s Budget and Service/Agency Budget Justification documentation. (n.d.). Under Secretary of Defense (Comptroller). https://comptroller.defense.gov/

PANEL 3. ASSESSING PROGRESS OF THE ADAPTIVE ACQUISITION FRAMEWORK

Wednesday, May 10, 2023	
10:30 a.m. – 11:45 a.m.	**Chair: James P. Woolsey,** President, Defense Acquisition University **Discussant: Stephanie Young,** Director, Resource Management Program, RAND Corporation ***Using Metrics to Understand the Performance of the Adaptive Acquisition Framework*** Megan McKernan, RAND Corporation Jeffrey A. Drezner, RAND Corporation Mark V. Arena, RAND Corporation Jonathan P. Wong, RAND Corporation Yuliya Shokh, RAND Corporation Nancy Young Moore, RAND Corporation Sydne Newberry, RAND Corporation Judith D. Mele, RAND Corporation Austin Lewis, RAND Corporation ***Middle-Tier Defense Acquisitions: Rapid Prototyping and Fielding Requires Changes to Oversight and Development Approaches*** Alexis Olson, U.S. Government Accountability Office Chris Durbin, U.S. Government Accountability Office Shelby Oakley, U.S. Government Accountability Office

James P. Woolsey—is President of the Defense Acquisition University (DAU), a position he has held since January 2014. In that role, he is responsible for delivery of learning products through the DAU regions, the Defense Systems Management College, and the College of Contract Management; curriculum development; online learning programs; learning technology; and library services for a major Department of Defense corporate university. DAU is strategically located within five geographical regions across the country and provides a global learning environment to develop qualified acquisition, requirements, and contingency professionals who deliver and sustain effective and affordable warfighting capabilities.

He previously served as the first Deputy Director for Performance Assessments (PA) in the office of Performance Assessments and Root Cause Analyses (PARCA). In standing up the PA organization, he created the processes and practices that allowed it to perform its statutory responsibility of assessing the progress of all Major Defense Acquisition Programs. The new office also made a substantial contribution to re-invigorating the Defense Acquisition Executive Summary process and provided the Under Secretary of Defense for Acquisition, Technology and Logistics with unique analyses to give him improved visibility into the status of the MDAP portfolio.

Mr. Woolsey was previously an Assistant Director in the Cost Analysis and Research Division of the Institute for Defense Analyses. His responsibilities included management of the division's cost analysis and research, and leadership of a wide range of cost and acquisition studies. His work included a congressionally-directed cost benefit analysis of the F-35 alternate engine, an evaluation of KC 767A lease prices, C-5 re-engineering costs and benefits, F-22 production readiness, Joint Air-to-Surface Standoff Missile costs, and space launch alternatives. Mr. Woolsey also served on a Defense Science Board Task Force on long-range strike.

Mr. Woolsey's other previous positions include service as a structures engineer for F/A-18 aircraft at Naval Air Systems Command, and work as an engineer for Lockheed Martin airlift programs in Marietta, GA.

Stephanie Young—is a senior political scientist at the RAND Corporation, and director of the Resource Management Program at RAND Project AIR FORCE. She manages a diverse portfolio of research in support of the Department of the Air Force on topics related to acquisition, logistics, industrial base, sustainment, installations/infrastructure, and organizational design. Her primary research interests relate to defense acquisition; budgeting; the planning, programming, budgeting, and execution system (PPBE); and broader resource allocation decisionmaking, but other recent work has focused on strategic competition, security cooperation and building partner capacity, countering-weapons of mass destruction, and U.S. policy in the Middle East and South Asia. In 2012 she spent three months as an analyst embedded with the Special Operations Joint Task Force–Afghanistan, in Kabul. At RAND she also taught a Ph.D. level course on the U.S. defense budget at the Pardee RAND Graduate School, and she previously served as the associate research department director of RAND's Defense and Political Sciences Department. She was educated at the University of California, Berkeley, where she earned a Ph.D. in history and a B.A. in physics and astrophysics.

.

Using Metrics to Understand the Performance of the Adaptive Acquisition Framework

Megan McKernan—is a Senior Defense Researcher at RAND. She specializes in DoD weapon systems acquisition along with data governance, management, sharing, and analytics. She also conducts defense acquisition-related analysis in many areas, including space and cyber rapid acquisition, software acquisition, requirements planning, and prototyping. Prior to working at RAND, McKernan was an Economic Analyst providing reports for policymakers, primarily at the National Security Council, Department of Treasury, and Department of State on global economic issues. She holds an MA in international trade and investment policy from The George Washington University and a BA in economics from William Smith College. [mckernan@rand.org]

Jeffrey A. Drezner—is a Senior Policy Researcher at RAND. He has over 35 years of professional experience conducting policy analysis on a wide range of issues, including planning and program management, analyses of cost and schedule outcomes in complex system development programs, aerospace industrial policy, and defense acquisition policy and reform. His research continues to emphasize mixed qualitative and quantitative approaches to analyze issues associated with technology development, organizational behavior, and program management. Drezner received his PhD in political science from Claremont Graduate University. [zner@rand.org]

Mark V. Arena—is a Senior Physical Scientist at the RAND Corporation. Since joining RAND in 1998, Arena has worked on a variety of research projects for the U.S. Navy, Air Force, OSD, USCG, the Australian DoD, and the UK MoD. Arena has focused on technology evaluations, cost and risk analysis, and industrial base simulations for acquisition programs. Arena graduated from Yale University with a BS degree in Chemistry. Subsequently, he pursued graduate studies at Stanford University in the Department of Chemistry. He was granted a PhD in physical chemistry. [arena@rand.org]

Jonathan P. Wong—is Associate Director of the Strategy, Doctrine, and Resources Program of the RAND Arroyo Center, a Policy Researcher at RAND Corporation, and a Professor at the Pardee RAND Graduate School. His research focuses on the role of new technologies and operational concepts, and processes in shaping how militaries fight. He also contributes to other force design and development research and RAND's military logistics, manpower, intelligence policy, and strategy portfolios. [jonwong@rand.org]

Yuliya Shokh—is a Technical Analyst at the RAND Corporation with experience in all-source intelligence analysis, intelligence, surveillance and reconnaissance (ISR) operations, and project management. Following her military service, Shokh completed graduate work in diplomacy and military studies. Her current research at RAND focuses on intelligence and acquisition communities, the role of intelligence support in military and domestic operations, and Russia's military planning and its impact on regional security. [yshokh@rand.org]

Nancy Young Moore—is a Senior Management Scientist at the RAND Corporation, where she has led or co-led analyses of small business policy and implementing best commercial practices in purchasing, supply chain, supply chain risk, and change management in a government setting. She is a registered engineer with the state of California and holds an MS and a PhD in water resources systems engineering from the University of California, Los Angeles. [nancy@rand.org]

Sydne Newberry—has served as a Research Communications Analyst and as the Medical Editor for the Southern CA Evidence-Based Practice Center since joining RAND in 2000. As a CA, Newberry assists researchers with proposal preparation, designing dissemination plans, drafting and revising research reports, and creating spinoff products—including research highlights, briefings, and blogs—for various stakeholders. She was the recipient of an NIH postdoctoral training grant and conducted postdoctoral research at the Ohio State University and the Fels Research Institute/Wright State University School of Medicine in molecular biology and virology. She received her PhD in nutritional biochemistry from MIT. [sydnen@rand.org]

Judith D. Mele—is a Research Programmer at the RAND Corporation. [judym@rand.org]

Austin Lewis—is a former Research Assistant at RAND. [austinl@rand.org]

Abstract

The Adaptive Acquisition Framework (AAF) is intended to improve defense acquisition performance by designing pathways to accommodate the diversity of systems and services that the U.S. Department of Defense (DoD) acquires. As of 2022, the AAF consists of six pathways: Urgent Capability Acquisition, Middle Tier of Acquisition, Major Capability Acquisition, Software Acquisition, Defense Business Systems, and Acquisition of Services. For each pathway, the authors identify an initial set of metrics that the DoD can use to measure performance and assess whether the pathway is achieving its goals. The authors also identify challenges to identifying metrics, both within and across pathways.

Key Findings

- Adaptive Acquisition Framework metrics should be regularly reviewed and are expected to change in response to changes in strategic goals, leadership priorities, and the results of analysis.
- Regular and well-defined data governance and management procedures need to be in place for all pathways.
- A high level of subject-matter expertise is required to gather, process, and analyze data and interpret results.
- Pathway-specific data challenges are exacerbated by programs interconnected through multiple pathways.
- The output of this initial set of metrics should be used to refine policy and process and to improve pathway performance and outcomes.

Introduction

One of the more significant changes to the Defense Acquisition System since 2015 is the revision to the U.S. Department of Defense (DoD) 5000 acquisition policy that created a set of distinct acquisition pathways, known as the Adaptive Acquisition Framework (AAF). Congress initiated these changes by providing statutory relief to the DoD through the introduction of the Middle Tier of Acquisition and Software Acquisition pathways, which were instantiated in law. The DoD then completed the AAF by designing additional pathways to accommodate the diversity of systems and services that the DoD acquires. The AAF is intended to create a more tailored process that reflects that diversity. The underlying assumption is that improved, and more specific, tailoring of program management and execution will enable the DoD to acquire the capabilities it needs more effectively and efficiently. Currently, the AAF has six pathways, all of which are further tailorable to the characteristics of the program. The objective of this study was to assist the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD[A&S]) with developing metrics to measure AAF performance and assess whether the pathways are achieving their goals.

The six pathways are shown in Figure 1. The pathways are defined in their respective policy documents as follows:

- Urgent Capability Acquisition (UCA): This policy establishes acquisition pathways for use in acquiring capabilities to fulfill urgent operational needs and quick reaction capabilities (DoD, 2019b).
- Middle Tier of Acquisition (MTA): This policy establishes procedures for rapid prototyping and rapid fielding of capabilities. It is intended to enable accelerated development and demonstration of capabilities (DoD, 2019a).
- Major Capability Acquisition (MCA): This policy establishes a pathway for Major Defense Acquisition Programs (MDAPs), other programs categorized as Acquisition Category (ACAT) I, major systems, usually categorized as ACAT II, and

Automated Information Systems (not managed by other acquisition pathways; DoD, 2021).

- Software Acquisition: This policy establishes an acquisition pathway for the development and procurement of custom software (DoD, 2020d).
- Defense Business Systems (DBS): This policy guides acquisition of business capabilities and their supporting business (information technology [IT]) systems across DoD components. It includes business system capability procured "as a service" (DoD, 2020c).
- Acquisition of Services (AoS): This pathway is for acquisition of services rather than products. Services can range from landscaping installations to IT support (DoD, 2020a).

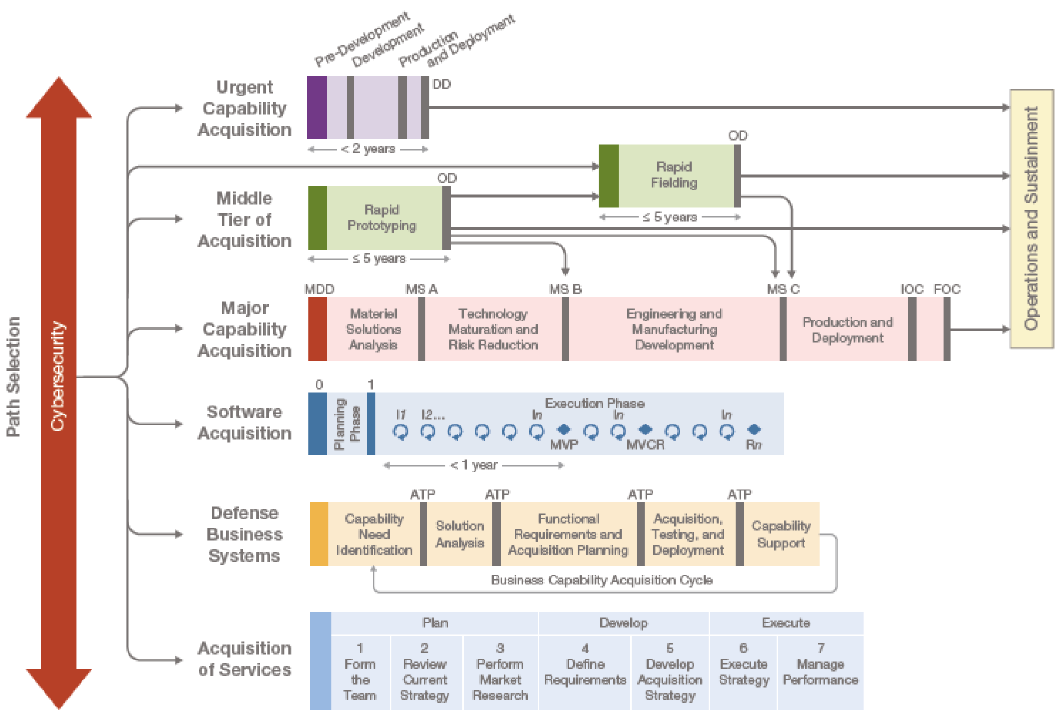


Figure 1. The Adaptive Acquisition Framework
(DoD, 2020b, p. 10)

NOTES: DD = deposition decision; OD = outcome determination; MDD = material development decision; MS = milestone; IOC = initial operational capability; FOC = full operational capability; I = iteration; R = release; MVP = minimum viable product; MVCR = minimum viable capability release; ATP = authority to proceed.

These policies implement applicable statutes, assign responsibilities, provide guidance and direction, and establish management structures for each pathway. Congress also provided some statutory relief for MTA and Software Acquisition that helped make these pathways viable, including how requirements and reporting are handled.

The AAF has existed since 2020 and needs to be examined to assess its effectiveness.[1] The U.S. Government Accountability Office (GAO) agrees and requested metrics to evaluate pathway performance (GAO, 2019). At the same time, DoD leadership is also interested in metrics and is pushing data to inform metrics (Deputy Secretary of

[1] We used 2020 as the approximate date for the release of the AAF because DoDI 5000.02 was effective as of January 23, 2020.

Defense, 2022);[2] however, this means that effective data governance is required for each pathway and for the AAF as a whole. Metrics that provide insight into pathway performance and health are part of this governance (Deputy Secretary of Defense, 2021; OUSD[A&S], 2020a). Therefore, the DoD is promulgating policy to that effect and establishing standards (OUSD[A&S] Office of Acquisition Enablers, 2020; OUSD[A&S], 2020b).

Study Objectives and Approach

This research builds on prior RAND research from fiscal years (FYs) 2019–2021 that identified acquisition metrics to assess the health of the overall acquisition system. The objective of the prior analysis was to systematically identify strategic questions, metrics, and analytics within OUSD(A&S) offices that would assist the DoD in understanding how well it is meeting its short-term and longer-term strategic goals with respect to acquisition (Arena et al., 2021).

The prior research adapted a process, described by Savitz et al. (2017), that provides an overview of how to identify measures and metrics that can be used to inform decision-making, assessment, planning, and communication. Central to this metrics identification and evaluation approach is generating a logic model that describes the linkages among inputs, activities, outputs, outcomes, and strategic goals. The prior research tailored the traditional logic model approach to measure the health of the acquisition system.

The objective of the research reported here was to identify metrics for each AAF pathway that can provide insight into whether a given pathway is performing as intended. We derived a simplified logic model (Figure 2) from the more detailed logic model in the previous work by Arena et al. We then applied this logic model to individual pathways with an additional step that compares proposed metrics with current required data.

The logic model constructed for each AAF pathway provided the analytical framework to identify metrics for that pathway. The analysis was supported by a rigorous review of AAF policy, a broader literature review focused on metrics, and a series of stakeholder interviews on topics that included pathway-specific goals, current metrics, and data governance, management, and analytical issues.

The next section addresses AAF challenges, both common and unique. We then identify an initial set of metrics for measuring the health of each pathway. Additional information on each AAF pathway, including the current state of the policy and data environment, is contained in the appendixes in McKernan et al. (2022).

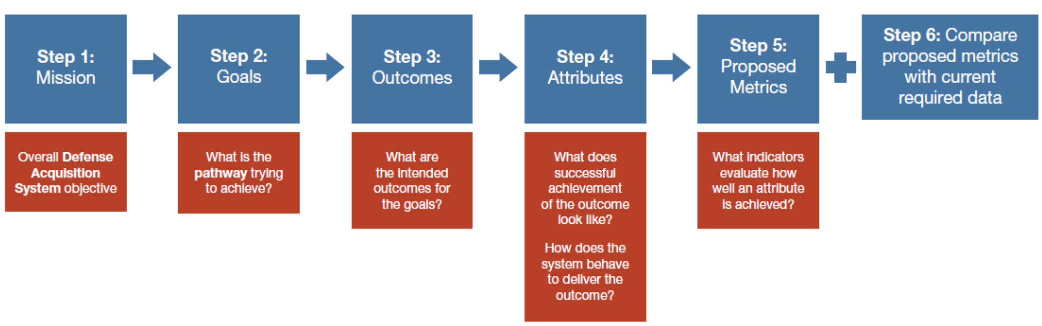


Figure 2. Simplified Logic Model Used to Identify AAF Metrics and Data Gaps (Savitz et al., 2017)

[2] For example, DoD senior leadership is also increasingly asking for information on the status of different mission-oriented portfolios of programs. This is in the Integrated Acquisition Portfolio Review and the Deputy's Management Action Group executive analytics efforts.

Challenges Identifying Metrics for AAF Pathways

Identifying metrics to measure the health or performance of each AAF pathway is associated with various challenges. Through our analysis of subject-matter expert interviews conducted during this study and drawing on prior work, we were able to identify challenges for implementing metrics for the AAF (Bartels et al., 2020). Although these challenges tend to fall into common categories of issues, the way or the degree to which they apply may be unique to each pathway.

Challenges common across AAF pathways include determining what programs are using a pathway and why, identifying the strategic goals related to pathway (not program) performance, defining metrics that provide insight into the extent to which those goals are being achieved, identifying authoritative sources of data, defining data standards that apply across the AAF pathways, and collecting and processing the data to support analysis. One challenge in particular exists across most of the pathways when conducting analyses of the AAF. The amount of and the specific data elements collected are intentionally different within and across the pathways, although that is not necessarily problematic. For example, the data are still governed for each pathway within the OUSD(A&S)'s Acquisition Visibility Data Framework (AVDF); however, the differences in data collected on smaller and larger programs may constrain the metrics that can be derived for each pathway and affect standardization.

The UCA, Software, and MTA pathways share a common challenge of trying to balance the schedule imperative of the pathway with information requirements for monitoring and oversight. Based on our review of the policies for each of these pathways, UCA, Software Acquisition, and MTA pathways are designed to facilitate acceleration of capability delivery, and they downplay reporting for purposes of monitoring and oversight of the pathway.

Within both the MTA and MCA pathways, there is less data availability for non-major MTA programs and lower ACAT-level programs than for major capabilities. This means that some metrics will reflect only larger programs, which poses a potential challenge when conducting analysis of these pathways. However, the OUSD(A&S) made the determination that less data are required for non-major MTA and lower ACAT-level programs than for major capabilities. Much of the data for major capabilities are driven by specific statutory guidance that may not be fully applicable for the non-major MTA and lower ACAT-level programs.

An AAF metrics framework also has pathway-unique challenges that need to be addressed. Figure 3 summarizes two key challenges for each pathway.

Urgent Capability Acquisition

1. No centralized data source exists for urgent needs due to disaggregated governance across Joint Staff/ Components
2. Tension exists between schedule imperative and information requirements; decreases available data for analysis

Middle Tier of Acquisition

1. There is less data available for analysis on non-major MTA programs than major MTA programs
2. Tension exists between schedule imperative and information requirements; decreases available data for analysis

Major Capability Acquisition

1. There is less data available for analysis on ACAT II–IV programs than ACAT I programs
2. Programs integrating into MCA from other pathways creates data governance and management challenges

Software Acquisition

1. While different from typical hardware metrics, software performance still needs to be measured to ensure capability delivery at the predicted cost
2. Data collection is in the early stages; no automation exists yet between OSD and component-level information systems

Defense Business Systems

1. Full list of DBS and associated data needs to be aggregated from information systems outside acquisition community
2. Some data is defined in the AVDF data standard, but is not readily available for most DBS programs

Acquisition of Services

1. No entry documentation, so analysis relies solely on labor-intensive data collection to assess who is using pathway
2. Limited post-award performance information to assess requirements and PALT to assess timeliness

Figure 3. Key Pathway-Specific Challenges

For example, we found that in the UCA Pathway, DoD leadership does not require a significant amount of data on these efforts in order to allow staff to focus on building the capability as quickly as possible. While this meets the main priority of the pathway (quickly fielding a capability), a lack of data makes analysis difficult. In addition, existing data are difficult to acquire due to disaggregated governance across the Joint Staff and the components. The Office of the Secretary of Defense (OSD) is responsible for joint urgent capabilities only. The components have additional urgent capability processes, but the existing data are mostly decentralized in the components and are almost entirely classified. The OSD has little formal leverage with component-level UCA Pathway owners to unify and standardize data collection.

We identified multiple MTA Pathway–unique challenges. First, a majority of MTA programs are lower-dollar value programs with a minimal set of information that is collected. The data may need to be supplemented on an ad hoc basis from component-level program offices. Secondly, the pathway contains a mix of programs (prototypes and items for rapid fielding/major or non-major), which means not every capability can be treated the same way in this pathway from a data perspective. Finally, there is tension between the schedule imperative and information requirements (i.e., leadership does not want to levy unnecessary information requirements on MTA programs that will lengthen schedule).

For the MCA Pathway, less data are available on ACAT II–IV programs than ACAT I programs at the OSD level. The components are not required to share all their smaller program data with the OSD. The OSD and the components are still working through what smaller program data need to be shared for the Department's pivot to capability portfolio analysis in the Integrated Acquisition Portfolio Review, which requires data from acquisition programs of all levels. Additionally, available ACAT II–IV data may differ among the components. For instance, the Navy and the Air Force use different software and collect slightly different sets of data elements for their smaller programs, though both are derived from the long history of MDAP reporting (Drezner et al., 2019).

Significant challenges also exist in transitions between the MCA Pathway and other pathways. DoDI 5000.02 recommends that program managers "may leverage a combination of acquisition pathways to provide value not otherwise available through use of a single pathway" (DoD, 2020b). These transitions need to be planned early with prototypes and software, and synchronization is needed for requirements, budgets, schedules, contracting, testing, intellectual property, and sustainment, between pathways and potentially programs that will merge into other programs.

It is also not clear whether there is or should be an agreement on the strategic questions and goals of the MCA Pathway between the OSD and the components. Because strategic questions and goals drive which metrics are of interest, and therefore what data are collected, differences between the OSD and components could lead to somewhat different sets of metrics. While that is not necessarily a problem—metrics should be consistent with senior leader preferences and interests, and they will change over time in response to both internal and external factors—this inconsistency could lead to confusion among outside organizations like the GAO or Congress.

Use of the Software Acquisition Pathway is still ramping up (14 programs are in planning and 21 are in the execution phase), so data collection is in the early stages. Also, programs have only recently started sending data to the OSD, which means no full set of information exists yet for analysis.[3] As experience is gained with reporting, both metrics and analysis can be refined. Additionally, software acquisition metrics are different from typical cost, schedule, and performance metrics (e.g., software supports continuing evolution across the lifecycle of the system and does not have discreet "acquisition" and "sustainment" phases; deliveries are continuous; and no Acquisition Program Baseline [APB] exists). These differences also mean that there is likely going to be a learning curve for the DoD acquisition workforce for understanding what these metrics mean and how they are measured. For example, the time it takes to recover from a cyber attack is a measure of software resilience. While no defined schedule endpoint may exist, the frequency with which new capabilities are added is a relevant schedule metric of interest to users.

For the DBS Pathway, the full list of DBSs and their associated data need to be aggregated from information systems outside of the acquisition community; those systems were not designed to capture the kind of information needed to assess program or pathway health. Additionally, while some data are defined in the AVDF[4] common data standard (i.e., program number, program name, required funding—total acquisition-related operation and maintenance quantity), many AVDF data elements are not readily available for most DBS programs.[5]

The AoS Pathway does not have entry documentation (i.e., a formal declaration that a program or effort is going to use the pathway, which may consist of an Acquisition Decision Memorandum), so analysis relies solely on labor-intensive data collection to assess what programs are using the pathway. There is also limited post-award performance information to assess requirements and Procurement Administrative Lead Time (PALT) to assess timeliness (except for major contracts). Other features unique to the AoS Pathway include the unit of analysis being a contract or contract action, not necessarily a program, and tremendous variation in the size of programs. In addition, no formal program office may exist, especially for smaller activities; program management and contract monitoring are often "other duty as assigned," rather than a full-time position.

---

[3] As of March 2022, there was only one biannual data collection.

[4] According to the Office of the Assistant Secretary of Defense for Acquisition, Office of Acquisition Data and Analytics/Enterprise Information (n.d.), "The AVDF provides the Acquisition community an authoritative, governed set of data elements, definitions, rules, and other metadata for the Adaptive Acquisition Framework
(AAF). The AVDF establishes a common enterprise data standard for DoD that will enable the six AAF pathways through data."

[5] According to the FY22Q1 Acquisition Visibility Data Framework, 85 data elements are available for DBS out of 624 total.

Finally, integration of programs into the Major Capability Pathway from other pathways creates data governance and management challenges such as understanding the applicable set of approved/governed data elements when combining the information from the different pathways and adjusting to the new pathway data reporting requirements.

Primary Set of AAF Pathway Metrics

Our focus is on identifying metrics to assess the performance of each AAF pathway—whether the pathway is achieving its intended outcomes and strategic goals. It is useful to think of the set of programs using a given pathway as a portfolio and the metrics of interest as those that provide insight into the status of the portfolio. Some potential metrics inherently measure status at the portfolio level. Other metrics are program-centric but can be aggregated to provide a measure of portfolio performance. For example, the cost growth of programs using a given pathway can be aggregated to produce an average portfolio cost growth value.

Figure 4 lists the five initial metrics recommended for each pathway. These metrics link back to the strategic goals of each pathway, as is best practice in identifying metrics. Among each of the five metrics per pathway, some measure more critical aspects of an individual pathway's health than others, but all will help provide DoD leadership and the GAO with better insight into the health of the AAF as a whole. Traditional cost, schedule, and performance metrics are included in this initial set of recommended metrics but are tailored to the way these metrics make sense for each pathway. We also include two additional unique metrics per pathway that provide more direct measures of pathway health. We have selected metrics for which data are available or data gaps can be readily resolved. More information on these metrics can be found in the corresponding appendix for each pathway in McKernan et al. (2022).

Pathway	Metrics	Pathway	Metrics
Urgent Capability Acquisition	1. Program cost estimate (total) 2. Time elapsed from requirement validation date to solution sponsor assignment 3. Total number of capabilities terminated, sustained, or transitioned at disposition decision 4. Time elapsed from requirement validation date to capability delivery or revalidation of requirement 5. Total number of joint urgent operational needs/joint emergent operational needs/ Warfighter Senior Integration Group special interest items	Software Acquisition	1. Program cost estimate (total) 2. Average lead time 3. Change fail rate 4. Average mean time to resolve experienced cyber incident or common vulnerability or exposure (CVE) 5. Average deployment frequency
Middle Tier of Acquisition	1. Average percentage cost growth (quantity adjusted, if applicable) 2. Difference between MTA start date and expected operational demonstration date 3. Beginning Technology Readiness Level 5 or greater 4. Percentage change in initial and current budget (year-over-year) 5. Number of rapid prototypes fielded, transitioned, or terminated	Defense Business Systems	1. Average percentage cost growth 2. Limited deployment authority to proceed date slippage (initial operational capability slippage equivalent)–percent delta of planned versus actual schedule 3. Percentage established performance parameters met for each release before development or delivery 4. Compliance with cyber policy is being monitored/ tracked 5. Fraction of contracts competitively awarded
Major Capability Acquisition	1. Average percentage cost growth (quantity adjusted, if applicable) 2. Average schedule slippage between planned and actual initial operational capability (or equivalent) 3. Average percentage of objective/threshold key performance parameters (KPPs) met (or equivalent) 4. Fraction of programs failing initial testing 5. Fraction of programs either entirely from or partly from other pathways	Acquisition of Services	1. Average percentage cost growth 2. Average schedule slippage between need date and service requirement received 3. Percentage of warfighter objectives met (or equivalent) 4. Average procurement acquisition lead time 5. Number of effective bid protests (per the GAO definition)

Figure 4. Primary Set of Pathway-Specific Metrics

The selected metrics are not intended to be comprehensive in providing insight to pathway performance. Rather, we found that it is important to start performance measurement in a way that is feasible—data are or could be made available—in order to demonstrate the utility of the metrics in terms of providing insight into pathway health and building confidence among stakeholder organizations. As confidence and experience in performance measurement are gained, the specific set of metrics for each pathway can and should be modified to address other aspects of pathway health. While different subject-matter experts might select a different set of metrics to initiate a performance measurement system, the most important thing is to begin, and to learn and improve data collection and analysis to support improved policy design and pathway outcomes.

We recommend that the DoD pilot this system of metrics. A pilot will help to better understand and address the challenges that we identified, generate lessons learned to modify or improve data governance and management for pathway metrics, and, of course, provide insight into the health and performance of each AAF pathway.

Conclusions and Observations

As is good practice in enterprise-level metrics, we chose a limited set of metrics per pathway to start (PricewaterhouseCoopers LLC, 2007). Five were chosen for each AAF pathway from a list of over 75 possible metrics per pathway identified in each logic model. There is no right or wrong answer for the exact number, but it is counterproductive for an organization to start by implementing a large number of metrics. The chosen metrics also need to show some consistency across pathways for comparison (if appropriate) in order to understand the entire framework. Importantly, the goals (and derived metrics) should align with leadership interests and policy preferences. It is also useful to focus on one or more specific attributes of pathway health as they relate to strategic goals using available data and collection tools. This is a manageable set of metrics to gain initial pathway health insights with the understanding that, given the DoD's complexities, implementation will require an iterative process (i.e., the metrics chosen will change over time as the DoD's goals and leadership change).

The DoD acquisition community should also consider several additional observations regarding implementation:

- Strategic goals are critical—they define the use cases for each pathway and therefore associated metrics and data needs.
- A high level of subject-matter expertise is required to gather and process the necessary data, conduct the analysis, and interpret results. This finding cannot be understated. Facts, assumptions, and limitations of the source data must be clearly and deeply understood—and explicitly documented, approved, and promulgated—to allow for accurate "processing" (consistent calculations, data curation, etc.) and subsequent analysis. Each pathway collects unique data and therefore has its own challenges and nuances that need to be understood when collecting and preparing the data for analysis. Interpretation of the results is likewise difficult and nuanced, given that the data may have outliers at the lower levels that are driving the metrics.
- The recommended metrics should be regularly reviewed for relevance and should be expected to change in response to changes in strategic goals, leadership priorities, and the results of analysis. This may be a challenge in that it requires discussions leading to agreement on metrics and the data needed. This first set of metrics focuses on those that will provide near-term insights with data that do not appear to have significant gaps. Additional metrics can be identified through changes in leadership's focus and the Department's strategic vision, along with data governance, management, and analysis as each pathway matures.
- Regular and well-defined data governance and management procedures should be established and maintained for all pathways. Within the OUSD(A&S), the Office of Acquisition Enablers has been working with the pathway owner and the data owners in the components to establish the governance and data standards. While this is a voluntary system of data reporting, the offices responsible for acquisition data in the OUSD(A&S) and the components have worked together for years to maintain and update standards for acquisition data to the benefit of all. In addition, senior leadership has recognized data as an enterprise resource that should be transparent and shared (Deputy Secretary of Defense, 2021; OUSD[A&S], 2020).
- Pathway-specific data challenges are exacerbated by programs interconnected through multiple pathways. Some programs will use multiple pathways for different elements of the system; if those pathways handle data differently, then values for the "merged" program may be misleading. This problem occurs at the juncture of program and portfolio (pathway) perspectives and is a significant analytic challenge that should be addressed.
- The output of this initial set of metrics should be used to inform decisions to refine policy and process and improve pathway performance and outcomes.

It is also important to acknowledge that the data needed for pathway performance metrics are not the only data needed for the operation of the Defense Acquisition System.

References

Arena, M. V., McKernan, M., Thompson, J., & Newberry, S. J. (2021). [Unpublished RAND Corporation research].

Bartels, E. M., Drezner, J. A., & Predd. J. B. (2020). *Building a broader evidence base for defense acquisition policymaking* (Report No. RR-A202-1). RAND. https://www.rand.org/pubs/research_reports/RRA202-1.html

Behn, R. D. (2003). Why measure performance? Different purposes require different measures. *Public Administration Review*, *63*(5).

Deputy Secretary of Defense. (2021, May 5). *Creating data advantage* [Memorandum].

Deputy Secretary of Defense. (2022, February 2). *Principles and standards for analysis supporting strategic decisions* [Memorandum].

DoD. (2019a, December 30). *Operation of the middle tier of acquisition (MTA)* (DoD Instruction 5000.80).

DoD. (2019b, December 31). *Urgent capability acquisition* (DoD Instruction 5000.81).

DoD. (2020a, January 10). *Defense acquisition of services* (DoD Instruction 5000.74).

DoD. (2020b, January 23). *Operation of the adaptive acquisition framework* (DoD Instruction 5000.02).

DoD. (2020c, January 24). *Business systems requirements and acquisition* (DoD Instruction 5000.75).

DoD. (2020d, October 2). *Operation of the software acquisition pathway* (DoD Instruction 5000.87).

DoD. (2021, November 4). *Major capability acquisition* (DoD Instruction 5000.85).

Drezner, J. A., McKernan, M., Lewis, A., Munson, K., Hill, D., Hastings, J., McGovern, G., Posard, M., & Sollinger, J. M. (2019). *Issues with access to acquisition data and information in the Department of Defense: Identification and characterization of data for acquisition category (ACAT) II–IV, pre-MDAPs, and defense business systems* [Not available to the general public]. RAND.

GAO. (2019, June). *DoD acquisition reform leadership attention needed to effectively implement changes to acquisition oversight* (GAO-19-439).

McKernan, M., Drezner, J. A., Arena, M. V., Wong, J. P., Shokh, Y., Lewis, A., Young Moore, N., Mele, J. D., & Newberry, S. J. (2022). *Using metrics to understand the performance of the adaptive acquisition framework* (Report No. RR-A1349-1). RAND. https://www.rand.org/pubs/research_reports/RRA1349-1.html

Office of the Assistant Secretary of Defense for Acquisition, Office of Acquisition Data and Analytics/Enterprise Information. (n.d.). *Homepage*. https://www.acq.osd.mil/asda/ae/ada/enterprise-information.html

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2020a, June 15). *Data transparency to enable acquisition pathways.*

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2020b, October 13). *Promulgation of the acquisition visibility data framework as the common data framework for acquisition and sustainment* [Memorandum].

Office of the Under Secretary of Defense for Acquisition and Sustainment, Office of Acquisition Enablers. (2020, December). *Acquisition and sustainment data and analysis strategic implementation plan.*

Performance-Based Management Special Interest Group. (2001, September). *The performance-based management handbook, volume 2: Establishing an integrated performance measurement system*.

Pinker, A., Smith, C. G., & Booher, J. W. (1997). Selecting effective acquisition process metrics. *Acquisition Review Quarterly*, Spring.

PricewaterhouseCoopers LLC. (2007). *Guide to key performance indicators: Communicating the measures that matter.* https://www.pwc.com/gx/en/audit-services/corporate-reporting/assets/pdfs/uk_kpi_guide.pdf

Savitz, S., Matthews, M., & Weilant, S. (2017). Assessing impact to inform decisions: A toolkit on measures for policymakers (Report No. TL-263-OSD). RAND. https://www.rand.org/pubs/tools/TL263.html

Middle-Tier Defense Acquisitions: Rapid Prototyping and Fielding Requires Changes to Oversight and Development Approaches

Alexis Olson—is a senior analyst in the U.S. Government Accountability Office's (GAO) Contracting and National Security Acquisitions team. Ms. Olson has 10 years of experience leading reviews and evaluating acquisition programs, acquisition and contracting policy, and emerging technologies. She has recently led reviews evaluating the Department of Defense's (DOD) middle tier of acquisition pathway and GAO's annual assessments of the Department of Homeland Security's major acquisition programs. Her past work includes reviews of biometric technologies, southwest border security, and a government-wide review of cost estimates for service contracts. Prior to joining GAO, Ms. Olson worked for the Department of the Navy and in the private sector. Ms. Olson holds a Master of Professional Studies in Homeland Security and Geospatial Intelligence degree and a Bachelor of Arts in Law and Society degree from Pennsylvania State University. [OlsonA@gao.gov]

Chris Durbin—is an assistant director in the U.S. Government Accountability Office's (GAO) Contracting and National Security Acquisitions team. He has 19 years of experience evaluating Department of Defense (DOD) acquisition programs, policies, and culture. He has recently overseen reviews evaluating DOD's middle tier of acquisition pathway and industry leading practices for successful product development. He previously oversaw GAO's annual assessments of execution risks and performance in over 80 major weapons acquisition programs and defense science and technology reviews on topics that included leading practices in innovation investments and management, laboratory governance, and industry independent research and development. Earlier in his career, he led detailed reviews of major Navy shipbuilding programs, along with an evaluation of the best practices that leading commercial shipbuilders and ship buyers around the world employ. He holds a Master of Public Administration degree and a Bachelor of Arts degree, both from the University of Kentucky. [DurbinC@gao.gov]

Shelby Oakley—is a Director in GAO's Contracting and National Security Acquisitions team. She oversees GAO's work examining the most complex and expensive acquisitions within the federal government. Her portfolio includes Navy Shipbuilding programs, DOD acquisition policy and oversight, and leading practices in product development. She is also responsible for GAO's annual work assessing the cost, schedule, and performance of DOD's portfolio of major defense and middle-tier acquisition programs. Previously, Ms. Oakley led teams reviewing activities of NASA with a focus on acquisition management. Her reviews covered key aspects of NASA's operations, such as sustainment of the International Space Station and reviews of major NASA systems including in-depth reviews of NASA's human spaceflight programs and the James Webb Space Telescope. Ms. Oakley earned a Master's Degree in Public Administration from the University of Pittsburgh's Graduate School of Public and International Affairs and her Bachelor's Degree from Washington and Jefferson College. [OakleyS@gao.gov]

Abstract

The Department of Defense (DOD) is continually challenged to deliver capabilities to its warfighters at the pace of innovation. Section 804 of the National Defense Authorization Act for Fiscal Year 2016 required DOD to establish guidance for an alternative acquisition process, now referred to as the middle tier of acquisition (MTA). Since GAO's June 2019 report on the use of MTA authorities, DOD has reported an increase in programs using the pathway, from 35 programs to nearly 100 in 2022. In light of this increased use, GAO was asked to review DOD's oversight and execution of MTA programs.

What the GAO Found

The Department of Defense (DoD) intends to facilitate rapid prototyping and rapid fielding of new weapons and other resources the military has identified it needs. This approach, known as the middle tier of acquisition (MTA), seeks to provide capabilities within 2 to 5 years of an acquisition program's start. The DoD established policies and guidance for managing the MTA pathway, but several factors hinder effective implementation and oversight.

For example, an unclear data framework and reporting guidance limit the visibility of MTA program structures, scope, and technical data. As a result, the oversight role of the Under Secretary of Defense for Acquisition and Sustainment with regard to the MTA pathway is diminished. The GAO also found that the DoD components provided the Under Secretary with inaccurate data. Together, these issues complicate the DoD's efforts to conduct data-driven oversight of the MTA pathway.

MTA policies from the Air Force, Army, Navy, and Special Operations Command (SOCOM) each partially implemented at least some of the four key product development principles that leading companies rely on to innovate quickly and successfully.

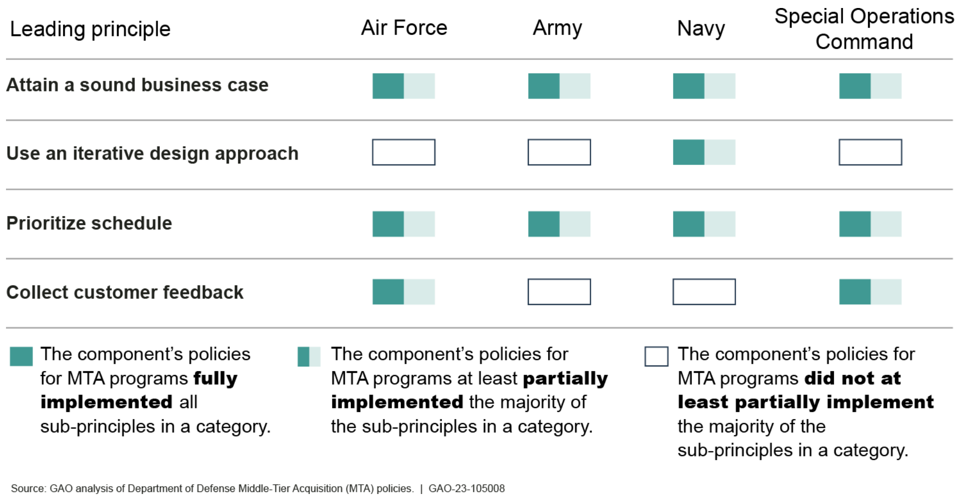


Figure 1. Component Policies Reflect Some Leading Product Development Principles

As the GAO's latest study of leading acquisition practices found in March 2022, leading companies rely on key principles for successful product development. These include attaining sound business cases, applying iterative design approaches, off-ramping capabilities when needed to prioritize schedule, and incorporating feedback from users of initial capabilities. If the military departments and other DoD components incorporated these leading principles more fully into their MTA policies, they would be better positioned to meet their users' needs with greater speed—the core goal of the MTA pathway.

Why the GAO Did This Study

The DoD is continually challenged to deliver capabilities to its warfighters at the pace of innovation. Section 804 of the National Defense Authorization Act for Fiscal Year 2016 required the DoD to establish guidance for an alternative acquisition process, now referred to as MTA. Since the GAO's June 2019 report on the use of MTA authorities, the DoD has reported an increase in programs using the pathway, from 35 programs to nearly 100 in 2022.

In light of this increased use, the GAO was asked to review the DoD's oversight and execution of MTA programs. This report assesses the extent to which (1) the DoD effectively implemented policies, guidance, and processes to provide the DoD with reliable data for MTA oversight; and (2) military components' MTA policies and selected programs implement leading principles for product development.

The GAO selected a non-generalizable sample of 15 active MTA programs. This selection includes MTA rapid prototyping and rapid fielding programs from the Air Force, Army, Navy, and SOCOM. The DoD estimates these programs will require more than $12 billion in funding. The GAO also reviewed DoD MTA policies, guidance, and program documentation; compared component MTA policies and programs to the principles; and interviewed DoD officials to corroborate its assessments.

What the GAO Recommends

The GAO is making 26 recommendations aimed at improving MTA oversight and development through policy and process changes. The DoD concurred with 25 recommendations and partially concurred with one. View GAO-23-105008.

PANEL 4. LEVERAGING DIGITAL ENGINEERING IN ACQUISITION

Wednesday, May 10, 2023	
10:30 a.m. – 11:45 a.m.	**Chair: Dennis K. McBride,** Director, Acquisition Innovation Research Center (AIRC) ***Decision Engineering and the Digital Twin of an Acquisition Program*** Stephen Waugh, Johns Hopkins University Applied Physics Laboratory Timothy Davis, Johns Hopkins University Applied Physics Laboratory Matt Tillman, Johns Hopkins University Applied Physics Laboratory Justin Shoger, Johns Hopkins University Applied Physics Laboratory ***Exploring Program Archetypes to Simplify Digital Transformation*** Nicole Hutchison, Stevens Institute of Technology David Long, Stevens Institute of Technology Paul Wach, Virginia Tech National Security Institute ***Digital Engineering Enhanced T&E of Learning-Based Systems*** Laura Freeman, Virginia Tech Paul Wach, Virginia Tech Justin Krometis, Virginia Tech Atharva Sonanis, Purdue University Jitesh Panchal, Purdue University Peter Beling, Virginia Tech

Dennis K. McBride, Ph.D.—is Director, Acquisition Innovation Research Center (AIRC), Office of the Under Secretary of Defense (A&S), Acquisition Enablers. Dennis has more than 40 years of experience at the intersection of science, technology, and public administration, including multiple levels of leadership in national security policy. Dr. McBride served in uniform as a Naval Aerospace Experimental Psychologist at six nationally prominent high tech RDT&E laboratories and multiple headquarters – including as Program Manager at the Defense Advanced Research Projects Agency (DARPA), tri-Service lead for Operational Medicine S&T at the Naval Medical Research & Development Command, Program Officer for Modeling and Simulation, Office of Naval Research, and extensive Additional Duties (ADDU) for the Deputy Assistant Secretary of the Navy (C4I) and for the Deputy Under Secretary of Defense for Advanced Technology.

Decision Engineering and the Digital Twin of an Acquisition Program

Dr. Stephen Waugh—is a recognized expert on the emerging field of digital engineering at JHU/APL. He served 20 years in the Marine Corps as an AV-8B pilot, and as a Deputy Program Executive Officer at Naval Aviation Systems Command, retiring as a Lieutenant Colonel. He holds a BS in Aerospace Engineering from USNA, an MBA in Technology Management from University of Phoenix, and a Doctor of Business Administration from University of Maryland Global Campus. [stephen.waugh@jhuapl.edu]

Dr. Timothy Davis—is expert in the fields of Test & Evaluation and Electromagnetic Spectrum Operations/Electronic Warfare at JHUAPL. He served 20 years as a Marine Corps EA-6B Prowler Electronic Countermeasures Officer, Forward Air Controller, Weapons & Tactics Instructor, and Developmental Test Flight Officer, retiring in 2017 as a Lieutenant Colonel. He earned a BS in Ocean Engineering from the U.S. Naval Academy, MS in Systems Engineering from the Johns Hopkins University, and a PhD in Systems Engineering from the George Washington University. [Timothy.Davis@jhuapl.edu]

Dr. Matt Tillman—is a Section Supervisor, Project Manager, and the Chief Scientist of the Mission Engineering Group at JHU/APL. He earned a BS in Chemical Engineering from the University of California Berkeley, and a PhD in Chemical Engineering from the University of Washington. [Matthew.Tillman@jhuapl.edu]

Mr. Justin Shoger—is an expert in decision science for command and control organizations and systems at JHU/APL. He served 25 years in the Navy as an E-2C naval flight officer and command center leader, as the battlespace awareness requirements officer within OPNAV N2/N6, and as the program manager at Naval Aviation Systems Command, retiring as a Commander. He earned a BA in economics from The University of Texas, Austin, TX, and an MS in Systems Analysis from the Naval Postgraduate School, Monterey, CA, and is a PhD candidate (abd) in Systems Science at Binghamton University-SUNY, Binghamton, NY. [Justin.Shoger@jhuapl.edu]

Abstract

The regulatory environment of a Major Defense Acquisition Program changes throughout its life cycle, challenging generations of leaders to be custodians of corporate knowledge, and make decisions across an enterprise, sometimes without a comprehensive view of factors influencing their programs. Tools such as Digital Twins, Digital Engineering, Model-Based Systems Engineering, and Modeling & Simulation have utility, but their value to managers is often illusive.

This paper explores if program decision-making can be digitally transformed by applying principles of decision science, theory & methods of systems engineering, and practices from business program management, to engineer decisions.

This cumulative case study describes the background, purpose, method, and conclusions from four projects.

A digital twin of a project can be constructed by modeling organization processes, digitalizing documents, linking live cross functional data, and connecting decisions to data to process. The resulting system has transparent processes, dynamic and relevant data models, and useful decision aids. This repository is an enduring, usable body of knowledge, linking decisions to the data required, and the business processes that create it.

A program digital twin supports decision engineering: it identifies decision points, data required for those decisions, and processes necessary to produce the data.

Keywords: Decision Engineering, Digital Twin, Strategy, Data Model, Decision Support System

Executive Summary

The regulatory environment of a Major Defense Acquisition Program (MDAP) changes throughout its life cycle, challenging generations of leaders to be custodians of arcane corporate knowledge, complicating decision-making across organizational levels and functions, often without a complete, common operating picture. Data critical to decisions may be inaccessible, and the processes that generate it may not be transparent. Tools and approaches such as Digital Twins, Digital Engineering (DE), Model-Based Systems Engineering (MBSE), and Modeling & Simulation (M&S) are being applied in an attempt to address this challenge, but their value to program managers may be illusory.

Four case studies demonstrate a digitally transformed program can create a digital twin of itself: a shared repository of data and analytics to excel at decisions. This repository is an enduring, usable body of knowledge that links management decisions to the data required, and to the business process that creates the data. The program can have the data it needs, when it needs it by engineering decisions: identifying the likely decision points, the data required for those decisions, and the processes necessary to produce the data.

The decisions are identified by a strategy, designed into a data model, and instantiated in a Decision Support System (DSS). The strategy identifies the priorities on program data, eligible processes, the ecosystem the model will reside in, the technology options/constraints, and a feedback loop. The data model drives transformation by digitalizing existing documents, combining existing cross-functional data, and modeling necessary processes. Once populated, this digital transformation results in a shared DSS with digitalized processes that are transparent, data models that are internally fluid and externally relevant, and accessible decision aids. With a digital twin of the program, managers can forecast health, remaining life, probability of success, response to events, mitigation of damage, and recommend changes.

Introduction

Many programs are a layered set of MDAPs with multiple, complex, related but unique programs passing through milestones in rapid succession. These programs will strain the highly specialized staff and managers, and their ability to make decisions and execute. Compounded with the other programs in a program office, the challenges are magnified further. Providing the staff and managers a mechanism to control the processes that generate the products necessary for making better decisions is essential. A construct for such a mechanism combines Department of Defense (DoD) standards with commercial practices in an innovative framework.

Problem Statement

The number of policy mandates imposed on a MDAP is so high it is unknown (Gansler et al, 2015). It is difficult to accurately count the layers of stakeholders empowered to impose new constraints on complex programs, let alone discern the directly applicable constraints from those indirectly affecting while avoiding those actually not applicable to a specific program or activity.

At the same time, executing plans in a predictable, fully resourced manner is challenging when the processes are often undocumented, unconstrained, or have unknown triggers, unspecified inputs or undefined outputs (Bolten et al, 2008). Processes executed purely based on the expertise of the process owners can fall prey to slowing shifting tribal knowledge and become untethered from legitimate regulation. Processes or activities that do not generate specified products essential to a decision of a given program should not be required, but may be imposed out of habit.

Managers of program make decisions continuously on a variety of levels, in a variety of functions, across an enterprise, usually without a complete, consistent understanding of the context around a given problem (Fast, 2010). For example, a problem that arises in an early developmental test may not be fully appreciated for its secondary impact on a risk related to the lagging schedule of a system component, simply because when the team meets to discuss the discrepancy they may be unaware of a related program risk, documented in a separate repository. In a different vein, a program may struggle to collect the products necessary to successfully pass a program review without a detailed understanding of what information that decision maker requires or will consider satisfactory.

Research Question

Can program decision making be digitally transformed by applying principles of decision science (DS), theory & methods of systems engineering (SE), and practices from business program management (BPM), to engineer decisions? Figure 1 reflects this question using the theoretical framework of General Systems Theory (Von Bertalanffy, 1972).

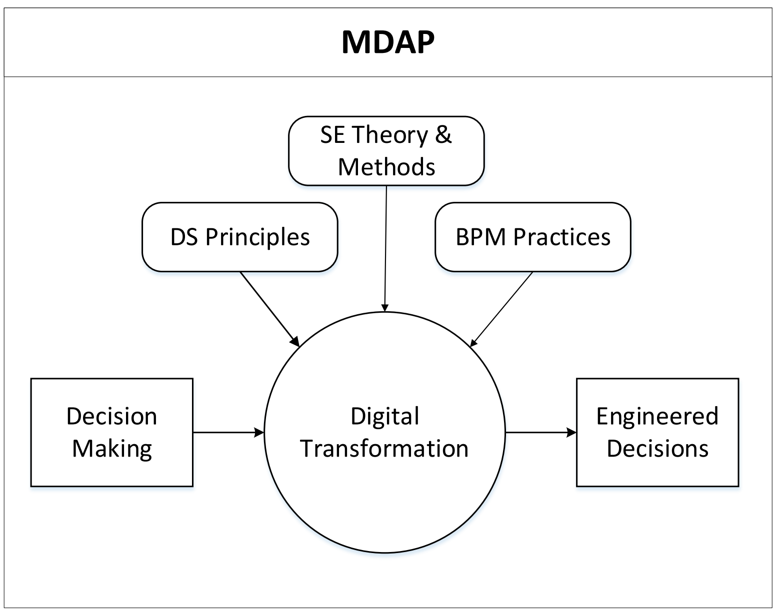


Figure 1. Research Question

Purpose

We assert that by constructing a digital twin of a program, the organization will be able to look into its own processes that define it, how it collects, processes and presents information across the decision-making spectrum, from executive to operational personnel. A digital twin can trace decisions to program objectives and goals – and how they were set. Additionally, this modeling can enable the organization to critically evaluate individual roles' inputs into the process, looking for which decision-making strategies are used when and for consistency. This provides the organization knowledge tools that level-set the values across the organization to get the results desired, and document the processes to achieve those goals.

Background

In order to better understand the problem space and case studies, the paper will review six key tools and their contribution to decision making. Those include modeling and simulation, model-based systems engineering, digital twins, digital engineering, business process modeling, and decision science.

Modeling & Simulation (M&S)

M&S is a commonly used term, if slightly misunderstood. A model has three characteristics. It is a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process (Maria, 1997). The model is a close approximation to the real system, and incorporates most of its salient features. A model is used to promote understanding of the real system. There are many valid types of model, from wooden ship hulls to a full-scale mockup of the Space Shuttle, or an Activity Diagram of software. A model is an abstraction of a real thing, from a perspective, with utility.

Simulations are a model with a twist. Simulation is a method for implementing a model over time (Coolahan, 2003). A simulation demonstrates the operation of a model of the system. A simulation enables an experimenter to perceive the interactions that would not otherwise be apparent because of their separation in time or space (Gupta & Grover, 2013). A simulation allows repeated tests of a system over time, in different configurations or under different conditions.

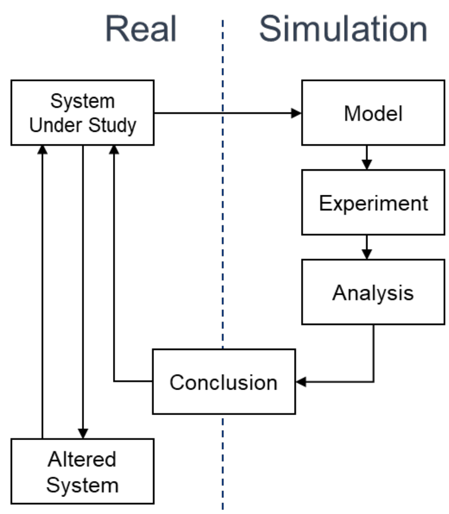


Figure 2. Simulation Study Schematic

Note: Adapted from Maria (1997)

Model-Based Systems Engineering (MBSE)

MBSE is a method of visualizing the systems engineering process: a top-down process of decomposing requirements into functions, then to designs that are verified against the requirements (INCOSE, 2007). Mandates for DoD Architecture Framework (DoDAF) views at program milestones reflect the same progression (i.e. Use Case, Operational Views, and System Views) (SYSCOMINST 4355.19D). However, there is no DoD requirement (or established method) to connect those System Views to test events, risk items, cost items, or staffing and schedule. Nor is there a connection to the processes that create them or use them.

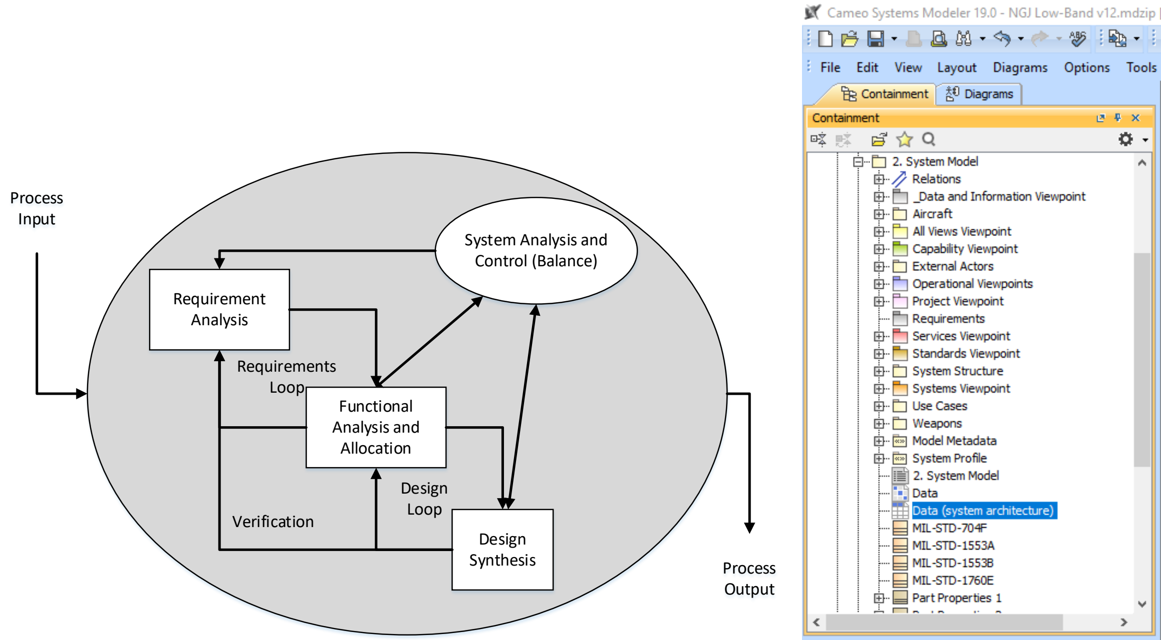


Figure 3. Systems Engineering Method and a SysML Model

Reference Architectures are pattern models at a level of generality that provide some degree of reuse, while a contractor 'solution architecture' portrays the relationships among all the elements of something that answers a problem (OASD/NII, 2010). Effectively, they are two sides of the same coin (what you want vs. what they sell). DoDAF is a framework for visualizing them, often using the Systems Modeling Language (SysML) (DoD, 2003).

Digital Twin

The concept of digital twins first arose in discussions of product lifecycle management (PLM) (Grieves, 2002). It has evolved since then, with extensive commercial use and continued research, such as Madni et al (2019). A digital twin requires a physical twin for data acquisition and context-driven interaction. The virtual system model in the digital twin can change in real-time as the state of the physical system changes (during operation). A digital twin consists of connected products, typically utilizing the Internet of things (IoT), and a digital thread. The digital thread provides connectivity throughout the system's lifecycle and collects data from the physical twin to update the models in the digital twin.

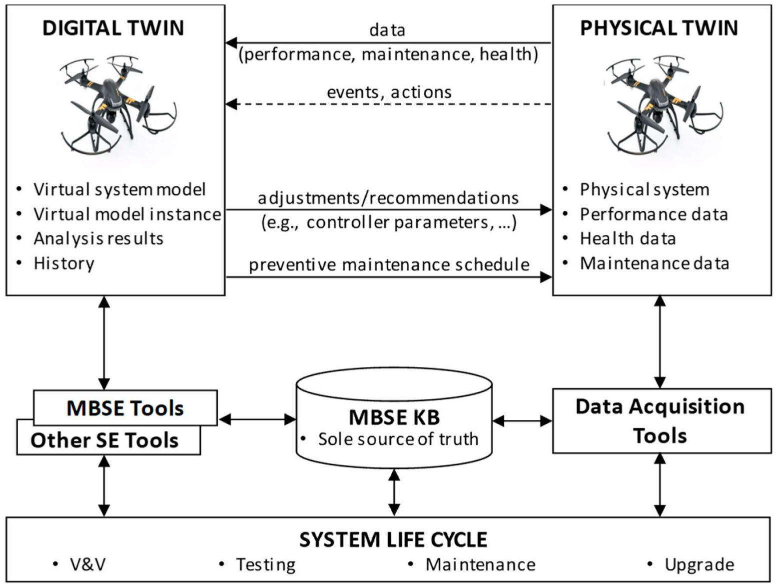


Figure 4. Digital Twin

Note: From Madni & Purohit (2019). No changes were made to the author's diagram. © 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).

Digital Engineering (DE)

The Defense Acquisition University defines digital engineering as "…an integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support life cycle activities from concept through disposal."(DAU, n.d.). DoD published its Digital Engineering Strategy in 2018, followed in 2020 by the Naval Digital Systems Engineering Transformation (DSET) Strategy (DoD, 2018, DASN RDT&E, 2021). Both have the same five goals, but neither gives direction on what or how to digitalize. The FY20 Defense Authorization defined DE in federal law. In §230 it defined DE as "…the creation, processing, transmission, integration, and storage of digital data, including data science, machine learning, software engineering, software product management, and artificial intelligence product management."

DE is often confused with MBSE, but the DE policy goals go far beyond the familiar DoDAF perspectives, or the Government Reference Architectures (DoD, 2003, OASD/NII, 2010). DE is not a new interdisciplinary branch of engineering, like systems engineering (SE) is a branch of industrial engineering (SEBoK, n.d.). At this time, DE has no distinct scientific principles applied to build particular things, no unique processes, methods or protocols; it is only a policy. However, the commercial world embraced digitalization out of necessity and has realized great opportunities that government can leverage (Carucci, 2020).

Business Process Management (BPM)

Business Process Management (BPM) is the art and science of overseeing how work is performed in an organization to ensure consistent outcomes and to take advantage of improvement opportunities (Dumas et al, 2013). Each system command (SYSCOM) implemented various BPM efforts that resulted in numerous products that have value, such as standard work packages (SWP). While the processes that have been mapped can be improved, they are not necessarily directly connected to the products they use or create.

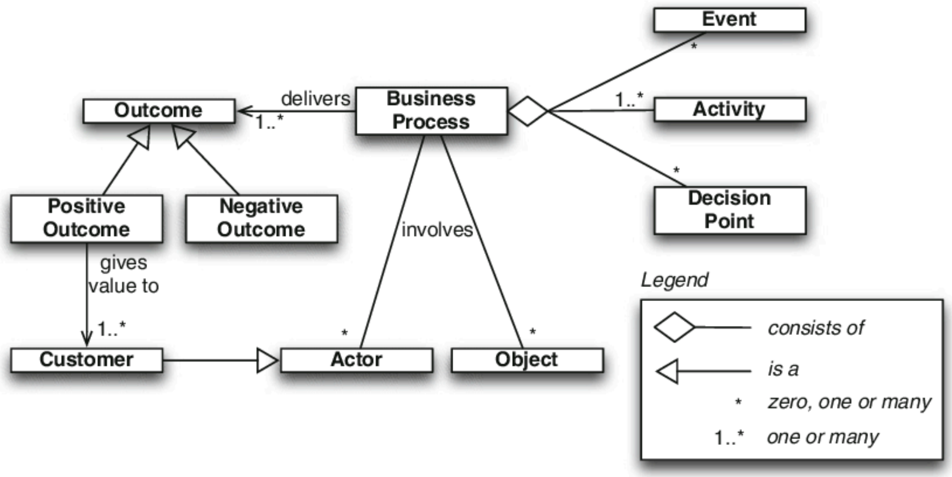


Figure 5. Ingredients of a Business Process

Note: Adapted from Dumas et al (2013)

Because of the "dot com" bust and the subsequent Sarbanes-Oxley legislation, the financial technology industry had to reshape operations (Senate, 2003). Global companies may find themselves financing a loan in Kentucky through a subsidiary in Virginia from a headquarters in New York using funds from the United Kingdom. Such a transaction crosses multiple jurisdictions and must comply with the laws of each, while achieving the intended business goals, satisfying the customer needs, and managing overall risk. As a result, several corporations offer Governance, Risk, and Compliance (GRC) software that keep business processes compliant with changing local, state, federal and international regulations while remaining easy to execute with defined inputs and formatted outputs to meet business goals and allowing only authorized amounts of risk (financial or reputational) (OCEG, 2016).

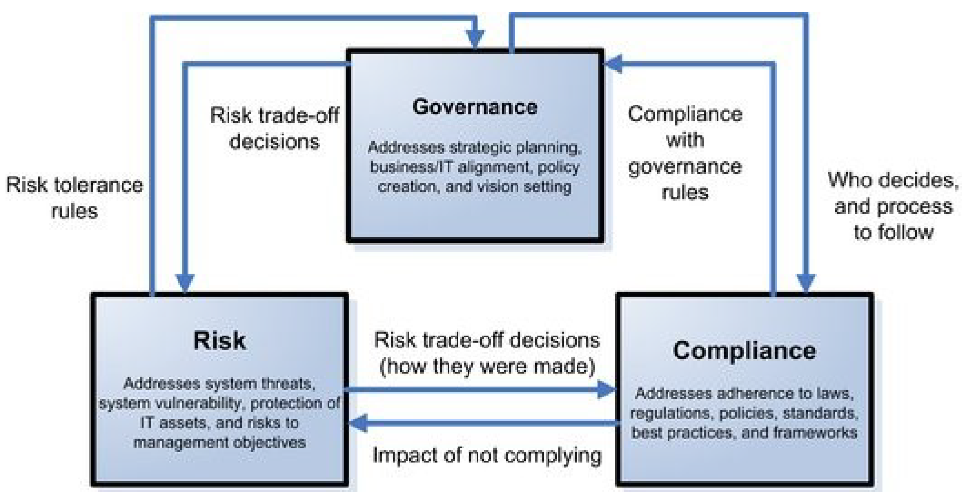


Figure 6. Governance, Risk, and Compliance (GRC) Relationships

Note: Adapted from Microsoft (2008).

Recent research suggests designing decision support systems to treat a decision as the end of a process, and reverse engineering the process from it (Carrucci, 2020). In other words, start by identifying the decisions to be made, who will make them, connect the governance groups, and build in quality control. This came to light in the course of four independent research projects. Each project demonstrated a principle that is essential to building effective decision support systems.

Decision Science (DS)

The theoretical foundations of decision making include classical, judgement, organizational, and naturalistic methods. Organizational Decision Making (ODM) is focused on decision making as an element of organizational behavior, specifically decision making behaviors in individuals when acting as a member of an organization (Hester & MAcG, 2017). DS has been defined as "(t)he application of the scientific method by intra-disciplinary teams to problems involving the control of organized (man-machine) systems so as to provide solutions which best serve the purpose of the organizations as a whole." (Ackoff, Sasieni, 1968). "The decision sciences … [depends on] strong ties to the professional schools (especially business, public policy, public health, medicine), to the engineering school, to the departments of economics, psychology, government, mathematics, statistics, philosophy, and especially to the school of education." (Raiffa, p.68) This is an acquisition programs concern, where individuals have the authority to make decisions that affect the organization (Hester & MacG, 2017).

Decision making happens at different levels across an organization, specifically executive, management and operational. (Simon, 2013). Although classical decision theory is rigorous and strives to be the most accurate, having all of the information, being able to assign occurrence probabilities, and ultimately define and evaluate ultimate utility, is nearly unobtainable. Organizations can be defined the decisions and decision processes that people make. For an organization to effective and efficient, the decisions that are made at the executive level need to be communicated in an understandable manner through the management level, enabling the operational personnel to meet the objectives and goals.

More information can be helpful if it brings deeper understanding to the options' attributes, however, more information about additional alternatives may increase uncertainty, making tradeoffs more difficult (Bettman, et.al., 1998; Schwartz & Schwartz, 2004). When looking to collect and process information, understanding how the decision-maker(s) process information is important. Many strategies are available and used when making a decision, singularly, and/or in combination. Applying one strategy in the early stages of problem solving to narrow the field focuses the information needed to process before switching to another for the final choice. Individuals make their choice based on the total amount of information processed, selectively processing information by attribute, amount of information of an attribute, etc. An individual's selectivity is based heavily on the information's salience to the chooser, and the decision-maker's pattern of gathering and evaluating information, i.e. breadth vs. depth across options and attributes, and order in which the information is consumed influences the final decision based on their decision-making strategy (Bettman, et.al., 1998).

Within a program office, quantifying those values which are to be applied to the execution of the program will enable clear guidance and consistency in decision and choice-making. The use of utility theory as related to multi-variate analysis within decision theory expresses the decision-maker's preferences to performance measures of chosen, key attributes, and the range in which trade-offs are acceptable. This allows the program office to make comparison across the different attributes in a holistic manner. Leading the decision-maker body (singular or group) through this process provides the human to model translation on the front side, and offers the tailored view of the model's results in a way that is understandable and tractable through consistency of value statement. (Garrett, 2011)

Method

Four case-studies are presented in this paper, each reflecting an aspect of a separate DoD acquisition activity. Each case study is a review of an independent research project. The paper will briefly cover the background, purpose, method and conclusions for each. The background describes the context and motivation for the project. The purpose of developing/implementation will be explained. The method will provide a description of the design and implementation of the project and how it incorporated best practices. Finally, the conclusions from each development/implementation case will be stated.

The Source Selection process is considered first, where the associated case study demonstrates the utility of modeling-to-understand in the context of policy and process, and highlights the merits of a product-centric approach. The management of Test & Evaluation through digitalization of test plans is considered next, with a focus on linkages and interdependencies that introduce complexity and program risk. The assembly of a Decision Support System through federation of models (e.g., system, requirements, T&E activities and projected cost) is reflected in the third case study. The fourth and final case study explores the transformation of the mandated Systems Engineering Plan (SEP) into a model that establishes traceability and connectivity from decisions back through process to requisite knowledge products and pedigreed, relevant data.

Findings

Modeling a Business Process like a Mission Computer

Background. One of the critical functions of each systems command (SYSCOM) is to procure goods and services. This is largely accomplished by contracting for those goods and services, and those contracts are largely competitive. Source selection is the process by which a SYSCOM awards competitive contracts. At one such SYSCOM, a single functional office is chartered to supervise the source selection process for every procurement within the SYSCOM above a nominal value threshold. Over time that process had grown unpredictably long and expensive, without clear explanation.

Purpose. The SYSCOM asked JHU/APL system engineers to help improve the source selection process, so the engineers approached it like designing a mission computer.

Method. The core concept was that every task in the business process is governed by inputs, outputs, constraints, and protocols. The figure below shows the relationships.

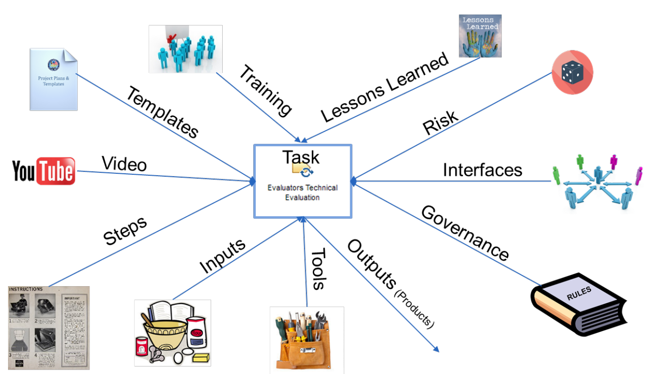


Figure 7. Task Analysis

Initially the process was modeled in Vitech CORE, then IBM Rational Method Composer, with some experiments in Bizagi Modeler. As the sponsor saw promise in the application, the project grew to include a graphic user interface that could be reproduced and tailored for subsequent competitions at a variety of scales. This required integration of several applications, and the project migrated to an IBM Rational Team Concert environment. The project used a variety of modeling languages, including one proprietary IBM language. For process modeling, the team switched from the familiar SysML to the more appropriate Business Process Model Notation (BPMN). When it was ready, a pilot source selection was conducted by government staff using the prototype system for a small competition. The competition was completed on schedule, within the planned staffing resources.

Over the course of these iterative evaluations, the JHU/APL team came to the realization that there were core elements of the source selection process that were ripe for digitalization. Key to this was the clear definition and documentation of the final products required at the conclusion of each source selection. These were all documents, and could all be traced to either Federal, DoD, service, or SYSCOM policies. With this traceability, it was possible to decompose the products into processes that produced them. This transformed the team's thinking of the project from one of data management into one of data generation.

Thinking of the source selection process in a way in which a production engineer might think of a factory, the team was able to approach the problem from a viewpoint that was substantially different than that of the sponsor. Using this viewpoint, the team evaluated each step of the process for the value it added to the source selection, with the ultimate requirement being to satisfy the output requirements defined by the external policies. Conveniently, the vast majority of the work of a source selection is documentary and this simplified the analysis of the core data of the process to allow the team to think about value in terms of creating, editing, and approving documents.

This methodology ultimately allowed the JHU/APL team to identify the actual value flows within the convoluted source selection process being used by the SYSCOM. The flow was redesigned to clearly show the steps that added value (as defined by the requirements) and suggested the elimination of unnecessary steps. As an additional benefit of this approach the team was able to recognize that the fundamental building block of source selection process value was a paragraph of text. It was possible to watch value flow through the process by tracing what happened to a paragraph of text as it was initially written by an evaluator, edited and approved by a team leader, consolidated with other paragraphs by source selection officials, and ultimately summarized for various required documents. This realization allowed the JHU/APL team to more accurately model the overall process and, more importantly, suggested a pathway to process efficiency through digitalization.

While much of the efficiency gained in this project was due to the value analysis and process streamlining, there was also a substantial interest in moving to a digital framework in which future source selections could be conducted. At the outset of the project, this was a complicated endeavor; however, it was greatly simplified when the team identified the core data element. More importantly, there was no interest from the sponsor in using digital technology to dissect the paragraphs produced by humans via data analytics, machine learning or any other means. This meant that the digitalization of the process was analogous to a logistics system. Humans would ultimately add all the value in the source selection, and the digital system could locate, move, and collate data and notify the humans when there was data upon which they could add value. There are many systems available in the marketplace today that offer the digital functions required to perform all of these tasks, and this provided a variety of excellent options to satisfy the requirements of the project without the development of unique source selection management software.

Conclusions. This case study exposed that the source selection process was largely governed by tribal knowledge, disconnected from Federal and Defense Acquisition Regulations (FAR/DFAR), and many data products were unicorns or orphans (inputs from no apparent source, or outputs unused by subsequent steps). The process model stabilized after many iterations, and instances were created for major defense acquisitions and small service competitions. Of key consequence in this project was the identification of the core data element, and the subsequent redesign of the process that resulted. In addition, it would not have been possible to apply digital toolsets for data control effectively without this understanding.

The sponsor was so pleased with the results of the pilot competition they ordered a final version for delivery that they could replicate and repeatedly use. It was at that point when JHU/APL system engineers discovered financial tech industry GRC software, and after quick discussions recommended the government use their funds instead to purchase licenses of GRC software from a major vendor. In an ironic twist, while they had sufficient funds, the source selection office could not award a contract for the software they needed because they did not have a Pentagon-validated requirement for it.

Digital Transformation of Documents Into Models

Background. A major program office (Acquisition Category (ACAT) 1) test team was struggling with a Master Objective Matrix (MOM) of over 1,000 requirements that were verifiable by many methods at numerous sites by a variety of staff. The complexity of test programs such as this example, are further complicated by the sheer volume and specialization of the physical test resources required (specific aircraft, M&S systems, test support equipment and facilities, etc), as well as test personnel with unique skills and qualifications (such as developmental test pilots, test conductors, data analysts, etc). Further, the test organization in this case was also required to track massive amounts of data associated with each of several hundred tests conducted, and the deficiencies discovered in the tests. The test team ultimately created a spreadsheet of several hundred thousand possible dependencies to track this manually, which proved difficult. It was observed that an object-oriented database might solve the problem.

Purpose. The program office wanted the MOM converted into a SysML database. Also, the program office requested some form of visualization to verify the information that was more user-friendly and less prone to error than a massive spreadsheet. The test organization wanted a means to manage test processes, execution, resourcing, and reporting.

Method. The SYSCOM had recently selected Cameo NoMagic as their DoDAF standard tool, so it was readily available. Using it first required converting from document-based to model-based requirements, modeling the verification methods, sites, equipment, and staffing, then relating them appropriately. SysML is provisioned for some of this so it offered a good starting point. Quickly completed, the sponsor asked if a developmental test plan could be digitalized, which required customized profile diagrams and stereotypes for data never contemplated by SysML. Test plans have considerable text, and several figures, but the central information is in tables: identifying objects, with properties, related to other objects.

The next challenge was linking developmental test (DT) and operational test (OT). The first step was digitalizing OT plans. DT and OT test plans both trace up to requirements (e.g. Capabilities Development Document), which provided a linkage. This logically led to further documents and processes being digitalized, including the Mission Based Test Design

(MBTD), Initial Evaluation Framework (IEF), and Test & Evaluation Master Plan (TEMP). This integrates contractor test (CT), DT, and OT at mission level. A change to one propagates automatically through all. The object-oriented database tool offers several methods of rapidly publishing global updates that do not require special software or skills, such as document reports and html.

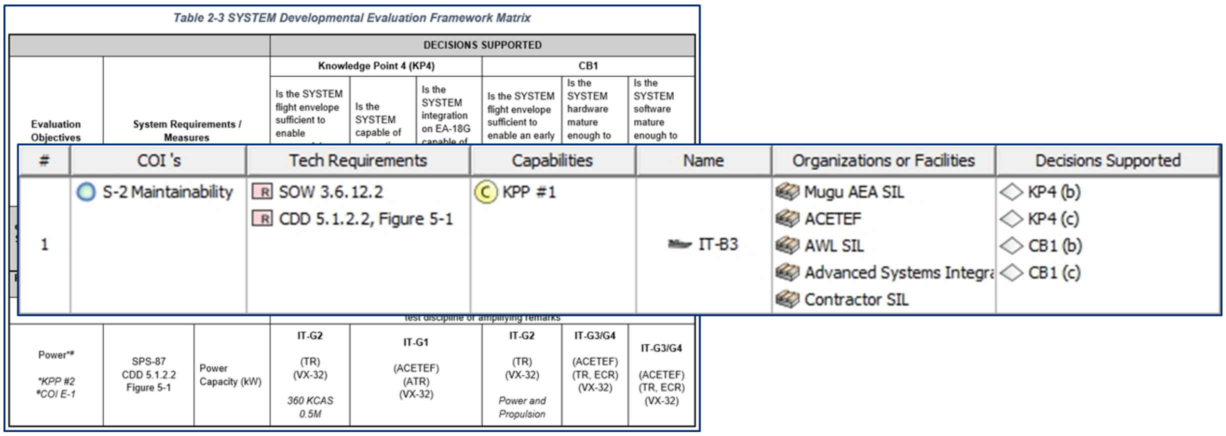


Figure 8. Digitalization of Documents

Conclusions. Not only was the program office satisfied with this method, their operational test force counterparts (DOT&E) became very interested in using a shared database, derived from their own manuals, to identify early OT opportunities, and assess the implications of DT results. The original method subsequently evolved into the exemplar for Capabilities Based T&E (CBT&E) in the service. Digitalization transforms documents into a database (without changing processes), optimizes resources, flows data, and reuses data. It further allows the modeling of processes to facilitate more efficient and error-proof planning and execution of programs. Direct benefits have been simplification of complex requirements, asset management, early identification of critical missing tasks, reconciling engineering and test plans, and relating every DT event to OT metrics. In sum, the benefits are coordination, efficiency and accountability.

Cross Functional Data Model

Background. A major program office needed a DoDAF system model for a mission planning system.

Purpose. To aid the government plan the second program increment, JHU/APL designed a decision support system (DSS).

Method. The DSS federated a T&E Model with a System Model, both connected to a Requirements Model, and invented a companion Cost Model and Risk Model to integrate with them. This DSS would also have program views to visualize integrated analytical products for alternative comparison and remain a queryable program database for subsequent excursions. The DSS was designed such that each of the five component models could be maintained independently within the DSS by the respective functional leads in a shared cloud environment, without breaking the established relationships. This allowed functional leads to retain ownership of their data repository while making it transparent to the other users and firmly related to the entire program. This connects data across the functions within a program office.

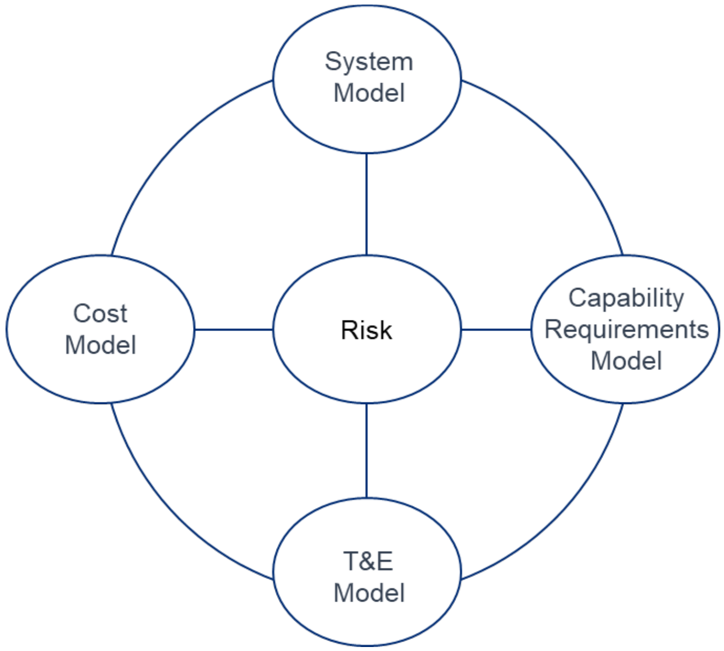


Figure 9. Cross Functional Data

Conclusions. This functioning DSS was a new conceptual framework, and the exemplar was well received. Since JHU/APL delivered it, the government hired three other research centers to replicate and extend it.

Connecting Decisions to Data to Process

Background. A service research lab program requested JHU/APL to draft a digitalized systems engineering plan (SEP), that document versions of the digitalized SEP (DSEP) be producible, and the SEP be widely available. Secondarily, the research lab wanted the SEP connected to the Office of Secretary of Defense (OSD) policy that required its content. In hindsight, the previous cross functional model provided for the majority of the data that a SEP covered, presenting an opportunity to connect the SEP directly to the data it managed.

Purpose. The purpose of this task was to digitalize a SEP, and connect that model to the data models it controlled as well as the process governing the SEP. This was housed in the related data repository (DSS).

Method. The DSS format contained virtually all the information resident in a Systems Engineering Plan (SEP): program technical requirements, engineering resources, technical activities and products. This directly connected the data (DSS) to the managing process (DSEP) and the approval authority decision, as described in a SEP example.

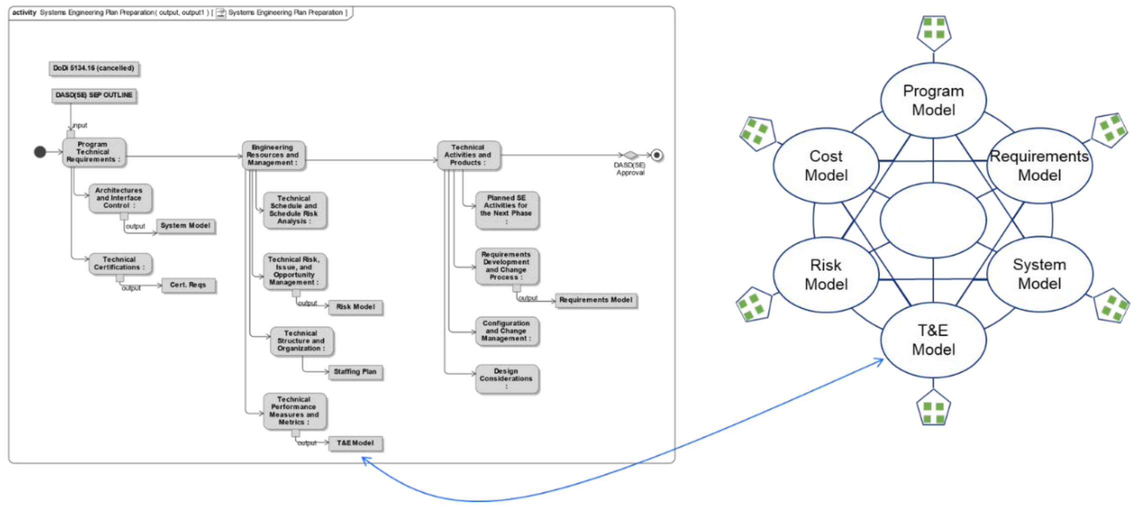


Figure 10. Connecting Decisions to Data to Process

Conclusions. A change in regulations immediately drives a change in process, which in turn causes change in the data. This is similar to commercial GRC. This connects data back to process and forward to decision.

Results

The principles learned from the cumulative case studies appear complementary:

1. Workable business processes models
2. Digitalization of documents into models
3. Cross functional data models
4. Connect decision to data to process

In combination, they can digitally reflect the totality of a real acquisition program. The data can change in real-time if so designed (e.g. T&E updates cascade to Integrated Master Schedule (IMS)). The cross-functional data repository connects critical program office products (e.g. Engineering to Risk). Data (and its changes) persist over the life of the program. These are the main attributes of a digital twin. Building these principles into a useable product requires three distinct steps.

The program needs a strategy spanning all program functions (engineering, test, logistics, cost, risk, etc.), defining what and how to digitalize processes that create data required for decisions. Using that framework, develop a program data model to support those decisions. Using that data model, populate a decision support system for execution over the lifecycle of the program, tied to the acquisition strategy and goals.

Digital Engineering Strategy

A conceptual framework for digital engineering was determined by systematic review of recent research, the objective being to select what and how to digitalize DoD acquisition processes, data, and decisions (Waugh, 2022). This study had five major findings: digitalization projects begin with strategic choices; digitalization is done within an ecosystem that constrains the technical options; digitalization requires a method of execution that assesses opportunity and limits risk; digitalization results in new processes using new data models that enable better decisions; feedback on that new business model will come internally from users and externally from customers.

External forces fall into ecosystem constraints and technology opportunities. The ecosystem includes people, resources, organization and the supply chain, which the entity may or may not control (Cong et al, 2021, Correani et al, 2020, Dethine et al, 2020, Garay-Rondero et al, 2020, Gastaldi et al, 2018, and Linde et al, 2021). Technical forces include the computing environment platforms, technologies, and data (Correani et al, 2020, Ghadge et al, 2020, Ivančić et al, 2019). Technologies do not equally benefit all desired outcomes, but several are key to Industry 4.0 application (Tortorella et al, 2021). The strategy will define what external forces are strengths, weaknesses, opportunities or threats (i.e. risk) (Linde et al, 2021).

Strategic choices determine the desired degree of change (Blackburn, 2017), the impact target (Tortorella et al, 2021) degree of circular economy (Kristoffersen et al, 2020), the design principles (Nosalska et al, 2019), and delimit the eligible processes (Donnelly, 2019). Continuous communications with the affected users (Rieken et al, 2020), customers (Ghage et al, 2020), and suppliers (Garay-Rondero et al, 2020) is necessary, seeking failure early and rewarding good outcomes. The strategy must consider necessary organizational changes. It will identify means to monitor feedback to propose future changes to the business model.

Data Model

The eligible processes are modeled as-is, and then to-be (Antonucci, et al, 2021). Compliance constraints (e.g. DoDI 5000.85) are modeled to discover information mandated at given decision points (e.g. milestones). Those decisions are decomposed into activity models that allocate actions to roles, showing data required and produced at each step. This Data Model documents likely decision points, the data required for those decisions, and the processes required to produce the data.

The data requirements are recoded as normalized terms (i.e. same name for same thing in DoDI, Service, SYSCOM instructions), themed into small groups of data (e.g. quality, security, and functional requirements), then synthesized into large groups (e.g. Requirements). The data items are characterized as objects, properties of objects, or relationships to other objects.

Decision Support System (DSS)

Populating the data model creates the DSS, the single repository for connected cross-functional program data, mapped to internal and external processes that manage or require it. It will visualize the data in simple decision aids, readily accessible to the program enterprise. The functional data will be segmented to allow internal fluidity while retaining external relevance: functional leads may redesign or repopulate their model (and not others) without breaking links to other models.

The DSS is the data platform to ingest, transform, and harmonize data to serve prioritized program manager needs, democratize the data environment using data services and business intelligence toolsets, with scalable and sustainable data /analytics products to accelerate time to value.

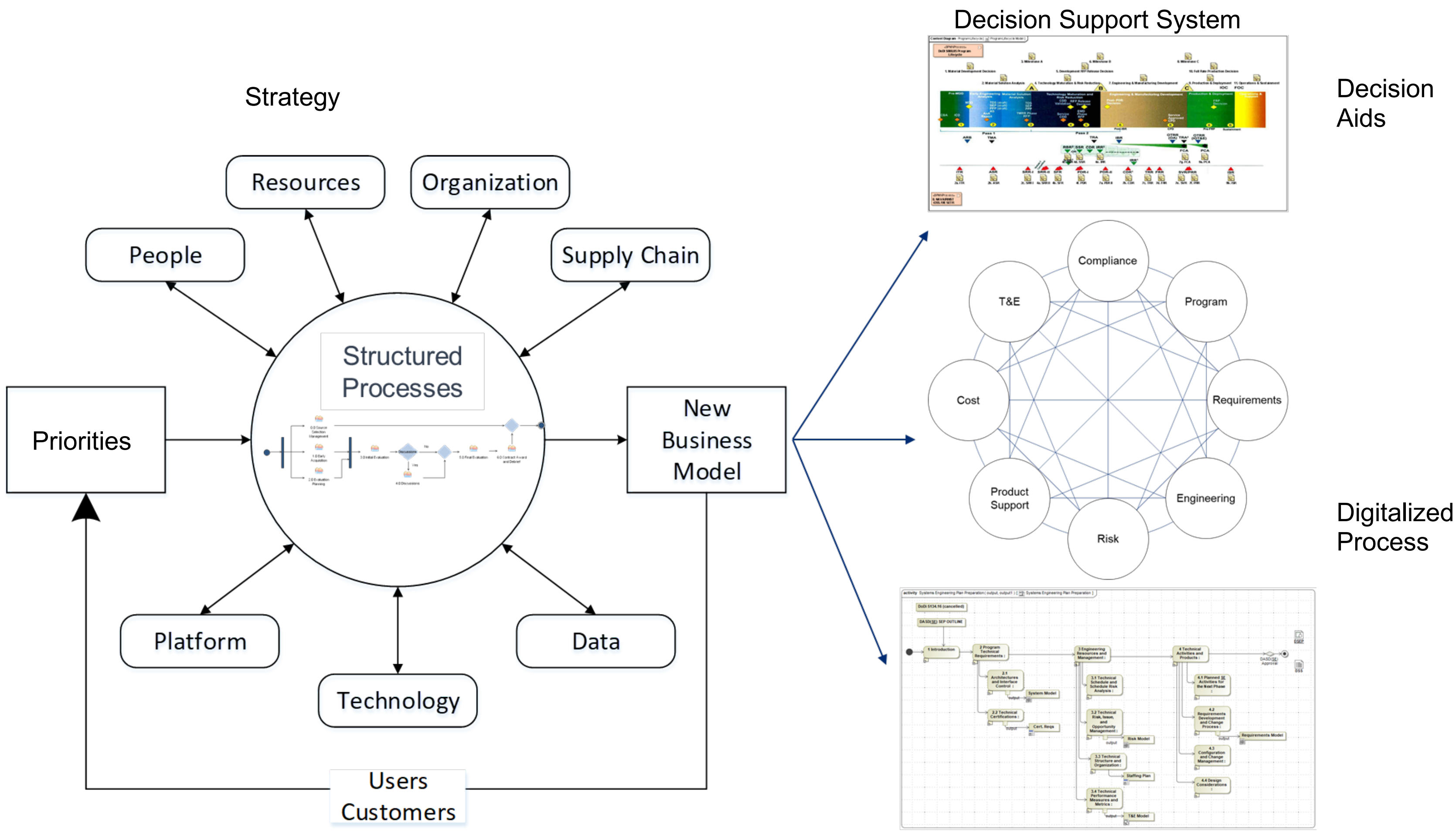


Figure 11. Decision Support System Derived from Strategy

Conclusion

The proper goal of digitalization is to make better decisions using quality data from lean processes. It is easy to see digitalization merely as a problem of new applications, or the introduction of Artificial Intelligence (AI) into processes, or new data models depending upon personal perspective or experience. However, none of those solutions alone will have sustained or meaningful impact. New models may be better, but may not result in better decisions if disconnected from a unified data model. A web services firm may be able to house petabytes of data for decades, but if it is not designed for people to use in conjunction with their digital supply chain, its customer value is limited. Using AI as support infrastructure to communicate with customers is common, but without integration with the business process, it may not deliver value.

Entities have known they should digitalize, but did not know what or how to implement it. A program digital twin supports decision engineering: it identifies decision points, data required for those decisions, and processes necessary to produce the data.

Acknowledgements

Distribution Statement A: Approved for public release. Distribution is unlimited.

© 2023 The Johns Hopkins University Applied Physics Laboratory LLC. All Rights Reserved

References

Ackoff, R. L., & Sasieni, M. W. (1968). *Fundamentals of operations research*.

Antonucci YL, Fortune A and Kirchmer M. (2021). An examination of associations between business process management capabilities and the benefits of digitalization: all capabilities are not equal. *Bus Process Manag J* 2021; 27: 124–144.

Bettman, J. R., Luce, M. F., & Payne, J. W. (1998). Constructive consumer choice processes. *Journal of consumer research, 25*(3), 187-217.

Blackburn M, Alexander J, Legan JD. (2017). Big data and the future of R&D management: the rise of big data and big data analytics will have significant implications for R&D and innovation management in the next decade. *Res-Technol Manag* 2017; 60: 43–51.

Bolten, J. G., Arena, M. V., Leonard, R. S., Sollinger, J. M., Younossi, O. (2008). *Sources of Weapon System Cost Growth: Analysis of 35 Major Defense Acquisition Programs*. United States: Rand Corporation.

Carucci, R. (2020). How Systems Support (or Undermine) Good Decision-Making. *Harvard Business Review Digital Articles*, 2-5.

Cong, L.W., Li, B. and Zhang, Q.T. (2021). Internet of things: business economics and applications. *Rev Bus* 2021; 41: 15–29.

Coolahan, J. (2003). Johns Hopkins University APL Technical Digest, 24/1

Correani A, De Massis A, Frattini F. (2020). Implementing a digital strategy: learning from the experience of three digital transformation projects. *Calif Manage Rev* 2020; 62: 37–56.

Defense Acquisition University. (n.d.). Digital engineering, https://www.dau.edu/glossary/Pages/GlossaryContent.aspx?itemid=27345#:~:text=An%20integrated%20digital%20approach%20that,activities%20from%20concept%20through%20disposal (n.d., accessed 20 May 2021).

Department of Defense. (2003). DoD Architecture Framework Version 1.0. August 2003.

Department of Defense. (2018). Digital Engineering. https://ac.cto.mil/digital_engineering (accessed 20 April 2021).

Deputy Assistant Secretary of the Navy, RDT&E. (June, 2020). Navy and Marine Corps Digital Systems Engineering Transformation Strategy.

Dethine B, Enjolras M and Monticolo D. (2020). Digitalization and SMEs' export management: impacts on resources and capabilities. *Technol Innov Manag Rev* 2020; 10: 18–34.

Donnelly, R. (2019). Aligning knowledge sharing interventions with the promotion of firm success: the need for SHRM to balance tensions and challenges. *J Bus Res* 2019; 94: 344–352.

Dumas M, La Rosa M, Mendling J, (2013). *Fundamentals of business process management*. Germany. Springer-Verlag Berlin Heidelberg, 2013.
Fast, W. (2010). Improving Defense Acquisition Decision-Making. *Proceedings of the Seventh Annual Acquisition Research Symposium* (30 April, 2010).
Gansler, J., Lucyshyn, W., Ouimette, R., Woollacott, B. (2015). Reforming Acquisition: This Time Must Be Different. Retrieved from https://spp.umd.edu/sites/default/files/2020-05/UMD%2014-004_LMCO_Reforming%20Acquisition_0.pdf
Garay-Rondero CL, Martinez-Flores JL, Smith NR. (2020). Digital supply chain model in Industry 4.0. *J Manuf Technol Manag* 2020; 31: 887–933.
Garrett, C., Levack, D., & Rhodes, R. (2011). Using Technical Performance Measures. In *47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit* (p. 5500).
Gastaldi L, Appio FP, Corso M. (2018). Managing the exploration-exploitation paradox in healthcare : three complementary paths to leverage on the digital transformation. *Bus Process Manag J* 2018; 24: 1200–1234.
Ghadge A, Er Kara M, Moradlou H. (2020). The impact of Industry 4.0 implementation on supply chains. *J Manuf Technol Manag* 2020; 31: 669–686.
GRC Overview. (2008). Microsoft. Retrieved from: https://learn.microsoft.com/en-us/previous-versions/tn-archive/cc531020(v=technet.10)
Grieves, M. (2002). *PLM Initiatives* [Powerpoint Slides]. Paper presented at the Product Lifecycle Management Special Meeting, University of Michigan Lurie Engineering Center.
Gupta, N. & Grover, S. (2013). International Journal of IT, Engineering and Applied Sciences Research (IJIEASR) ISSN: 2319-4413 Volume 2, No. 4.
Hester, P. T., & MacG, K. (2017). *Systemic decision making*. Springer International Publishing AG.
INCOSE. (2007). Systems Engineering Vision 2020. *INCOSE-TP-2004-004-02* September, 2007.
Ivančić L, Vukšić VB and Spremić M. (2019). Mastering the digital transformation process: business practices and lessons learned. *Technol Innov Manag Rev* 2019; 9: 36–50.
Kristoffersen E, Blomsma F, Mikalef P. (2020). The smart circular economy: a digital-enabled circular strategies framework for manufacturing companies. *J Bus Res* 2020; 120: 241–261.
Linde L, Sjödin D, Parida V. (2021). Evaluation of digital business model opportunities: a framework for avoiding digitalization traps. *Res-Technol Manag* 2021; 64: 43–53.
Maria, A. (1997). Introduction to Modeling and Simulation. Proceedings of the 1997 Winter Simulation Conference. ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson
Nosalska K, Piątek ZM, Mazurek G. (2019). Industry 4.0: coherent definition framework with technological and organizational interdependencies. *J Manuf Technol Manag* 2019; 31: 837–862.
OCEG. (2016). A Maturity Model for Integrated GRC. Retrieved from https://go.oceg.org/maturity-model-integrated-grc
Office of the Assistant Secretary of Defense Networks and Information Integration (OASD/NII). (2010). Reference Architecture Description.
Raiffa, H. (2007). "Decision Analysis: A Personal Account of How It Got Started and Evolved." Advances in Decision Analysis: From Foundations to Applications. Ed.s Ward, Miles, and von Winterfeld.
Rieken F, Boehm T, Heinzen M. (2020). Corporate makerspaces as innovation driver in companies: a literature review-based framework. *J Manuf Technol Manag* 2020; 31: 91–123.
Schwartz, B., & Schwartz, B. (2004, January). *The paradox of choice: Why more is less*. New York: Ecco.
SEBoK. (n.d.). Systems Engineering and Industrial Engineering. Retrieved from https://www.sebokwiki.org/wiki/Systems_Engineering_and_Industrial_Engineering
Senate Hearing 108-840. (2003). Retrieved from https://www.govinfo.gov/content/pkg/CHRG-108shrg99603/html/CHRG-108shrg99603.htm
Simon, H. A. (2013). *Administrative behavior*. Simon and Schuster.
SYSCOMINST 4355.19D, SYSTEMS ENGINEERING TECHNICAL REVIEW PROCESS (SETR) HANDBOOK.
Tortorella, G., Sawhney, R., Jurburg, D. (2021). Towards the proposition of a lean automation framework: integrating Industry 4.0 into lean production. *J Manuf Technol Manag* 2021; 32: 593–620.
Von Bertalanffy, L. (1972). The History and Status of General Systems Theory. *Academy of Management Journal, 15*(4), 407–426. https://www.jstor.org/stable/255139
Waugh, S. (2022). Determining a Digital Engineering Framework: A Systematic Review of What and How to Digitalize. *Naval Engineers Journal*, vol. 134(3), 2022.

Exploring Program Archetypes to Simplify Digital Transformation

Nicole Hutchison—is a Senior Research Scientist at the Systems Engineering Research Center (SERC). She led the development of competency frameworks around systems, mission, and digital engineering. She is the principal investigator for a digital engineering simulation training environment intended to provide hands-on simulated real-world experiences. Prior to the SERC, Hutchison worked for ANSER and supported projects in public health and biodefense, emergency management and policy, forensics, and large-scale exercise delivery and training for the Department of Defense, Homeland Security, Health and Human Services, and Justice. She holds a PhD in systems engineering and is an INCOSE Certified Systems Engineering Professional. [nicole.htuchison@stevens.edu]

David Long—is the Chief Engineer for Digital Engineering at the SERC, working to coordinate and advance their digital portfolio. He has spent more than 30 years helping organizations increase their systems engineering proficiency while simultaneously working to advance the state of the art. Long was the founder and president of Vitech where he led the development of innovative, industry-leading methods and software to engineer next-generation systems. He co-authored “A Primer for Model-Based Systems Engineering” and frequently delivers keynotes, tutorials, and workshops around the world. An INCOSE Fellow and Expert Systems Engineering Professional, Long was the 2014/2015 president of INCOSE. [dlong3@stevens.edu]

Paul Wach—is a member of the Intelligent Systems Division, Virginia Tech National Security Institute. His research interest is the intersection of theoretical foundations of systems engineering, digital transformation, and artificial intelligence. Wach is also serves as a SME on digital transformation for The Aerospace Corporation. Previously, he served in lead engineering and management roles at the Department of Energy. He also worked at two National Laboratories and in the medical industry. He received a BS in Biomedical Engineering from Georgia Tech, an MS in Mechanical Engineering from the University of South Carolina, and PhD in Systems Engineering at Virginia Tech. [pwach86@vt.edu]

Abstract

In the U.S. Department of Defense (DoD), evidence across the Services and industry has affirmed that digital transformation is critical for successful acquisition in an environment of increasing global challenges, dynamic threats, rapidly evolving technologies, and increasing life expectancy of systems currently in operation (Zimmerman et al., 2019). The DoD must continue to practice systems engineering efficiently and effectively to provide the best advantage for successful acquisitions and sustainment. Digital transformation will require the update of both acquisition and systems engineering practices to take full advantage of the digital power of computation, visualization, and communication throughout the life cycle.

There are a wide variety of variables that shape the profile of a program: What type of acquisition is being done? What is the risk profile of the program? What is the balance of the acquisition in terms of fidelity versus abstraction of data? The research described in this paper is intended to build a set of program archetypes that will help to template the considerations for programs that need to utilize digital acquisition approaches, whether they be existing programs transitioning to digital or new programs.

Research Issue Statement

Program offices across the Department are faced with the challenge of digital transformation. For some, this is the challenge of starting a program in a digital way. For many others, it is a challenge of taking the approaches and processes currently being used and updating them and their staff to take advantage of digital approaches. Though each of the Services is working to create reference models and best practices, this digital transformation process is often hindered by the workforce's understanding of how to tailor approaches to fit the program's needs.

This research theorizes that though there are many characteristics of a program—size, scope, acquisition pathway, novelty, risk, etc.—there is likely a smaller number of archetypes or commonly-occurring patterns. The researchers will develop a framework to characterize programs then gather data from existing programs in order to refine that framework and identify the most frequent archetypes. With this information, the team will work to document the flavors of digital engineering that are most commonly required based on archetype, including common templates, considerations for the environment, etc.

Methodology

This section highlights the frameworks the researchers are using to characterize programs. The team is working on gathering data from existing and recently-completed programs across the Department and classifying each program with respect to these variables. The team hypothesizes that though there are hundreds of potential program archetypes across all of the combinations of these variables, the data for actual programs will likely cluster around a few common profiles or archetypes. The team's goal is to first identify and classify these archetypes. Then, following up with additional data and, where possible, data collection from these programs, identify what DE approaches are working for each profile as well as common challenges. The team's objective is to develop a framework that links program archetypes with the common DE approaches, methods, tools, templates, etc. that are likely to be best suited to their needs. This is intended to get to the "70%–80% solution" space, giving programs a head start on developing their DE approaches while still leaving room for tailoring.

Program Characteristics

Within the scope of DoD acquisition, there are several different ways that programs can be characterized:

- Type of acquisition
- Complexity
- Novelty
- Technology
- Pace
- Scope
- Greenfield vs. brownfield
- Life cycle approach

For each of these, frameworks already exist for classification, and the team plans to utilize these existing frameworks in the characterization of programs and development of archetypes.

Type of Acquisition: Adaptive Acquisition Framework

The Adaptive Acquisition Framework (AAF) was defined in DoD 5000.02 (2022) and classifies programs based on the type of acquisition to be performed (all definitions from DAU [2023]):

- **Urgent capability acquisition**—is intended to "field capabilities to fulfill urgent existing and/or emerging operational needs or quick reactions in less than 2 years. Though the pathway did not exist at the time, the mine-resistant ambush protected (MRAP) vehicle developed during operations Iraqi Freedom and Enduring Freedom is an example of the type of capability that would fall into this category."

- **Middle tier of acquisition** (also called mid-tier acquisition)—is focused around rapid prototyping and is "intended to rapidly develop fieldable prototypes within an acquisition program to demonstrate new capabilities and/or rapidly field production quantities of systems with proven technologies that require minimal development." In general, these are programs that are intended to be fielded in less than five years.
- **Major capability acquisition** (also called MCA)—is intended to "acquire and modernize military unique programs that provide enduring capability." The F-35, Littoral Combat Ship, and the Griffin II light tank are examples of the types of systems that would be acquired through the MCA pathway.
- **Software acquisition**—is intended to "facilitate rapid and iterative delivery of software capability to the user" for software-intensive systems. In general, this pathway uses incremental delivery/continuous improvement processes for software systems. Within a larger program, the software acquisition pathway can be used to rapidly develop and deliver the software components of a system.
- **Defense business systems**—is intended to "acquire information systems that support DoD business operations." This applies to all defense business capabilities and their supporting business systems, such as: financial and financial data feeders; contracting; logistics; planning and budgeting; installation management; human resources management; and training and readiness systems. This pathway may also be used to acquire non-developmental, software-intensive programs that are not business systems.
- **Acquisition of services**—is intended to support the "acquisition of contracted services with a total estimated value at or above the simplified acquisition threshold (SAT)." The SAT changes year to year. In Fiscal Year (FY) 2023, that amount is $250,000, meaning that for acquisitions at or under this amount, the processes required are greatly simplified. In FY 2018, 49.0% of the Department's contract spend, or $123.9 billion, was spent on acquiring services.

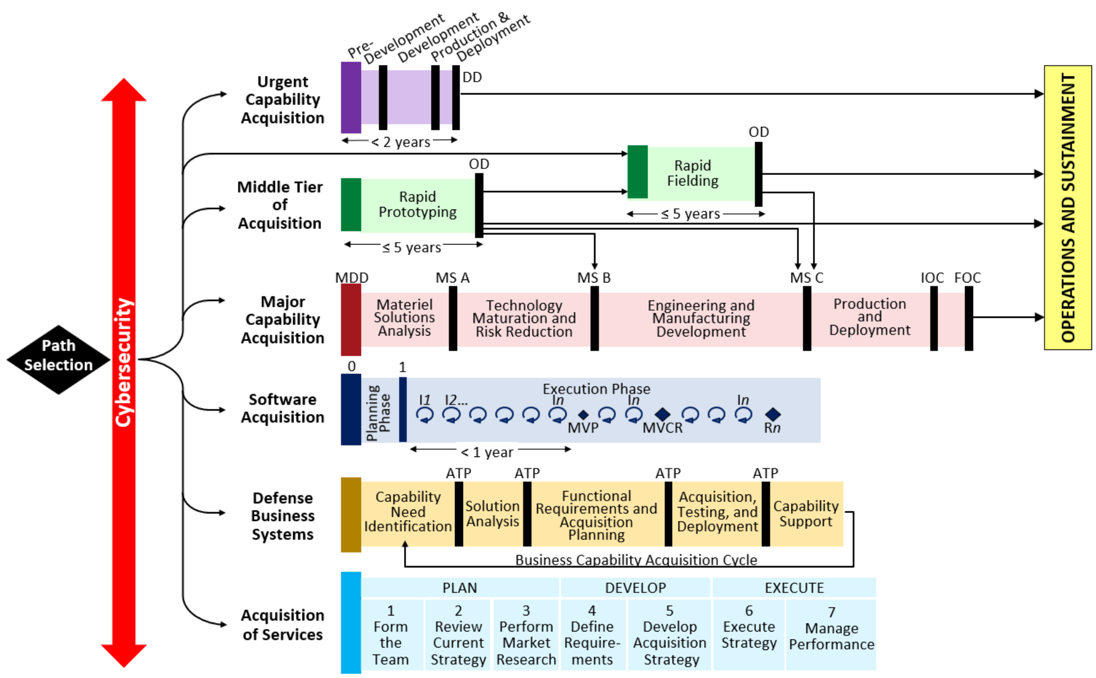


Figure 1. Adaptive Acquisition Framework (AAF)
(DAU, 2023, public domain)

Because the framework being developed is intended to be useful to programs across the DoD portfolio, the acquisition pathway is a critical characteristic of the program. It also gives insight into the type and scope of the system being developed and the level of complexity expected.

Shenhar and Dvir's Diamond Project Profile

In their 2007 book *Reinventing Project Management*, Shenhar and Dvir created a framework for classifying programs based on four characteristics: complexity, novelty, pace, and technology, as illustrated in Figure 2.

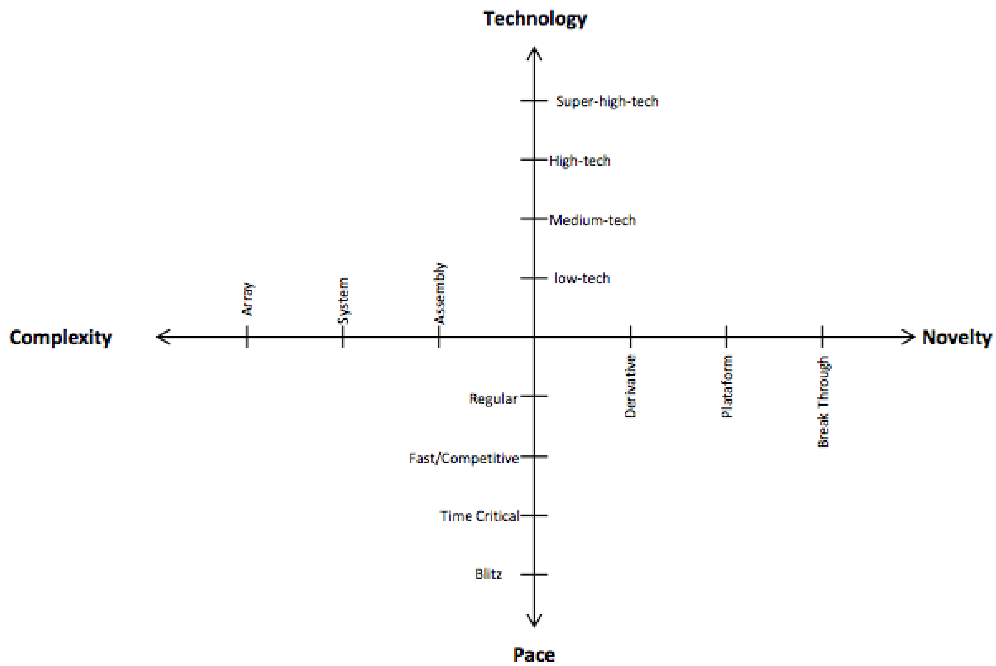


Figure 2. Shenhar and Dvir's Diamond Profile

Their classification system is relatively simple, with only three to four "bins" for each category, as outlined in Table 1 (data from Shenhar and Dvir [2007]).

Table 1. Shenhar and Dvir Classification System

Area	Level	Definition
Technology	Low-tech	Uses only existing, well-established, and mature technologies.
	Medium-tech	Mostly existing technologies; limited new technology or a new feature.
	High-tech	Uses many new, recently developed, and existing technologies.
	Super-High-Tech	Key project technologies do not exist at the time of project initiation.
Novelty	Derivative	Extending or improving existing products or services.
	Platform	Developing and producing new generations of existing product lines or new types of services to existing or new markets and customers.
	Breakthrough	Introducing a new-to-the-world product or concept, a new idea, or a new use of a product that customers have never seen before.
Pace	Regular	Time not critical to organizational success.
	Fast/Competitive	Project completion on time is important for company's competitive advantage and/or the organization's leadership position.
	Time-Critical	Meeting time goal is critical for project success; any delay means project failure.
	Blitz	Crisis projects; utmost urgency; project should be completed as soon as possible.
Complexity	Component	A fundamental element of a subsystem that never works alone.
	Assembly (or sub-system)	A collection of components and modules combined into one unit and performing a single function of a limited scale.
	System	A complex collection of units, subsystems, and assemblies performing multiple functions.
	Platform of systems	A single structure used as a base for other installed systems that are serving the platform's mission.
	Array (or system of systems)	A large, widespread collection or network of systems functioning together to achieve a common mission.

Note that with respect to "technology," it is really a measure of technological uncertainly, which can be highly coupled with risk and has implications for complexity.

With respect to "novelty," the definition aligns with commonly used greenfield, brownfield, and bluefield approaches:

- **Greenfield** approach is a clean slate approach, assuming no legacy implications.
- **Brownfield** approach is utilized when an organization (or program) has a significant history of valuable project data they wish to retain while transforming their technology systems. As many DoD programs have some legacy components, at least some aspects of most DoD programs are expected to have brownfield approaches.
- **Bluefield** approach is somewhat of a hybrid between the greenfield and brownfield, which either take the view of scrapping everything to start fresh or upgrading everything, respectively. Bluefield is a careful consideration of which existing systems should be evolved and which should be scrapped for entirely new capabilities.

With respect to "complexity," the definitions in Shenhar and Dvir refer more specifically to the scope and scale of a project. The *Systems Engineering Body of Knowledge (SEBoK)* uses similar terms: product, service, enterprise, and system of system. However, there is a more nuanced approach to complexity that is useful for building program archetypes.

Cynefin Framework

In 2007, Snowden and Boone published the Cynefin framework, which defines complexity with respect to behavior.

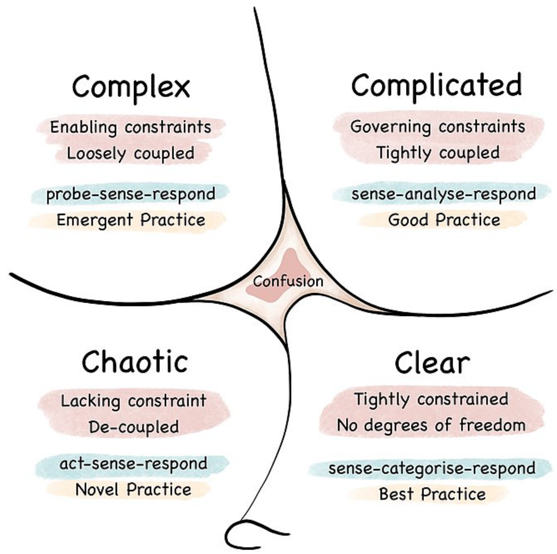


Figure 3. Snowden and Boone's Cynefin framework. (Snowden & Boone, 2007).

The framework classifies programs or systems into four bins:

- Clear (or simple or obvious) represents the "known knowns" and indicates that a system or program is functioning in a space with clear and established rules. Importantly in terms of behavior, there is clear cause and effect in this condition, with predictable outcomes (i.e., less uncertainty).
- Complicated represents the "known unknowns." Cause and effect can be discerned through data collection and analysis, but often requires expertise for correct interpretation. This is the realm of engineers where the correct answer starts with, "It depends."
- Complex represents the "unknown unknowns" or a high degree of uncertainty. Cause and effect may be identified in retrospect, though these insights are less likely to be clear causal relationships and more likely to emerge as useful patterns.
- Chaotic represents conditions where cause and effect are completely unclear. In these systems or programs, individuals must first act to try bring some order to the situation.

There is also a "center of confusion" or disorder, which generally indicates that there is not enough known to classify a program.

Clear and simple programs can often rely on established processes, even those that have a fair amount of bureaucratic overhead, because the "tried and true" approaches will eventually yield appropriate results. The more uncertain a program becomes, however, the more effective incremental approaches become.

System Scope and Type

Several of the frameworks discussed include ways of looking at systems scope. Shenhar and Dvir's complexity metric identifies a program's system of interest on a spectrum from a component to a system of systems (or a mission system in the DoD). The SEBoK highlights system types as product, service, enterprise, or system of systems. Clearly, there is a direct relationship between some system types and acquisition pathways. For example, services would be achieved through a service acquisition pathway. Many ACAT 1 programs are, in fact, developing complex systems of systems. However, the team wants to look at data across as many existing programs as possible to determine whether or not there are additional useful correlations.

Life Cycle Approach

This leads to the question of life cycle. There are clear relationships between the acquisition pathway and the level of complexity with the life cycle approach. For example, traditional waterfall methods are unlikely to be effective in a complex or chaotic environment (and many studies and examples have borne this out). A program in the software acquisition pathway will likely relay on continuous development/continuous improvement (CD/CI) approaches, for example agile or DevSecOps methodologies.

Outside of these obvious areas of alignment, however, the team will look to the data to highlight any correlations between lifecycle approaches and other factors.

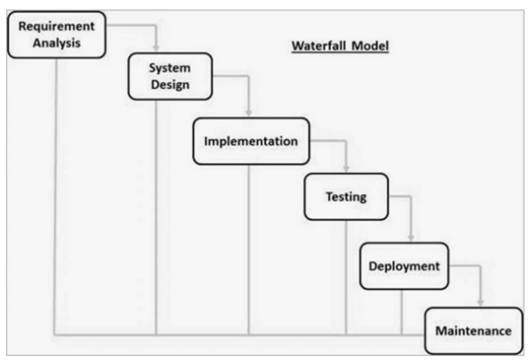


Figure 4. Generic Representation of the Waterfall Life Cycle Model

For the sake of this study, four main life cycle approaches will be considered: waterfall, Vee, incremental/spiral, and CD/CI/agile.

- Waterfall: This should be a very familiar life cycle approach to anyone in DoD acquisition. In general, it lays out the life cycle in a very linear fashion, starting with requirements through to deployment and maintenance.
- Vee: "The technical aspect of the project cycle is envisioned as a 'Vee,' starting with user needs on the upper left and ending with a user-validated system on the upper right" (Forsberg & Mooz, 1991). The Vee model is an evolution of waterfall. It incorporates the same general life cycle activities, but better embraces the relationships and feedback between the different phases.

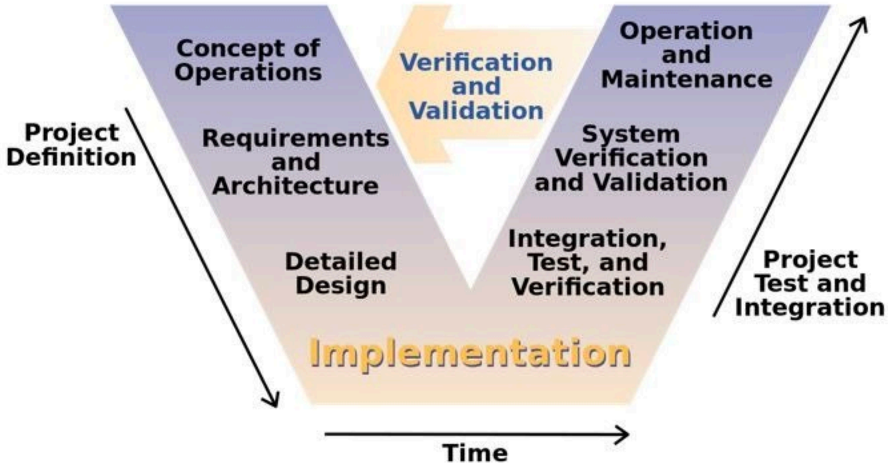


Figure 5. Generalized Vee Model.
(Osborn et al., 2005, public domain).

- Incremental/Spiral: This model was first described by Barry Boehm in 1986. The concept, overall, is the application of the lifecycle approach to a small increment of a system—in Boehm's original model, specifically a software product. Risk is reduced because there is a prototype that delivers some functionality at the end of each increment. This is different from waterfall for Vee, as the full capability is really only delivered at the end for these.

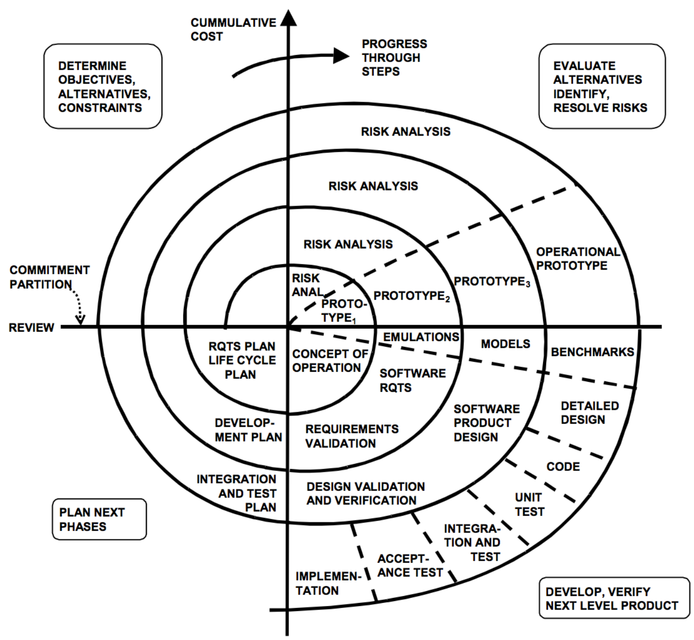


Figure 6. Spiral Development Model.
(Boehm, 1986).

- Continuous development/continuous integration: In the DoD the most commonly discussed CD/CI approach is DevSecOps (Development Security Operations).

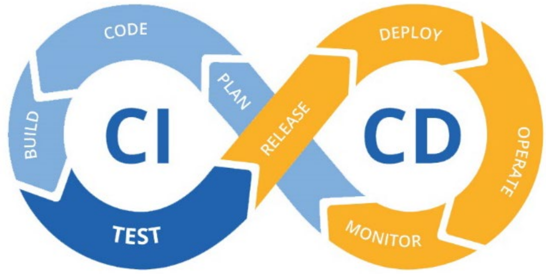


Figure 7. Generic Representation of the CI/CD (or DevSecOps) Approach

There is an overlap between life cycle models. For example, one could use an Agile approach, delivering continuously into an operational environment and integrating the principles of DevSecOps. Likewise, it is possible software development in a program may follow an incremental approach while the physical aspects of a system follow more of a Vee-model. Understanding the primary life cycle approach for a program will provide some insights.

The team is particularly interested in available data that could indicate the overlap or nesting of life cycle models as this likely will have specific implications for how a digital program environment would be developed and maintained.

Data

The researchers are in the process of collecting data. Currently, data with respect to ACAT 1 programs is more readily available than for smaller programs.

Expected Results

The team hopes to look at data from as many programs as possible—ideally a minimum of 200 programs across the spectrum. Grounded theory will be used to identify archetypes based on how the program data clusters.

For each archetype, the team will analyze available data, supplemented by subject matter expert insights into the available and appropriate DE methods, processes, tools, templates, etc. for each archetype. Figure 8 provides a conceptual example of the planned results, with specific patterns of characteristics defining the most common archetypes and recommendations for each archetype based on the programmatic and systems characteristics paired with available resources.

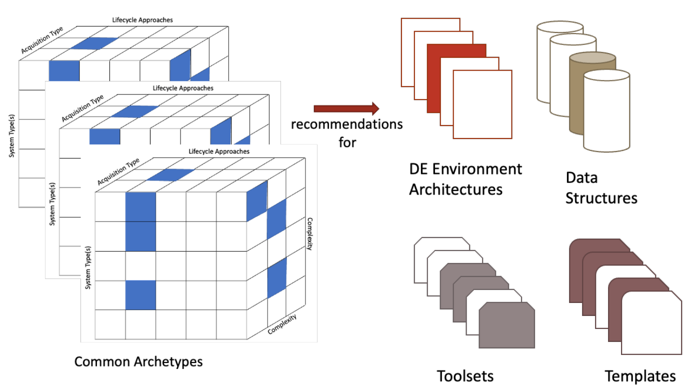


Figure 8. Conceptualization of the Proposed Framework

Conclusion

This framework is intended to provide programs that are beginning their transition to digital engineering and new programs that are being stood up in a digital engineering environment a place to start. This is meant to provide roughly a 70%–80% solution that will allow a program to quickly set up a digital engineering environment that is "good enough" to begin work, with the caveat that program specific tailoring is expected. Likewise, like most systems, the starting point is not the end. Programs will still need to evolve their digital engineering capabilities as the program grows and changes. However, this framework should provide guidance that will be applicable throughout that journey.

Participation

While the researchers are exploring available data sources such as the Defense Acquisition Visibility Environment (DAVE), the researchers are also working to make contacts across a variety of programs to supplement the data and have the opportunity to gather additional data that is not as readily available, such as the specifics of digital engineering implementation in different programs.

If you would like to participate in the study, please contact Nicole Hutchison (hicole.hutchison@stevens.edu).

References

Acarer, C. (2020). *CI/CD—Continuous integration, continuous delivery, and continuous deployment*. https://cacarer.com/ci-cd-continuous-integration-continuous-delivery-and-continuous-deployment/

Boehm, B. (1986). A spiral model of software development and enhancement. *Software Engineering Notes*, (11), 14–24. https://doi.org/10.1145/12944.12948

DAU. (2023). *Adaptive acquisition framework pathways*. https://aaf.dau.edu/aaf/aaf-pathways/

DoD. (2022, June 8). *DoD instruction 5000.02: Operation of the adaptive acquisition framework*. Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S)).

Osborne, L., Brummond, J., Hart, R., Zarean, M., & Conger, S. (2005, October). *Clarus concept of operations* (Publication No. FHWA-JPO-05-072). Federal Highway Administration (FHWA).

Shenhar, A. J., & Dvir, D. (2007). *Reinventing project management: The diamond approach to successful growth and innovation*. Harvard Business School Press.

Snowden, D.J., & Boone, M. E. (2007, November). A leader's framework for decision making. *Harvard Business Review*. https://hbr.org/2007/11/a-leaders-framework-for-decision-making

Digital Engineering Enhanced T&E of Learning-Based Systems

Laura Freeman—is a Research Associate Professor of Statistics and dual hatted as the Deputy Director of the Virginia Tech National Security Institute and Assistant Dean for Research for the College of Science. Her research leverages experimental methods for conducting research that brings together cyber-physical systems, data science, artificial intelligence (AI), and machine learning to address critical challenges in national security. She develops new methods for test and evaluation focusing on emerging system technology. Previously, Freeman was the assistant director of the Operational Evaluation Division at the Institute for Defense Analyses (IDA). Freeman also served as that acting senior technical advisor for Director Operational Test and Evaluation (DOT&E). Freeman has a BS in aerospace engineering, an MS in statistics, and a PhD in statistics all from Virginia Tech.

Paul Wach—is a Research Assistant Professor in the Intelligent Systems Division of the Virginia Tech National Security Institute. His research interests include the intersection of theoretical foundations of systems engineering, digital transformation, and artificial intelligence. Paul is a member of the Intelligent Systems Division of the Virginia Tech National Security Institute. He is the President and Founder of the Virginia Tech student division of INCOSE. Wach also works for The Aerospace Corporation, leading enterprise digital engineering transformation. His prior work experience is with the Department of Energy, two National Laboratories, and the medical industry. Wach received a BS in Biomedical Engineering from Georgia Tech, MS in Mechanical Engineering from the University of South Carolina, and completed a PhD in Systems Engineering at Virginia Tech with graduation in December 2022.

Justin Krometis—is a Research Assistant Professor in the Intelligent Systems Division of the Virginia Tech National Security Institute. His research is in the development of theoretical and computational frameworks to address data analytics problems, such as how to incorporate and balance data and expert opinion into decision-making, how to fuse data from multiple sources, and how to estimate model parameters, including high- or infinite-dimensional quantities, from noisy data. His areas of interest include Bayesian inference, parameter estimation, machine learning, data science, and experimental design. Dr. Krometis holds a PhD in mathematics, a MS in mathematics, and a BS in mathematics, and a BS in physics, all from Virginia Tech.

Atharva Sonanis—is an MS in Mechanical Engineering student working with Jitesh Panchal at the Design Engineering Laboratory at Purdue University (DELP). Atharva's research interests include robotics, controls, computer vison, machine learning and systems. He received his BE in Mechanical Engineering from M.I.T. College of Engineering, Pune. While pursuing his bachelor's degree, he was selected as a Cummins Scholar, and received the opportunity to work at Cummins Technical Centre India in the R&D department. Additionally, he holds a diploma in Mechanical Engineering from Government Polytechnic, Miraj.

Jitesh Panchal—is a Professor of Mechanical Engineering at Purdue University. He received his BTech (2000) from Indian Institute of Technology (IIT) Guwahati, and MS (2003) and PhD (2005) in Mechanical Engineering from Georgia Institute of Technology. Panchal's research interests are in (1) design at the interface of social and physical phenomena, (2) computational methods and tools for digital engineering, and (3) secure design and manufacturing. He is a recipient of CAREER award from the National Science Foundation (NSF); Young Engineer Award, Guest Associate Editor Award, and three best paper awards from ASME; and was recognized by the B.F.S. Schaefer Outstanding Young Faculty Scholar Award, the Ruth and Joel Spira Award, and as one of the Most Impactful Faculty Inventors at Purdue University. He is a co-author of two books and has co-edited one book on engineering systems design. He has served on the editorial board of international journals including ASME Journal of Mechanical Design, ASME Journal of Computing and Information Science in Engineering. He is a program chair of the ASME IDETC/CIE conference, and the past chair of the ASME Computers and Information in Engineering (CIE) division.

Peter Beling—is a professor in the Grado Department of Industrial and Systems Engineering and Director of the Intelligent Systems Laboratory at the Virginia Tech National Security Institute. Beling's research interests lie at the intersections of systems engineering and artificial intelligence (AI) and include AI adoption, reinforcement learning, transfer learning, and digital engineering. His research has found application in a variety of domains, including mission engineering, cyber resilience of cyber-physical systems, prognostics and health management, and smart manufacturing. He received his PhDin operations research from the University of California at Berkeley.

Abstract

The design of test and evaluation (T&E) programs requires new thinking for learning-based systems enabled by AI. A critical question is how much information is needed about the training data, the algorithm, and the resulting performance for testers to adequately test a system. The answer to these questions will inform acquisition of data/model rights for learning-based systems. The principal objective of this research is to understand how increasing government access to the models and learning-agents (AI algorithms) used in system design might decrease the need and expense of testing and increase confidence in results. The principal hypotheses investigated in this incubator project are that the number of samples needed to test AI/ML models to an acceptable degree of assurance ca be reduced if we have access to the models themselves (in mathematics or software), reduced still further if we also have access to the algorithms and data used to train the models, and reduced further yet if we also have access to systems models and other artifacts of the digital engineering process. Therefore, the cost of acquisition can be reduced if T&E programs are based on the optimal balance between the cost of acquiring the technical data/algorithm rights of AI/ML systems, and the cost of testing those systems. This research establishes theory and methods for exploring how T&E requirements can and should change as a function of the test team knowledge of the technical specifications of learn based systems (LBS).

Introduction

Artificial intelligence and machine learning (AI/ML) has moved beyond being a research field to being an essential element of next-generation military systems. The discipline of verification and validation of AI/ML enabled complex systems, however, in its nascent stage. Little is understood about how to identify changes in operating conditions or adversarial actions that might cause the performance of an AI/ML model to deviate from design limits (McDermott, 2021). The challenges in this regard are amplified when considering autonomous functions that may engage in self-learning over the long-life cycles seen in military systems.

The objective of this research was to develop approaches to the design of test and evaluation (T&E) programs and the acquisition of data/model rights for learning-based systems (LBS). Freeman (2020) proposes 10 different themes for how T&E will need to change for ML/AI systems. One theme is the need for a risk-based framework approach. This research seeks to explore the risks associated with varying levels of knowledge of ML/AI training data and model insights. The principal objective was to understand how increasing government access to the models and learning-agents (AI algorithms) used in system design might decrease the need and expense of testing and increase confidence in results.

The current approach to T&E involves treating the system in a black-box fashion, i.e., the system is presented with sample inputs, and the corresponding outputs are observed and characterized relative to expectations. While such an approach works well for traditional static systems, test and evaluation of autonomous intelligent systems presents formidable challenges due to the dynamic environments of the agents, adaptive learning behaviors of individual agents, complex interactions between agents and the operational environment, difficulty in testing black-box machine learning (ML) models, and rapidly evolving ML models and AI algorithms (Cody, 2019).

Our principal hypotheses are that the number of samples needed to test AI/ML models to an acceptable degree of assurance can be reduced if we have access to the models themselves (in mathematics or software), reduced still further if we also have access to the algorithms and data used to train the models, and reduced further yet if we also have access to systems models and other artifacts of the digital engineering process. Therefore, the cost of acquisition can be significantly reduced if T&E programs are based on the optimal balance between the cost of acquiring the technical data/algorithm rights of AI/ML systems, and the cost of testing those systems.

This paper develops theory based in systems theory that captures changes in the systems and the state-space in which it operates through the concept of systems morphisms. The Theoretical Background section provides overarching theory and a system concept model. The onion model describes different levels of system knowledge and a context for defining the abstraction of the system. The Experimental Testbed section describes two pilot scenarios to demonstrate how multiple phases of testing contribute to the evaluation of an AI enabled systems. The Bayesian Framework section presents the Bayesian analytical framework for combining information across the multiple phases of testing. This analytical framework also reflects the changing system configuration and context. The Potential Testbed and Future Work section discusses future work for validating the concept through a full system model and experiment. In summary, this work essentially constitutes the building blocks for investigating the cost-benefit for test data collection on a realistic system in future phases.

Theoretical Background

At the core of this research is systems theory outlined by Bertalanffy and Sutherland (1974). Specifically, we build from the lineage of the systems theorist Wymore (1967) defined the Mathematical Theory of Systems Engineering and has been credited for coining the term model-based systems engineering (Bjorkman et al., 2013). A mathematical mechanism used in Wymorian systems theory is the system specification morphism; where a morphism is a mathematical characterization of the preservation of equivalence between a pair of system specifications (Zeigler, 2018).

System specifications may be defined at many levels within a hierarchy. The hierarchy of system specification is a prominent aspect of a branch of Wymorian systems theory commonly referred as computational systems theory, or formally known as the Theory of Modeling and Simulation (Wach et al., 2021). Each level of the hierarchy of system specification reveals further detail as to the knowledge of the structure from external interfaces and interactions to internal component and coupling knowledge. Furthermore, within each level of system specification, a morphism essentially characterizes abstraction and elaboration of detail.

Simply put, parameter morphisms coupled with specifications within the hierarchy, is a mapping of parameter space along with state space. The parameter morphism is an explicit documentation of allowable deviations (approximations) from exact morphisms, as is the expectation with the input/output observation frame and network of systems morphisms, relative to changes in parameter sets. A simple example of a parameter morphism is the selection of the mean versus a distribution as a parameter test set.

Lastly, the framing of the hierarchy and associated morphisms is important to understand the systems theoretical context as a whole. First, the relationship between the input/output (IO) observation frame and the network of systems is a one-to-many specification relationship, meaning that one system specification at the IO observation frame can lead to specification of many (maybe infinite) network of system specifications. However, each network of system specification can map to only one specification at the IO observation frame level. Second, a morphism at the IO observation frame level does not guarantee a morphism at the network of systems level. Third, however, a morphism at a network of systems level implies a morphism at the input/output observation frame level. These are systems theoretic concepts we use to underpin our methodology for T&E of LBS.

Methodology

The practice of engineering systems is reliant on use of surrogate analogies for T&E. In some cases, we may not have access to the fielded system until late in the program and, therefore, select a surrogate as an analogous representation of the current (phase appropriate) design of the system of interest. In other cases, the system of interest may be fielded and we want to understand observed behavior, for which we may use a surrogate, analogous environment for testing the fielded system (or analogous test system). These activities are typically thought of as necessary risk reduction, for which we characterize the validity of the analogies through the use of systems theoretic morphisms.

Consider the following example to provide further context: The IO observation frame morphism could be used to characterize the change in operational conditions and change in adversarial action. The network of systems morphism can be used to characterize the changes in implementation of a LBS subsequent to changes in operational conditions and adversarial actions. Furthermore, from the last paragraph of the previous section, a morphism between system implementations (i.e., network of systems morphism) implies a morphism at the mission level, which, therefore, is indicative of mission success.

Commonly associated with LBS is the onion model shown in Figure 1. In the outer layer, we have minimum knowledge of the system context, which we categorize as mission knowledge. In the second to outer layer, we begin to have knowledge of the interior structure in the form of a functional architecture. In the third to outer layer (second to inner layer), we have knowledge of the agent cognitive functions. In the inner most layer, we have maximum knowledge in the form of knowledge of the physical implementation of the system of interest. From a systems theory perspective, we can provide a view of validity of analogies relative to the onion model.

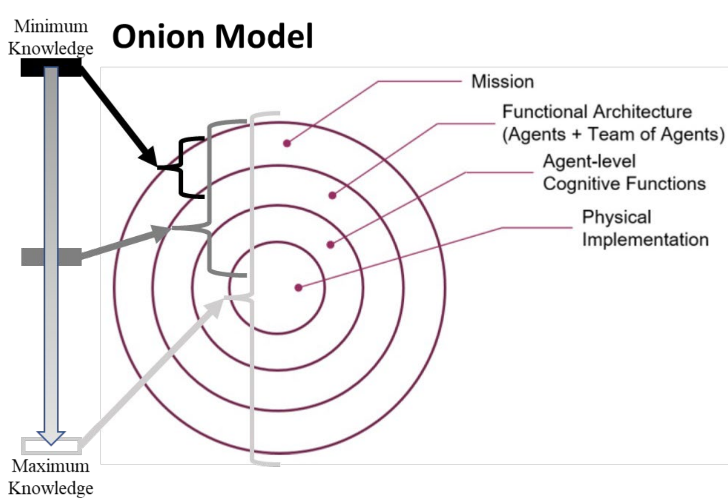


Figure 1. Onion Model Used to Understand Layers of LBS

In Figure 2, we provide a systems theoretic context. We show the real mission to the top left and the preservation of equivalence to surrogate T&E context shown in the top right. We propose characterization of this equivalence through systems theoretic mechanisms, such as the IO observation frame and associated morphism. We also show the field system to the bottom left and the preservation of equivalence to surrogate model shown in the bottom right. We propose characterization of this equivalence through systems theoretic mechanisms, such as the network of systems and associated morphism.

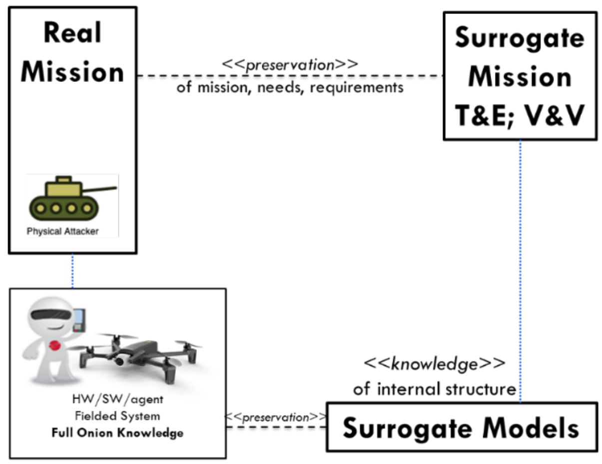


Figure 2. High-Level View of Systems Theory Perspective of the Onion Model

For this project we used the mission context of detection of a potential attacker, consistent with Silverfish (Carter et al., 2019). Rather than focus on the full system of systems of Silverfish, we selected to focus on the unmanned aerial vehicle (UAV) component as the system of interest for this research project. In Figure 3, we provide further explanation to our set of experiments within the context of systems theory and the onion model.

First, we have used the You Only Look Once (Agent YOLO) algorithm as our agent, which has an unknown T&E context conducted prior to our acquisition of the agent. Therefore, we cannot determine its morphic equivalence to the real mission and must conduct further testing. The new T&E mission analogies are expected to be characterized through systems theoretic morphisms. For this project, we used a series of T&E surrogate mission contexts of the potential attacker in the form of a soccer match (i.e., red versus blue) and automobile detection (truck versus other type of vehicle). While the soccer match was a simulation (video from the internet), the automobile surrogate mission context was both a simulation and physical test.

Second, we were not able to acquire the physical hardware expected for the fielded system at the onset of the project. Therefore, we relied on surrogate models, for T&E, that we believe to be analogous to the fielded system. Each surrogate model is expected to be morphically characterized to determine its equivalence relative to the fielded system. For this project we have selected a series of surrogate models for the UAV. First, the initial Agent YOLO may only be analogous as far as the cognitive function is concerned. Second, we used a surrogate drone, which has lower cost and quality of hardware than the fielded systems. Last, it should also be noted that even when we have access to the expected fielded system, the morphic validity of the analogies must also be confirmed. For this, we suggest that a digital twin (i.e., simulation) and final product (or physical twin) from low-rate initial production (LRIP) be used for an initial operational test and evaluation (IOT&E), both of which should be morphically characterized for its equivalence to the expected (or measured) reality.

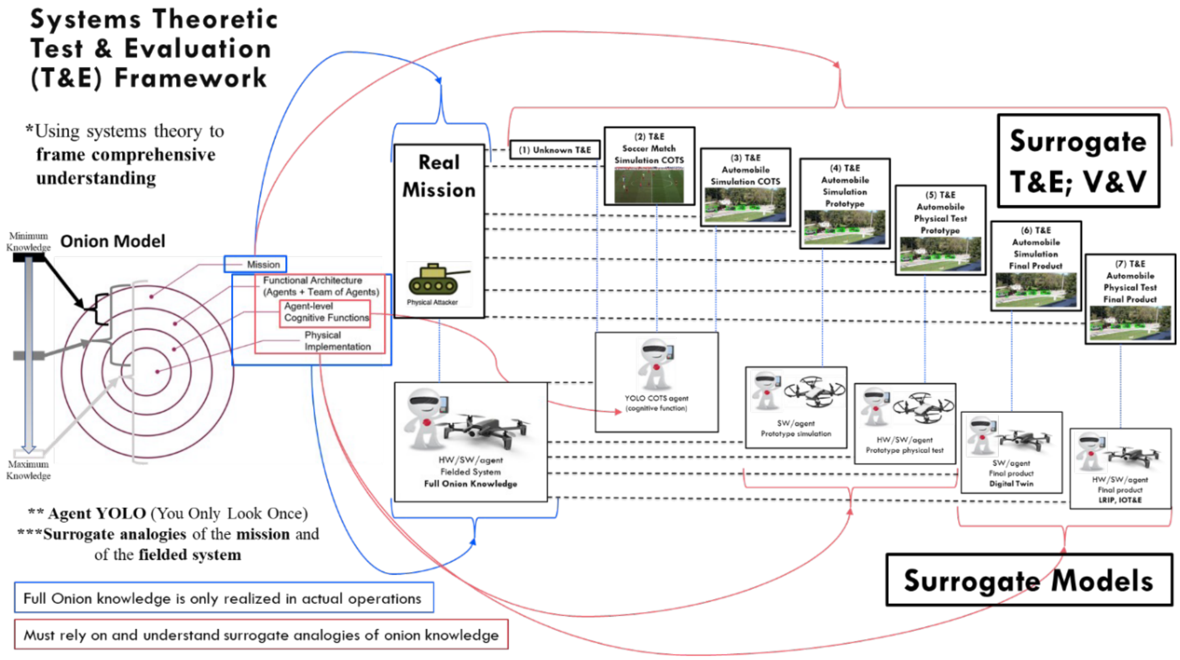


Figure 3. Proposed Systems Theoretic Test and Evaluation Framework

Because the full knowledge relative to the onion model can only be known once the final product design becomes the fielded system and is placed in its real mission context, we must rely on and understand surrogate analogies to provide confidence in mission success. We have selected to use Bayesian methods, such as discussed by Salado and Kannan (2018), to characterize confidence in mission success relative to knowledge on the morphic equivalence. Further detail on the use of Bayesian methods is provided in another section.

Experimental Testbed

The broader objective for creating the experimental testbed is to assist in validating the T&E framework for learning-based systems. For this research, the specific goal is to demonstrate how the T&E framework can be utilized for a specific scenario where the goal is to detect the presence of enemies, tracking them, and sending a signal for Silverfish protected field.

The testbed consists of (a) scenarios, (b) hardware, and (c) software. Two scenarios are created as surrogate problems as a part of creating experimental testbeds.

Scenario 1: Person Identification and Tracking in a Soccer Game: This scenario is based on a soccer game as a surrogate problem using stock video to detect players belonging to different teams and their location in the field. The players, shown in Figure 4, are classified into two different teams based on their apparel colors and patterns. The idea here is to showcase the different teams as allies and enemies. In addition to this, the location coordinates of the players are continually tracked.

Figure 4. Scenario 1: Person Identification and Tracking in a Soccer Game

Scenario 2: Vehicle Detection and Tracking: This scenario is based on automobile detection and tracking as a surrogate problem to detect vehicular traffic, location coordinates and their velocities (see Figure 5). The vehicles are categorized based on their sizes, i.e., small vehicles represent allies (friends) and large vehicles represent enemies. Similar to Scenario 1, the location coordinates of the vehicles are detected along with their velocities.

Figure 5. Scenario 2: Vehicle Detection and Tracking

The coordinates obtained from the two scenarios are mapped and visualized on a grid shown in Figure 6.

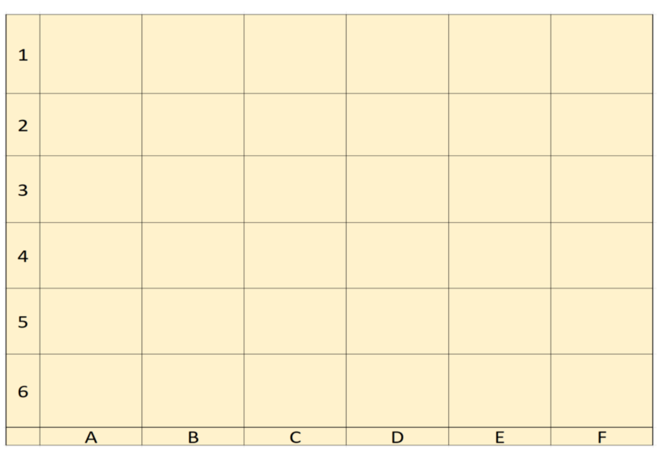


Figure 6. Grid Used for Visualization and Mapping

HARDWARE. For hardware implementation, two drones namely, Ryze Tello (lower fidelity prototype drone) and Parrot ANAFI (higher fidelity prototype drone) are used. The specifications of the Ryze Tello drone and the Parrot ANAFI drone are shown in Figure 7.

Figure 7. Comparison of the Specifications of the Higher and Lower Fidelity Drones

Lower fidelity prototypes are used to test whether the high-level design concepts can be translated into tangible outputs. On the other hand, higher fidelity prototypes provide outputs that are as similar as possible to the desired requirements defined initially. The drones capture videos which are then segmented into images frame by frame. The differences in the images from the two drones can be clearly seen in terms of the resolution, field of view and stability.

SOFTWARE. The primary goal of the software implementation is to identify the location coordinates of the allies and enemies and track them in real time. To do so, videos captured from the drones are used as input, and the output being series of location coordinates. This implementation broadly consists of four steps: image preprocessing, object detection and classification, object tracking, and mapping. Figure 8 provides a high level overview of the process.

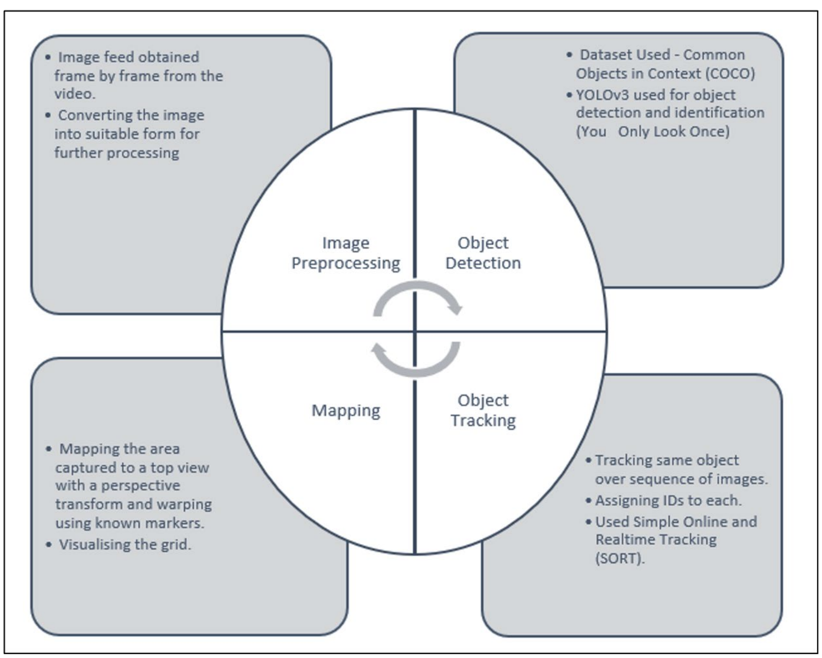


Figure 8. High Level Overview of Software Processes

Image Preprocessing: The goal of this step is to retrieve a series of clean images from the videos to prepare them for the further steps and to reduce computation time. The steps in image preprocessing are as follows:

1. Raw videos obtained from the hardware are segmented frame by frame into a series of images.
2. Images are resized to a lower size to increase computation speed.
3. Gaussian Blur is used to smoothen the images and to reduce unwanted noise.
4. Images are cropped to obtain the region of interest.

To simulate the different qualities of video camera from different hardware, i.e., a lower fidelity and higher fidelity input in Scenario 1:Person Identification and Tracking in a Soccer Game, the original video is used as a higher fidelity input and the blurred version of the original video is used as a lower fidelity input. Figure 9 shows the results for Scenario 2.

Figure 9. Drone Image Comparison (Above: Higher Fidelity, Below: Lower Fidelity)

Object Detection and Classification: The goal of this step is the detection, classification, and localization of the objects present in the frame. Here, the preprocessed images are used as the input, and passed through a trained or pre-trained object detection model to receive object location and classes. For this purpose, YOLOv3 (You Only Look Once, version 3) is used, which is an object detection algorithm that identifies specific objects in videos or images. A custom object detection model is trained for the soccer game scenario to detect and classify the players into different teams. Whereas, for the vehicle scenario, to detect and classify allies (friends) and enemies, a pre trained model is customized using the COCO (Common Objects in Context) dataset (Lin et. al., 2014), which is a large-scale object detection, segmentation, and classification dataset. The COCO dataset has more than 2,00,000 labelled images and more than 100 categories.

Object Tracking: The goal of this step is to track the movement of an object, which involves tracking of the detected objects frame-by-frame and storing its location coordinates along with some relevant information. A unique identification number is assigned to each detected object for the duration of which it is continuously tracked. There are several challenges associated with object tracking such as occlusion, discontinuity in detections, etc. To tackle these issues, the Simple On-line Real-time Tracking (SORT) algorithm is used. We are successfully able to perform tracking of each object along with finding its approximate velocity.

Mapping: The output obtained from the object tracking step is utilized to map and visualize the allies and enemies on a grid. The visualization is useful for sending a signal to silverfish protected field. This is accomplished using warping techniques and perspective transformations of a known field or using markers to a visualization grid. Figure 10 is a representation of the soccer scenario in the grid format with exact location coordinates. The blue and white dots depict players in the teams whereas the black dot is the soccer ball.

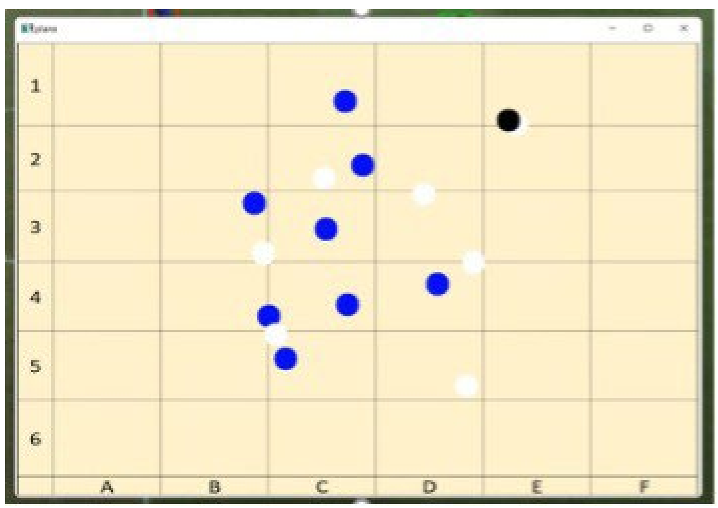


Figure 10. Grid Data Representation Example

The results obtained from above steps, i.e., the location coordinates of the detected objects are used to evaluate the detection accuracy of identified objects to be used in the Bayesian Framework, described next.

Bayesian Framework

We can characterize the relationships between different models—simulation environments vs. low-fidelity systems vs. higher-fidelity systems—via a Bayesian network. A Bayesian network is a graph model that describes the relationship between nodes via probabilities. To illustrate the concept, we consider a detection system with two outcomes—either the target is detected or it is not detected—and two true states—either the target is present or it is not—with four possible combinations. These cases are summarized in Table 1.

Table 1. Cases for a Target Detection Problem

Case #	Case	Target Present?	Target Detected?
1	True Positive	Yes	Yes
2	False Negative	Yes	No
3	False Positive	No	Yes
4	True Negative	No	No

One might imagine each of these cases having a different "cost" from a T&E perspective—i.e., a false negative (target is present but not detected) may have more operational cost than a false positive (target is falsely detected). The goal of T&E is ultimately to characterize that cost, e.g., to compute its *expected value*, i.e., the cost of each case (C_i) times the probability of each case (P_i):

$$E(C) = \sum_{i=1}^{4} C_i P_i$$

The Bayesian framework considers each of the probabilities P_i for the final fielded system as a function of the probabilities for the analogous systems. That is, if the probabilities for the simulated environment and a lower-fidelity prototype are P^{sim} and P^{low}, respectively, then the final probability P_i can be written in terms of conditional probabilities:

$$P_i = P(x \in C_i) \propto \sum_{i=1}^{4} P\left(x \in C_i \middle| x \in C_i^{sim}\right) P(x \in C_i^{sim})$$

Here the more complicated equation has necessitated more complicated notation: $P(x \in S_i)$ is the probability of Case i and $P(A|B)$ is the probability of A given B. So, the above equation means that the probability of, for example, getting a true positive (Case 1) in the fielded system is the probability of getting Case j in the low fidelity system multiplied by the probability of getting Case 1 in the fielded system given that we got Case j in the low-fidelity system, summed across j. This may seem like—and indeed is—a more complicated way of writing the same thing. However, if we can accurately estimate the conditional probabilities in, it allows us estimate the probabilities P_i and ultimately the cost by mostly running lower-fidelity tests. The same mechanism can then be used to capture the relationship between the lower-fidelity test and the simulated environment. The Bayesian network summarizing the relationship between these conditional probabilities is shown in Figure 11.

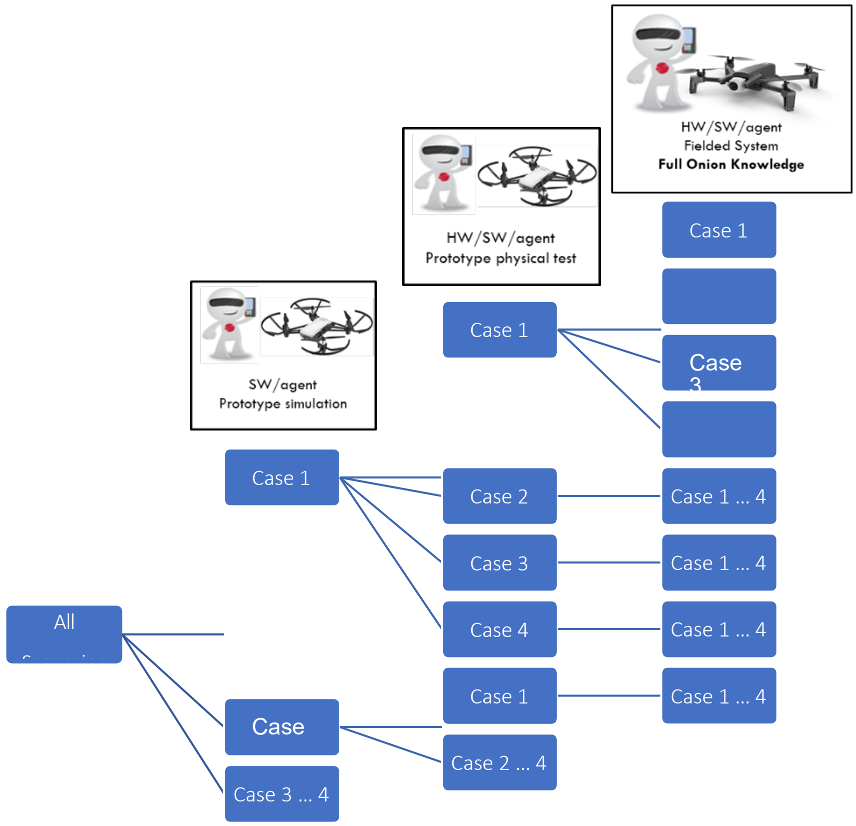


Figure 11. A Bayesian Network for the Detection Case. Scenarios are Divided into Four Cases (True/ False Positive/Negative) Across Three Test Cases (Software Environment, Prototype/Low-Fidelity, Fielded System).

Next, we describe briefly how to estimate the probabilities in the previous section. In this case, we actually use a different kind of Bayesian procedure known as Bayesian inference. We begin with an estimate of the probability distribution called the *prior*, and then update that estimate as we test. For the detection case, we can model the outcomes with a binomial distribution with unknown success probability p. There is a fairly standard approach in the statistics community to estimating p. First, the prior is typically chosen to be a beta distribution $B(\alpha, \beta)$ where α, β are parameters that can be tuned to the problem. For example, one might give the prior a weight N_{prior} and start with a guess for p which we denote p_{prior}; we then would set $\alpha = p_{prior} N_{prior}$

and $\beta = N_{prior} - \alpha$. Then if tests yield s successes and f failures, we would update our estimate

to be $B(\alpha + s, \beta + f)$. This procedure is illustrated in Figure 12. Here $p_{prior} = 0.4$ but we see the inference procedure closing in on the true value of $p = 0.7$ as more tests are taken.

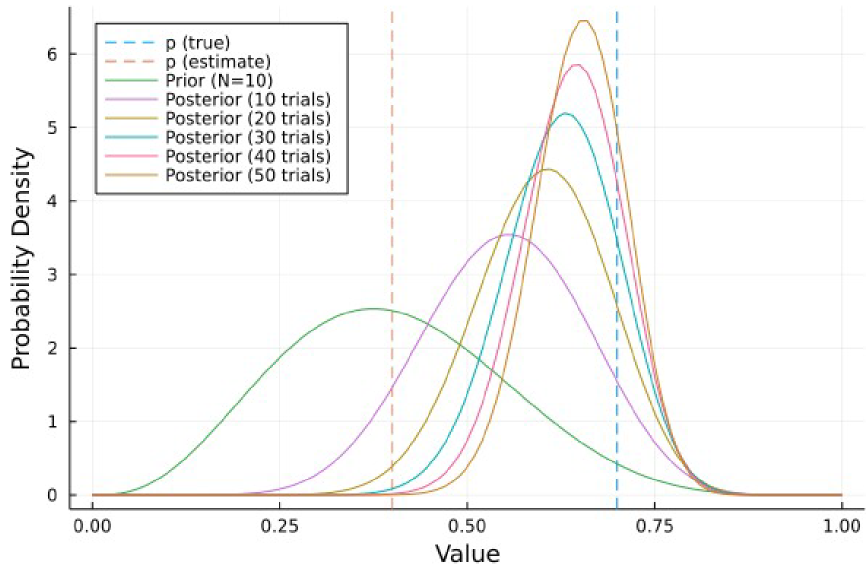


Figure 12. A Bayesian Approach to Estimating the Probability of Success in a Binomial Distribution; Here the Prior Estimate of the Probability of Success is 0.4 and the True Value is 0.7. The Inference Procedure Updates the Estimates as Tests are Conducted, Closing in on the True Value.

Potential Testbed and Future Work

A major challenge in conducting AI enabled systems research is that physical realizations are needed for T&E research. As a testbed for the methodologies, future work should explore these concepts on a full hypothetical weapons system, moving beyond the embedded AI algorithm. The system highlighted earlier, known as Silverfish, is a networked munition system designed to deny ground to the enemy using ground-based weapons, known as obstacles, that can engage unauthorized persons or ground vehicles within the denied area. Surveillance sensors including static infrared and video cameras and target characterization sensors, such as acoustic and seismic sensors, monitor the area to provide the operator with situational awareness regarding persons and vehicles. An unmanned aerial vehicle also provides surveillance and early warning information. Silverfish exists as a hybrid simulation/hardware emulation characterized in model-based systems engineering (MBSE) terms by a set of SysML models describing its architecture and functions from several perspectives. It also includes AI/ML models for detecting cyber-attacks on the UAV.

Future work could leverage the Silverfish testbed and expand the testbed into physical implementations beyond the computer vision use case. Physical implementations in addition to MBSE representations would enable the direct execution of a T&E program on the Silverfish testbed. Future work should also include purposefully varying the systems knowledge (based on the onion model), the complexity of the systems and its operating environments (number of morphisms), and determine minimally adequate testing as a function of those variables.

This paper stablished the theory and methods for exploring how T&E requirements can and should change as a function of the test team knowledge of the technical specifications of an AI enabled system. The research developed theory based in systems theory that captures changes in the systems and the state-space in which it operates through the concept of systems morphisms. The onion model describes different levels of system knowledge and a context for defining the abstraction of the system. The project experimented with two pilot scenarios to demonstrate how multiple phases of testing contribute to the evaluation of an AI enabled system. Finally, we present the Bayesian analytical framework for combining information across the multiple phases of testing. This analytical framework also reflects the changing system configuration and context. In summary, this work essentially constitutes the building blocks for investigating the cost-benefit for test data collection on a realistic system in future phases.

References

Bertalanffy, L. V. (1968). *General system theory: Foundations, development, applications*. G. Braziller.

Carter, B., Adams, S., Bakirtzis, G., Sherburne, T., Beling, P., Horowitz, B., & Fleming, C. (2019). A preliminary design-phase security methodology for cyber–physical systems. *Systems*, *7*(2), 21.

Cody, T., Adams, S., & Beling, P. A. (2019, April). A systems theoretic perspective on transfer learning. In *2019 IEEE International Systems Conference (SysCon)* (pp. 1–7). IEEE.

Fleming, C., Elks, C., Bakirtzis, G., Adams, S. C., Carter, B., Beling, P. A., & Horowitz, B. (2020). Cyberphysical security through resiliency: A systems-centric approach. *arXiv preprint arXiv:2011.14469*.

Freeman, L. (2020). Test and evaluation for artificial intelligence. *Insight*, *23*(1), 27–30.

Lin, T. Y., Maire, M., Belongie, S., Hays, J., Perona, P., Ramanan, D., ... & Zitnick, C. L. (2014). Microsoft coco: Common objects in context. In *Computer Vision–ECCV 2014: 13th European Conference, Zurich, Switzerland, September 6–12, 2014, Proceedings, Part V 13 (pp. 740–755*). Springer International Publishing.

McDermott, T. A., Blackburn, M. R., & Beling, P. A. (2021). Artificial intelligence and future of systems engineering. *Systems Engineering and Artificial Intelligence*, 47–59.

Salado, A., & Kannan, H. (2018). A mathematical model of verification strategies. *Systems Engineering*, *21*(6), 593–608.

Wymore, A. W. (1967). *A mathematical theory of systems engineering: The elements.* Wiley.

Zeigler, B. P., Muzy, A., & Kofman, E. (2018). Theory of modeling and simulation: Discrete event & iterative system computational foundations. Academic Press.

PANEL 5. ENHANCING DECISION MAKING

Wednesday, May 10, 2023	
12:45 p.m. – 2:00 p.m.	**Chair: Mark E. Krzysko,** Principal Deputy Director, Enterprise Information, Acquisition Data and Analytics ***Cost Estimating and Affordability Case Study: Air to Ground Missile Program*** Robert Mortlock, Naval Postgraduate School ***Calculating Return on Investment in a Department of Defense Context*** Eric Burger, Virginia Tech Robin Dillon-Merrill, Georgetown University Erika Heeren-Moon, Georgetown University ***Avoiding The "I'll Know it When I See It" Pitfall: Furthering A Choice-Based Conjoint (CBC) Model for Government Source Selections*** Lt Brittany Thompson, USAF, Naval Postgraduate School LtCol Daniel Finkenstadt, USAF, Naval Postgraduate School

Mark E. Krzysko—is the Principal Deputy Director of Enterprise Information in the Acquisition Data and Analytics (ADA) organization. In this senior leadership role, Mr. Krzysko directs acquisition data governance, data access, and data science to enable the Department to make sound business decisions with data. He is leading a philosophical and technical transformation within the Department to make timely, authoritative acquisition information available to support insight and decision-making on the Department of Defense's major programs—a portfolio totaling approximately $2 trillion of investment funds over the lifecycle of the programs—as well as smaller programs and nontraditional acquisition approaches.

In 2016, Mr. Krzysko was invited to be a member of the White House Office of Science and Technology Policy's Data Cabinet, which was initiated to lead the effort to make leveraging the power of data the norm across the Federal government. In addition, he is a charter member of the Defense Science Interagency Working Group, which has a similar purpose.

Preceding his current position, Mr. Krzysko served as Assistant Deputy Under Secretary of Defense (ADUSD) for Business Transformation, providing strategic leadership for re-engineering the Department's business system investment decision-making processes. He also led efforts as ADUSD for Strategic Sourcing and Acquisition Processes and as Director of the Supply Chain Systems Transformation Directorate, championing innovative uses of information technologies to improve and streamline the supply chain process for the Department. As the focal point for supply chain systems, Mr. Krzysko led the transformation, implementation and oversight of enterprise capabilities for the acquisition, logistics and procurement communities.

In March of 2002, Mr. Krzysko joined the Defense Procurement & Acquisition Policy office as Deputy Director of e-Business. As the focal point for the Acquisition Domain, he was responsible for oversight and transformation of the acquisition community into a strategic business enterprise. This included driving the adoption of e-business practices across the Department, leading the move to modernize processes and systems, and managing the investment review process and portfolio of business systems.

From June 2000 to March 2002, Mr. Krzysko led the Electronic Commerce Solutions Directorate for the Naval Air Systems Command. From April 1991 until March 2000, Mr. Krzysko served in senior-level acquisition positions at the Naval Air Systems Command, including Contracting Officer of F/A-18 Foreign Military Sales, F/A-18 Developmental Programs, and the F-14. Mr. Krzysko began his career in the private sector in various executive positions including Assistant Managing Director for Lord & Taylor Department Stores and Operations Administrator for Woodward & Lothrop Department Stores.

Mr. Krzysko holds a Bachelor of Science Degree in Finance and a Master of General Administration, Financial Management, from the University of Maryland University College, and numerous certificates from Harvard University.

Cost Estimating and Affordability Case Study: Air-to-Ground Missile Program

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

Abstract

This case study is written to produce an active learning environment to increase the capability of acquisition and program management professionals regarding cost estimating and the program decision-making. The Joint Common Missile is the program of record used for the case study due to the variance of its program office estimate and the independent cost estimate (ICE). Both estimates were developed in preparation for program decision review and were critical to the decision-making process used by the milestone decision authority and the program manager. Affordability is always a major factor in development and procurement decisions for defense acquisition programs. All programs procured with taxpayer dollars for use within the Department of Defense are constrained by budgeted dollars. Cost estimates aid in decision-making along a program's timeline at key program milestones with a prediction of future program costs and inform milestone decision authority about the program's affordability.

Case Study Learning Objectives:

- Demonstrate understanding of acquisition program cost estimating and how they are applied in acquisition program baseline planning and decision-making.
- Demonstrate an understanding of the difference between the learning rate effect (improvement curve) and the production rate effect when applied in production cost estimates in acquisition programs.
- Enhance critical thinking, problem-solving, resource management, and stakeholder management skills to develop recommendations for affordability decision-making that are defensible based on data and the acquisition sciences.

Keywords: cost estimating, affordability, decision-making, critical thinking, project management

Situation

It was beautiful Friday afternoon, and Colonel Nicole Smits was looking forward to a great weekend until the phone rang. The caller ID indicated that it was from the Pentagon. "Why would the Pentagon be calling directly?" she thought as she answered the call. The call was from the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD[A&S]). The chief of staff for the Under Secretary of Defense for Acquisition and Sustainment (USD[A&S]) indicated that the USD(A&S), as the milestone decision authority (MDA), cancelled the planned Defense Acquisition Board (DAB) review scheduled to approve entry of the Joint Common Missile (JCM) program of record into the engineering and manufacturing development (EMD) phase due to funding concerns. Colonel Smits was a newly assigned project manager (PM), and the DAB review was planned before her assumption of the charter, giving her responsibility for the total life cycle systems management. She knew she'd have to bring in her project management office (PMO) team, as well as all the other stakeholder representatives, to address the program affordability concerns of the USD(A&S) and reschedule the DAB review. She wondered, "How could the program be facing issues before even being formally initiated as a program of record?"

Background

Colonel Smits contacted her user counterparts (customers) to explain the DAB review delay. The user counterparts for the Army, Navy, and Marine Corps represented the warfighters in the acquisition process and were responsible for the JCM program requirements. The user representatives understood the affordability concerns of the MDA but stressed that the operational need for the JCM remained a top priority. The Department of Defense (DoD) had a growing need to replace its family of aviation-launched missiles, including the Hellfire missile, the tube-launched, optically-tracked, wire-guided (TOW) missile, and Maverick missile systems. The JCM would enable the Army, Navy, and Marine Corps rotary-wing aircraft (helicopters) as well as Navy fixed-wing aircraft (fighter jets) to execute numerous missions with one common missile—the JCM—greatly increasing capability and reducing the DoD logistics footprint across military operating environments. Figure 1 shows the current missiles being replaced by the JCM. The single JCM was replacing variants of Hellfire, Maverick, and TOW missiles, and provided the Army, Navy, and Marine Corps warfighting communities increased range, lethality, and force protection with ability to operate in austere battle environments. The following was a summary of aviation-launched missiles fired from platforms (prior to JCM):

- Army AH-64 Apache helicopters fired multiple versions of the Hellfire missile with either precision point (PP) targeting, using laser designation technology, or fire and forget (active) targeting, using millimeter wavelength (MMW) radar technology and separate warheads for different target sets. The Hellfire average unit procurement cost (AUPC) was $86,900.
- Marine Corps AH-1Z Cobra helicopters fired all versions of the Hellfire missiles and TOW missiles with wire guided targeting technology. The TOW AUPC was $78,100.
- Navy MH-60 Seahawk helicopters fired the Hellfire missiles and TOW missiles.
- Navy F/A-18 E/F Super Hornet fighter jets fired Maverick missiles with either PP or fire and forget (passive) targeting using infrared (IR) technology with separate warheads for different target sets. The Maverick AUPC averaged $179,000.

Each version of the current missiles was limited to operating with a single mode seeking capability and single warheads destroying a specific set of targets. Replacement of these missile variants meant integration of tri-mode seeker, multipurpose warhead, and common propulsion technologies. Luckily, the MDA was not questioning the need for the JCM or the JCM performance requirements. The MDA was questioning the JCM affordability.

Figure 1. Missile Being Replaced by JCM
(Joint Requirements Oversight Council [JROC], 2004)

JCM Program Details

At the materiel development decision (MDD), the JCM program MDA (USD[A&S], also designated as the Defense Acquisition Executive [DAE]), determined that the JCM should become a program of record and officially enter the acquisition framework at Milestone (MS) B to begin the EMD phase. The decision was based on the urgency of need, available resources, and technology maturity level of critical missile components. Figure 2 displays the notional proposed JCM design and highlights the three critical technology areas of the missile: seeker, warhead, and propulsion. Not unlike all programs within the DoD, affordability was a concern with the JCM program. The Army and Navy were fully committed to the program and issued affordability memoranda stating that the JCM program was affordable within the services' planned budgets. The Army and Navy acquisition executives supported the joint cost position (JCP). Based on the JCP, the proposed acquisition program baseline (APB), contained a 48-month EMD phase with an AUPC of $108,000 and an acquisition procurement objective of 48,613 missiles. Refer to Exhibit 1 for the JCM program APB details.

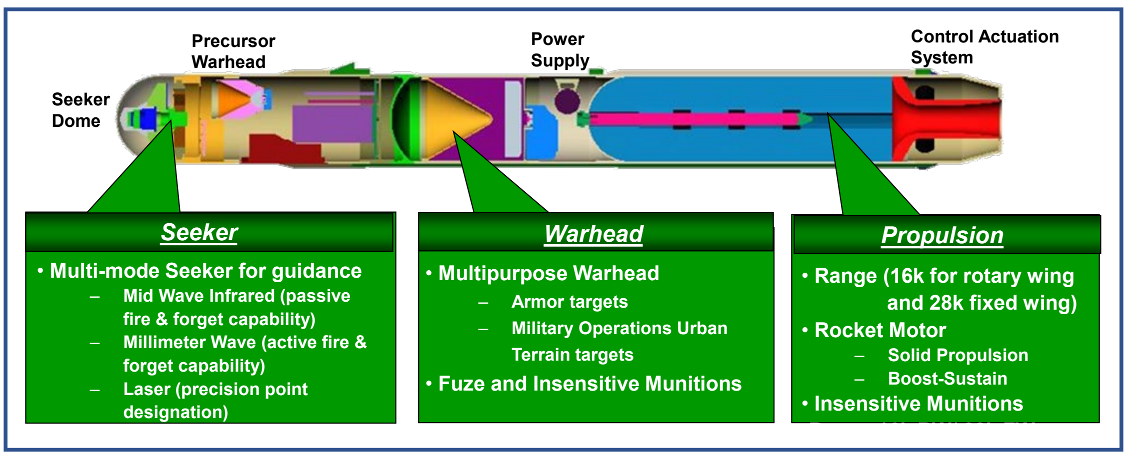


Figure 2. Notional JCM Design
(Common Missile Project Office, 2003)

The JCM program completed a successful technical maturation and risk reduction (TMRR) phase, meeting the exit criteria in which all critical technologies were assessed as mature. The program's integrated product team conducted a thorough risk assessment approved by the appropriate Army and Navy stakeholders, informed by the results of the multiyear science and technology effort and a 3-year TMRR phase, with multiple vendors demonstrating competitive prototypes through experimentation, extensive modeling and simulation, and early warfighter demonstrations. (Refer to Exhibit 2 for a summary risk assessment.) Figure 3 shows JCM critical technology strategy used to mature the seeker, warhead, and propulsion technologies to the level required (technology readiness level [TRL] 6) to initiate system integration and demonstration efforts (the EMD acquisition phase). The capabilities-based assessment documented the need for JCM, and an analysis of alternatives solidified the requirements, including the key performance parameters (KPPs). The JCM requirements traced to a simplified work breakdown structure (WBS) that highlighted the three critical technologies in the system design (refer to Figure 4).

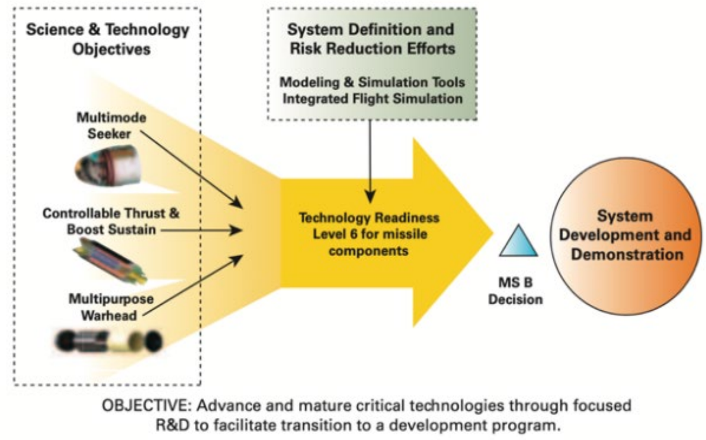


Figure 3. JCM Critical Technologies Maturation Strategy (Mortlock, 2005)

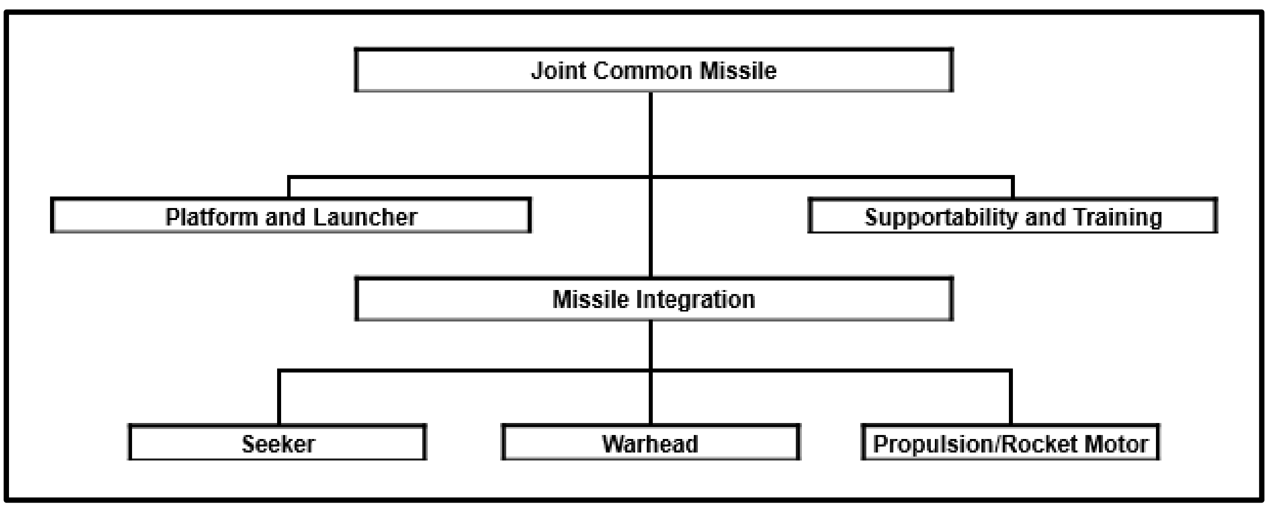


Figure 4. JCM Design Work Breakdown Structure (Sleevi & Mount, 2003)

Dilemma

The proposed JCM APB was approved by the Army and Navy, which incorporated and funded a 48-month EMD phase and AUPC of $108,000. Every major defense acquisition program was required by law to have an independent cost estimate (ICE) to support MDA decision reviews. In the ICE developed by the Cost Analysis Improvement Group (CAIG), the recommended JCM EMD phase length was from 72 to 144 months with an estimated AUPC of $153,000, raising affordability concerns.

Given the differences between the JCP and ICE, the JCM business and financial management director provided the details of the cost estimates (CEs). The impending DAB review required the following cost estimating documents: program office estimate (POE), JCP, cost analysis requirements description (CARD), and ICE. The draft CARD developed for the JCM program was based on the approved requirements document resulting in a proposed design (depicted in Figures 2 and 4). The CARD prepared for the JCM program formed the basis for the JCP and the ICE. Exhibit 3 provides an overview of DoD cost estimating policies and procedures.

The JCM JCP combined an Army POE and Navy POE that was reconciled through the Cost Review Board Working Group (CRBWG). The JCP documented the multiple cost estimating methodologies, including analogy, engineering, and actuals, as well as expert opinion. The estimated costs developed in the JCP broken down by appropriation categories (DoD "colors" of money) is depicted in Table 1. The two areas to highlight within the JCP are research, development, test, and evaluation (RDT&E) costs and procurement costs (funds production and manufacturing). The RTDE costs relied heavily on the analogy cost estimating method, specifically analogies to Hellfire and Javelin missile development efforts. The most important cost driver to procurement was recurring production, estimated to be $4.79 billion for the JCM program in the JCP. It was within recurring production that the learning curves and production rates greatly impacted the cost estimates. The JCP estimate derived theoretical first unit cost values (T1s) for the components and subcomponents of recurring production based on comparisons to the Javelin and Hellfire missile programs.

Table 1. JCP JCM Life-Cycle Costs (Gregory, 2004)

Cost Element		JCP (dollars in millions)		
		Army POE	Navy POE	Total
1.0	Research, Development, Test & Evaluation	552	418	970
2.0	Procurement	2,162	3,861	6,023
4.0	Military Personnel	15	-	15
5.0	Operations and Maintenance	179	88	267
	Total Life-Cycle Costs	2,908	4,367	7,275

The following assumptions were factored into the cost estimates:

- Costs presented in constant fiscal year (FY) dollars
- EMD Phase: 48 months with a cost plus incentive fee-type contract
- Low-rate initial production: 1 year with fixed price incentive-type contract
- Full-rate production: 10 years with fixed price contract
- Army platform: Apache (AH-64D)
- Navy platforms: Cobra (AH-1Z), Super Hornet F/A-18 E/F, and Seahawk MH-60
- Acquisition objective (AO) of 48,613 missiles
- Assumed Production Profile

Fiscal Year	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
Production Quantity	220	1,519	2,511	3,217	5,030	5,367	5,587	5,908	6,483	6,089	6,682

Like the JCP, the ICE was also based on the CARD but differed substantially from the JCP. The ICE and JCP variance of life-cycle costs are depicted in Table 2. The primary differences between the two cost estimates were the estimated development time for the EMD phase and the recurring production costs for the missile. According to the Army and Navy, the critical technologies were matured in the previous TMRR effort to the recommended TRL 6 and did not require more than 48 months for system integration and development efforts. The CAIG disagreed with this assumption, using a review of historical missile programs that incorporated multimode seeker, multipurpose warhead, and common motor technologies. In doing so, the CAIG estimate determined a developmental effort lasting 26 months longer. This increase made the total time the JCM program required RDT&E funding to increase from 48 months to 74 months. The increase to 74 months was the primary driver for the 39% increase in forecasted dollars for RDT&E in the ICE. Although the CAIG settled on 74 months for development effort duration, they opined that the JCM program could easily incur a 147-month development effort given the complexity of the JCM and its requirements.

Table 2. JCM ICE and JCP Life-Cycle Cost Comparison
(Burke, 2004)

Cost Element		Cost Estimate Source		Difference (dollars in millions)
		JCP (dollars in millions)	CAIG (dollars in millions)	
1.0	RDT&E	970	1,350	380
2.0	Procurement	6,023	7,490	1,467
4.0	Military Personnel	15	20	5
5.0	Operations and Maintenance	267	270	3
	Total Life-Cycle Costs	7,275	9,130	1,840

The other difference between the JCP and the ICE rested with the recurring production cost estimates. The T1 used for the CAIG CE was lower than the T1 used in the JCP despite the overall increase the CAIG predicted recurring production costs 25% greater than recurring production estimated costs in the JCP. To compare the difference between the two estimates, the CAIG offered its method of application for the learning and production rates. The rate of learning applied by CAIG was 88% and a production rate effect of 90%. The CAIG developed these rates through regression analysis of 12 previous missile production programs. As the CAIG compared its rates to the JCP, it was determined that the JCP used T1s and cost progress curves for each component and subcomponent of production. For comparison purposes, the ICE determined that the JCP used a 93% learning curve rate and an 83% production rate effect. The CAIG also highlighted that the procurement profile of the JCM program was not typical for missile programs. According to the CAIG, missile programs normally desired to achieve a "tooled rate" earlier in production, and then have quantities at a level rate thereafter. The JCM production profile exhibited a continual increase in production amounts over 11 years.

Path Forward

With all this information, Colonel Smits knew her team was prepared to address the concerns of the MDA. Further coordination with the OUSD[A&S] revealed that the MDA wanted to discuss answers to the following before rescheduling the DAB review:

- What were the key differences between the joint cost position (JCP) and the independent cost estimate (ICE), and why did those differences exist?
- What should the program manager recommend for the length of the engineering and manufacturing (EMD) phase?

- What's the difference between the learning rate effect and the production rate effect in estimating recurring production costs?
- For recurring production,
  - How was the cost estimated for a specific missile from the production schedule?
  - What were the assumed T1 values used in the JCP and ICE?
  - Why would the JCP and ICE assume different learning rate effect values and different production rate values?
- What were the PM recommendations to the MDA on how to certify the JCM program as affordable and fully funded to Congress with the differences between the JCP and ICE?

References

Burke, R. P. (2004, April 16). *Cost Analysis Improvement Group (CAIG) independent cost estimate (ICE) for Joint Common Missile Program Milestone B review* [Memorandum]. Under Secretary of Defense for Acquisition, Technology, & Logistics.

Common Missile Project Office. (2003). *Acquisition strategy & acquisition plan for the Joint Common Missile (JCM)* [Acquisition strategy report]. Army Program Executive Office, Tactical Missiles.

Defense Acquisition University. (2013). *Defense acquisition guidebook*. https://www.dau.edu/tools/dag

Defense manufacturing management guide for program managers. (2012, October 16).

DoD. (2018). *Independent government cost estimate (IGCE): Handbook for services acquisition*. https://www.acq.osd.mil/dpap/sa/Policies/d333333333ocs/DOD_IGCE_for_SA_Handbook.pdf

Forces Command DCS for Logistics. (2000). *FORSCOM handbook for cost and price analysis*. https://www.dau.edu/tools/Lists/DAUTools/Attachments/25/Cost_and_Price_Handbook.pdf

GAO. (2019a). *GAO cost estimating and assessment guide*.

GAO. (2019b). *Weapons systems annual assessment: Limited use of knowledge-based practices continues to undercut DOD's investments* (GAO-19-336SP).

Gregory, E. J. (2004, May 7). *The Joint Common Missile (JCM) joint cost position* [Memorandum for the Army Acquisition Executive]. Department of the Army.

International Society of Parametric Analysts. (2008). *Parametric estimating handbook* (4th ed.). https://www.dau.edu/tools/Lists/DAUTools/Attachments/112/Parametric%20Handbook%204th%20Edition.pdf

Joint Common Missile Program Office. (2004, April 22). *Joint Common Missile: Defense Acquisition Board brief*.

Joint Requirements Oversight Council. (2004). *Capability development document for Joint Common Missile*. Defense Acquisition Board.

Mislick, G. K., & Nussbaum, D. A. (2015). *Cost estimation methods and tools*. John Wiley and Sons.

Mortlock, R. F. (2005, January–February). The Joint Common Missile project: Program management lessons learned. *Army AL&T*, 36–39. https://asc.army.mil/docs/pubs/alt/2005/1_JanFeb/articles/36_The_Joint_Common_Missile_Project_200501.pdf

NASA Cost Analysis Division. (2015). *NASA cost estimating handbook version 4.0*. https://www.nasa.gov/sites/default/files/files/01_CEH_Main_Body_02_27_15.pdf

Office of Cost Assessment and Program Evaluation. (2017, October 2). *Cost analysis guidance and procedures* (DoDI 5000.73). DoD. https://fas.org/irp/doddir/dod/i5000_73.pdf

Office of the Secretary of the Army. (2011, January). *Army strong: Equipped, trained and ready*. DoD. https://archive.org/details/DTIC_ADA546200/page/n3/mode/2up

Office of the Under Secretary of Defense for Acquisition & Sustainment. (2020a). *Operation of the adaptive acquisition framework* (DoDI 5000.02). DoD. http://acqnotes.com/wp-content/uploads/2014/09/DoD-Instruction-5000.2-Operation-of-the-Adaptive-Acquisition-Framework-23-Jan-2020.pdf

Office of the Under Secretary of Defense for Acquisition & Sustainment. (2020b). *The defense acquisition system* (DoDD 5000.01). DoD.

https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/500001p.pdf?ver=2020-09-09-160307-310
Parker, W. (2011). *Defense Acquisition University program managers tool kit* (16th ed.). http://www.acqnotes.com/Attachments/DAU%20Program%20Managers%20Toolkit.pdf
Rausch, J. (2019). *Joint Capabilities Integration & Development System overview: New manual and sustainment key performance parameters*. Joint Staff, Office of the Secretary of Defense. https://www.acq.osd.mil/log/MR/.PSM_workshop.html/2019_Files/Day_One/3_New_JCIDS_Instruction_Guidebook_Rausch.pdf
Richey, K., Echard, J., & Cha, C. (2009). *GAO cost estimating and assessment guide: Best practices for developing and managing capital program costs* (GAO-90-3SP). GAO. https://permanent.access.gpo.gov/LPS113168/LPS113168/www.gao.gov/new.items/d093sp.pdf
Sleevi, N. F., & Mount, R. (2003). *Joint Common Missile (JCM) joint analysis of alternatives final results* [Military Senior Advisory Group briefing]. U.S. Army Training & Doctrine Command Analysis Center.
Sower, V., & Sower, C. (2015). *Better business decisions using cost modeling* (2nd ed.). ProQuest.
Srull, D. (1998). *The cost analysis improvement group: A history*. Logistics Management Institute.
Weapon Systems Acquisition Reform Act of 2009, Pub. L. No. 111–23, 123 Stat. 1704 (2009, May 22).

Exhibit 1. JCM Acquisition Program Baseline

The JCM program acquisition strategy outlined a 4-year EMD phase that met the warfighter required initial operational capability (IOC) dates and had support from the warfighting community, the services' requirements communities, the service chiefs, and service acquisition executives. The APB outlined the following performance, schedule, and cost constraints applied to the JCM program.

PERFORMANCE: The Joint Requirements Oversight Council–approved JCM capability development document (CDD) contained the KPPs that formed the basis for the performance section of the APB.

#	Key Performance Parameter	Performance
1	**Targeting**	Precision Point (Laser Designated / Guided)
		Fire & Forget – Active (Radar Designated / Guided)
		Fire & Forget – Passive (Infrared Designated / Guided)
2	**Combat Effectiveness**	Anti-tank (T-90 Soviet tanks)
		Anti-personnel behind triple brick & concrete walls in military operations in urban terrain (MOUT)
3	**Range**	Rotary wing (RW): 16 Km
		Fixed wing (FW): 28 Km
4	**Interoperability (Platforms)**	AH-64D (Apache), AH-1Z (Cobra), F/A-18 (E/F) Super Hornet, MH-60R Seahawk
5	**Carrier / Shipboard Capibility**	F/A-18 (E/F) Super Hornet, MH-60R Seahawk

SCHEDULE: The approved CDD documented an IOC for the JCM at MS B + 5 years (60 months) based on the urgency of the need. The EMD phase was planned for 4 years (48 months). The schedule part of the APB had the following events: critical design review (CDR) at MS B + 2 years (24 months), MS C at MS B + 4 years (48 months), and IOC at MS B + 5 years (60 months).

COST: The approved CDD specified an acquisition objective for the JCM of 48,613 missiles to be procured for the Army and Navy. Cost estimates from the JCP determined an AUPC of $108,000. The program funding was incorporated into the approved services' program objective memoranda. The JCP was approved by the Army and Navy that funded a 48-month EMD phase with RDT&E funding and a 11-year production and deployment (P&D) phase with procurement funding.

Exhibit 2. JCM Technology Risk Assessment

The JCM program stakeholders collectively assessed the TRLs of the three critical technologies and other risks based on the JCM WBS (Sleevi & Mount, 2003).

- Risk 1: Seeker Technology Maturity—The JCM employed precision point, fire and forget passive, and fire and forget active targeting capability (mandated by KPP 1) that required the development of a tri-mode seeker. A tri-mode seeker required the integration of hardware and software for real time acquisition and tracking of targets in each of the three seeker modes and integrated with guidance and control (G&C) and inertial navigation system (INS). Additionally, the seeker radiation dome (Radome) had to transmit radiation for the millimeter wave radar, infrared signature, and laser designations.

  Tri-mode Seeker—TRL 6 (prototype demonstrated in militarily relevant operational environment)

- Risk 2: Warhead Technical Maturity—The JCM was designed to defeat a wide array of targets (mandated by KPP 2), including threat tanks and threat personnel in bunkers that required the development of a multipurpose warhead and fuse. The warhead technology was highly complex because each target requires different engagement mechanisms to achieve the required lethality effectiveness.

  Multipurpose Warhead—TRL 6 (prototype demonstrated in militarily relevant operational environment)

- Risk 3: Propulsion / Rocket Motor Technology Maturity—The JCM was to be fired from both rotary wing and fixed wing aircraft (required by KPP 3). The boost and sustain technology required high turn down ratios to adjust the propulsion nozzle to achieve rotary and fixed wing ranges. The JCM required a turn down ratio of approximately double that of existing missiles from current platforms. In addition, the wide range of environmental conditions as well as vibration and shock constraints for both rotary and fixed wing platforms was challenging to address in a single common motor.

  Common Rocket Motor—TRL 6 (demonstrated in militarily relevant operational environment)

- Risk 4: Missile Integration—The tri-mode seeker, multipurpose warhead, and common rocket motor system required intensive software synchronization.

- Risk 5: Platform Integration—The missile was to be integrated with the on-board fire control systems and launcher systems for each of the service platforms (required by KPP 4).

Exhibit 3. Basics of DoD Cost Estimating

The planning, programing, budgeting, and execution (PPBE) process was implemented before the start of the Vietnam conflict as the DoD's revolutionary budget process (Srull, 1998). The resourcing of acquisition programs in the DoD occurs through the decision support systems referred to as the PPBE process. Refer the Exhibit 4 for an explanation of how the PPBE process fits within DoD big "A" acquisition system. The purpose of the PPBE process is to ensure that resources are properly allocated within the DoD to support the National Defense Strategy and National Security Strategy objectives. Within the PPBE process, acquisition professionals rely on cost estimates to inform decision-making and determine the APB. At each program milestone, the MDA must certify to Congress the program is affordable and fully funded in the services' programmed annual budgets.

In December 1971, the CAIG was established to assist the DoD with estimating costs early and often within the acquisition life cycle (Srull, 1998). The CAIG began comparing initial cost estimates with actual program costs to better understand the cost breaches of the APBs. The application of cost estimating requires the understanding of a CE's function within the acquisition framework as well as the methods used to produce these snapshots in time. Regardless of one's understanding, cost estimates are critical for effective MDA acquisition oversight and decision-making (Office of Cost Assessment and Program Evaluation [CAPE], 2017). The GAO guidebook states that CEs also support the cyclical DoD budget cycle, impacting budget requests and proper alignment of resources, and seek to improve the financial performance of the DoD (Richey et al., 2009).

According to *Cost Estimation Methods and Tools* (Mislick & Nussbaum, 2015), some general principles exist to use CEs as a method to assist in decision-making. The first is that cost estimates are *not* precise, but rather are thorough and complete, meaning they possess key characteristics: completeness, reasonableness, credibility, and analytical defensibility. Second, despite being thorough and complete, CEs require assumptions. Understanding the assumptions within the CEs is critical to sound decision-making. Third, change will occur that affects the accuracy of CEs over time. Fourth, "cost issues are always a *major* concern, but they are almost never the *only* concern" (Mislick & Nussbaum, 2015, p. 4). Fifth, CEs are "guides" to enable a more-informed decision, not the answer. And last, CEs are an amalgamation of people, processes, and the data. Each of these elements is a product of its time and likely to change as newer technology creates ways to capture and apply data, people receive higher levels of education, and newer ways to analyze the data become available (Mislick & Nussbaum, 2015).

As required by the Weapons Systems Acquisition Reform Act (WSARA) of 2009, in response to continued congressional and constituent concerns about mismanagement of taxpayer dollars, the CAIG was replaced with the office of the Cost Assessment and Program Evaluation (CAPE), the organization now charged with developing independent government cost estimates for acquisition programs. CAPE executes the statutory guidance and regulatory requirements found within DoD Directive 5000.01 and DoD Instruction 5000.02 to support MDAs and acquisition professionals in sound data-driven decision-making practices. As a result of the requirements to influence broader objectives, CAPE is deliberately intertwined throughout the defense acquisition framework to ensure compliance.

The program management office coordinates with CAPE for support of major events and with the development of the CARD that contains the data about the program necessary to develop CEs. Before the PMO is authorized to begin its POE, the CARD must be deemed sufficient by CAPE. The final outputs required by the PMO include a completed POE and a full funding memorandum used to grant approval at the upcoming milestone. CAPE not only supports review of the CARD developed by the PMO, but it also produces the required ICE at major decision points.

The DoD utilizes five common methods when needed to develop CEs. Each method used carries different risks for the decision-maker regarding its utility for program decision making. A good understanding of the cost estimation methods may effectively reduce the risk of a program setting unrealistic cost and schedule parts of the APB. Selecting the appropriate CE methodology, and likely combination of methods, may likely yield the greatest quality CE (NASA Cost Analysis Division, 2015). Figure 5 shows where each method is likely used with respect to the acquisition phases. This figure highlights the relationship between the CE method and the amount of detail an estimate may produce given the program's position across the life cycle.

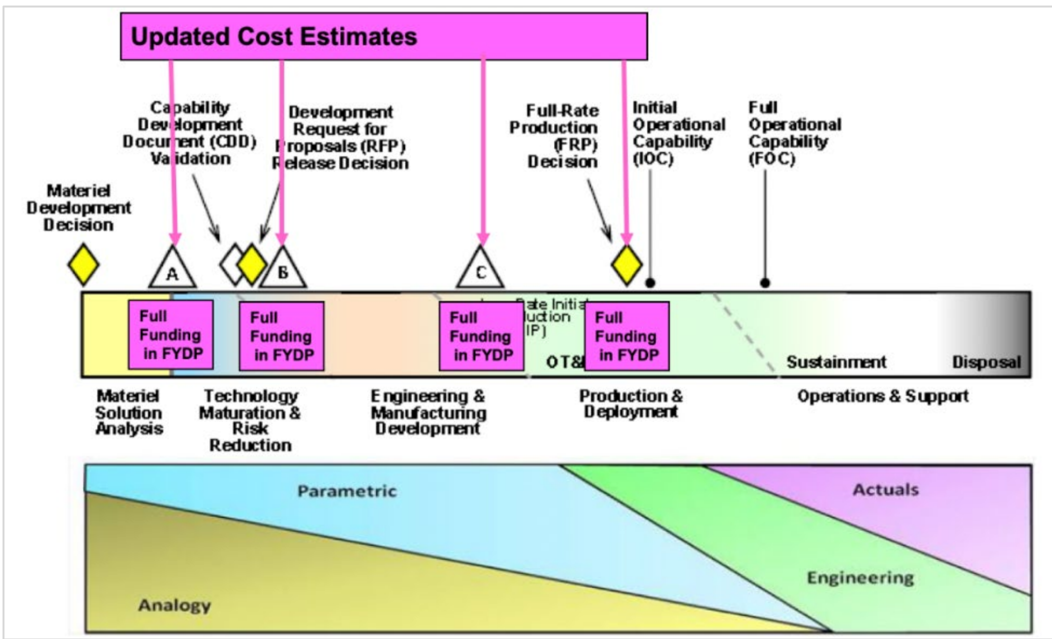


Figure 5. Cost Estimates Required and Methods Used
(Defense Manufacturing Management Guide for Program Managers, 2012)

The analogy cost-estimating methodology is typically used early in a program's life cycle due to the lack of specific data relating to the actual program. With the lack of a clearly defined system, analogy cost estimating seeks to find a previously fielded system that is comparable and is an aspect that reliably drives cost, then baselines those costs subjectively and accepts the former program's costs as a basis for the estimate. This method often relies heavily on the expertise of the cost estimate team (CET) to subjectively adjust upward or downward depending on the complexity of the comparable systems (Richey et al., 2009).

The *Parametric Estimating Handbook* (International Society of Parametric Analysts [ISPA], 2008) is a complete guide to the application of what is considered the "top down" approach to cost estimating—parametric methodology. It uses statistical relationships between key data of cost drivers within like programs. Understanding the cost drivers of similar programs enables the CET to develop a hypothesis to predict the future costs of the current program. The historical data in comparison that used the same cost drivers is normalized before conducting a regression analysis (ISPA, 2008).

Considered a “bottom up” estimate, the engineering cost estimate methodology requires significant amounts of data. Engineering CEs require a WBS at the lowest levels, historical data of similar programs, and actual costs. Engineers familiar with the work being analyzed assist the CET in developing the CE. This method is typically used once a program has entered production or after the program has gone through either a preliminary or critical design review.

Often referred to as extrapolation from actual costs, this methodology uses the current program’s costs to predict future costs of the same item(s). The most common actual CEs are those predicting costs through improvement curves, commonly known as learning curves. Estimating costs using learning curve theory can increase the accuracy of the CE. Advancements in cost theory have led to an added variable to the improvement curve calculations. That variable becomes the production rate, indicating the number of units produced during the period. Use of production rates to influence CEs is applicable where large production occurs at various rates (ISPA, 2008).

Although entirely subjective in nature, expert opinion is used when necessary. Typically, expert opinion is leveraged when no historical data is available, although the CET pays attention to the expert’s credibility to derive the source of the expert’s opinion. This method is not synonymous with the expertise applied by the CET to develop cost estimates.

In *Better Business Decisions Using Cost Modeling for Procurement, Operations, and Supply Chain Professionals*, the example of performing a task repetitively results in a reduced amount of time for future executions of the same task (Sower & Sower, 2015). This is learning curve theory in practice. The reduction in time per repetition represents the learning rates. The same principle applies the reduction in the unit cost of an item as more items are produced. Figure 6 highlights the learning rate and its effect. In this example, the first unit (referred to as T1) costs 1,000. With a 90% learning curve (10% learning), the unit cost decreases by 90% for every doubling of the number of units. Therefore, Unit #4 costs 810 (1,000 x .9 x .9) and Unit #8 costs 729. A 70% percent curve (30% learning) represents a steeper drop in unit costs for every doubling of the quantity.

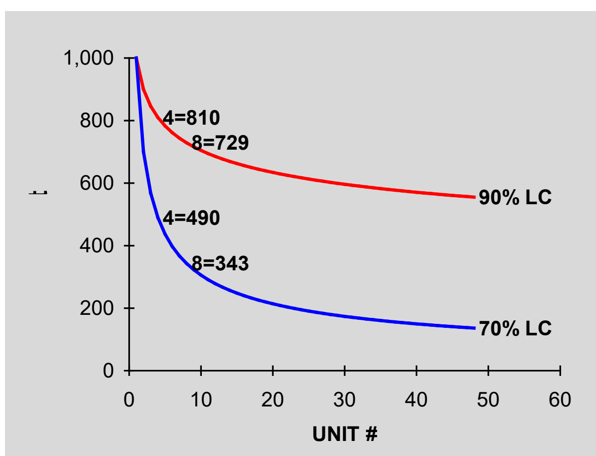


Figure 6. Example of Learning Rate on Unit Cost

According to the *FORSCOM Handbook for Cost and Price Analysis* (Forces Command DCS for Logistics, 2000), aeronautical engineers, when analyzing historical labor data regarding aircraft production, determined that there were specific rates of improvement for each successful completion of production when the successive production quantities doubled. In other words, the number hours to complete a task deceases at a constant rate for each doubling of the task attempts. Furthermore, "The learning curve, as originally conceived, analyzed labor hours over successive production units of a manufactured item, but the theory behind it has now been adapted to account for cost improvement across the organization" (ISPA, 2008, p. 2-7). Improvement, or learning curve theory is demonstrated using the following equation from the ISPA (2008, pp. 2-7):

$$Y = AX^b$$

where:

Y = the cost of the X^{th} unit

A = (theoretical) first unit (T1) cost

X = unit number

b = the learning slope coefficient (defined as the Ln (slope) / Ln (2))

The ISPA handbook finds that

> In parametric models, the learning curve is often used to analyze the direct cost of successively manufactured units. Direct cost equals the cost of both touch labor and direct materials in fixed dollars. This is sometimes called an improvement curve. The slope is calculated using hours or constant year dollars. (ISPA, 2008, p. 2-7)

In addition to understanding the improvement curve theory formula, applying the right technique is appropriate. The *GAO Cost Estimating and Assessment Guide* (GAO, 2019a) orients estimators to analyze production environments after analyzing the following factors:

1. Analogous systems
2. Industry standards
3. Historic experiences
4. Anticipated production environment

The basic understanding of unit curve theory is that as the production doubles, the cost to produce that amount decreases by a constant percentage. That percentage is the inverse of the learn rate applied. For example, if an 80% learning rate is applied, the cost of producing those units is reduced by 20%. Unit curve theory is typically used when production is well-defined, design is stable, and production lead times are typically longer (Mislick & Nussbaum, 2015).

The production rate effect is an advancement of learning curve theory. As production increases, economies of scale are realized, thereby reducing costs. The inverse is also true: as breaks in production occur, or production rates decrease, costs tend to rise. The efficiency of production can be explained by adding a variable rate to the preexisting learning curve formula (Richey et al., 2009). This is demonstrated using the following equation:

$$Y = AX^bQ^r$$

where:

Y	=	the cost of the X^{th} unit
A	=	(theoretical) first unit (T1) cost
X	=	unit number
b	=	the learning slope coefficient (defined as the Ln (slope) / Ln (2))
Q	=	production rate (quantity produced during the period or lot)
r	=	production rate coefficient (Ln (production curve slope) / Ln (2))

The ISPA handbook recommends

> the equation is generally applicable only when there is substantial production at various rates. The production rate variable (Q^r) adjusts the first unit dollars (A) for various production rates during the life of the production effort. The equation also yields a rate-affected slope related to learning. (ISPA, 2008, p. 2-8)

Exhibit 4. U.S. Defense Acquisition Institution—Decision Framework

Within the DoD, the development, testing, procurement, and fielding of capability for the warfighter operates within a decision-making framework that is complex. Within the private sector, similar frameworks exist. The U.S. defense acquisition institution has three fundamental support templates that provide requirements, funding, and management constraints. The executive branch, Congress, and industry work together to deliver capability with the program manager (PM) as the central person responsible for cost, schedule, and performance. Figure 7 depicts this framework.

Figure 7. Defense Acquisition Institution

The government PM is at the center of defense acquisition, which aims to deliver warfighter capability. The PM is responsible for cost, schedule, and performance (commonly referred to as the “triple constraint”) of assigned projects—usually combat systems within the DoD. The executive branch of government provides the PM a formal chain of command in the DoD. The PM typically reports directly to a program executive officer, who reports to the service acquisition executive (an assistant secretary for that service—either Army, Navy, or Air Force), who reports to the defense acquisition executive (the Under Secretary of Defense for Acquisition and Sustainment). Depending on the program’s visibility, importance, and/or funding levels, the program decision authority is assigned to the appropriate level of the chain of command.

Programs within defense acquisition require resources (for funding) and contracts (for execution of work) with industry. Congress provides the resources for the defense programs through the annual enactment of the Defense Authorization and Appropriation Acts, which become law and statutory requirements. The PM, through warranted contracting officers governed by the Federal Acquisition Regulation, enters contracts with private companies within the defense industry. Other important stakeholders include actual warfighters, the American public, the media, and functional experts (like engineers, testers, logisticians, cost estimators, etc.), as well as fiscal and regulatory lawyers.

As a backdrop to this complicated organizational structure for defense PMs, there are three decision support templates: one for the generation of requirements, a second for the management of program milestones and, and a third for the allocation of resources. Each of these decision support systems is fundamentally driven by different and often contradictory factors. The requirement generation system is driven primarily by a combination of capability needs and an adaptive, evolving threat. The resource allocation system is calendar-driven by Congress writing an appropriation bill—providing control of funding to Congress and transparency to the American public and media for taxpayer money. The defense acquisition management system (now referred to as the Adaptive Acquisition Framework) is event-driven by milestones based on commercial industry best practices of knowledge points and off-ramps supported by the design, development, and testing of the systems as technology matures.

Calculating Return on Investment in a Department of Defense Context: A Pilot Study

Eric Burger—serves as the Research Director of the Commonwealth Cyber Initiative (CCI) and Research Professor of NextG Security and Public Policy at Virginia Tech. From 2017–2019, he served as the CTO of the Federal Communcations Commission. From 2019–2021, he served as the Assistant Director of the White House Office of Science and Technology Policy. Burger also served as the CTO of several public and private companies. His research includes how to apply economic analysis to business decisions to improve the security and resiliency of individual companies and industries. [Eric.burger@vt.edu]

Robin Dillon-Merrill—is a Professor in the McDonough School of Business at Georgetown University. From 2017–2019 she served as the Program Director for the National Science Foundation's Humans, Disasters, and the Built Environment program in the Directorate of Engineering. She seeks to understand and explain how and why people make the decisions that they do under conditions of uncertainty and risk. [Robin.dillonmerrill@georgetown.edu]

Erika Heeren-Moon—is currently a second-year master's student in the Communication, Culture and Technology Program at Georgetown University. She currently serves as a Public Policy Graduate Research Intern with CCI at Virginia Tech. In 2023, Heeren-Moon will begin her JD/PhD with Rutgers Law School and Virginia Tech with a research focus on technology policy as it relates to cybersecurity, commerce, and the future of work. [Elh96@georgetown.edu]

Abstract

With few exceptions, there does not exist a generic framework for reliable calculations of return on investment (ROI) with the Department of Defense (DoD) that effectively take into account the unique mission values for DoD acquisition. This research explores the questions of whether the DoD can benefit from such an ROI acquisition model, and how that model may be implemented. In this paper, the researchers examine methods by which the DoD currently approaches acquisitions and what methods are used for creating Request for Proposals, evaluating bids, and awarding contracts. This information is then contrasted with how the private sector applies ROI models in acquisitions to identify critical differences and challenges in applying these methods to the DoD. Our results support that an ROI model can be built to encompass DoD objectives to enable the acquisition of superior systems and services and at the same time speed the contract process, better aligning bidders' interests with the DoD and addressing critical acquisition issues. Further, this research identifies specific areas where such a model can be applied in the short term to increase efficiency in internal acquisition data analysis and examines using a Single Source of Truth (SSoT) framework.

Keywords: Defense Acquisition, Acquisition, Acquisition Innovation, Contract Management, Research & Development (R&D), Data Analysis, Data Management, Operational Efficiency

Introduction

Return on Investment (ROI) is a metric used by companies to measure the profit potential of future projects or acquisitions. This paper poses whether the Department of Defense (DoD) can apply an ROI model for its investments. The interviews in this research raised several key themes relating to DoD acquisitions. These themes compared how private sector companies work with other private sector companies versus the DoD.

Our research began with surveying how the DoD currently approaches acquisitions and what methods are used for creating RFPs, evaluating bids, and awarding contracts. We contrasted this with how the private sector applies ROI models in acquisitions and identified critical differences and challenges in applying these methods to the DoD. Most notably, private companies seek to maximize profit. The DoD does not generate revenue from its operations or acquisitions and is not a profit-maximizing organization. Instead, mission objectives such as enhancing operational capabilities or reducing life safety risks are the goal.

The team conducted interviews with DoD acquisitions personnel, private-sector vendors who have bid on DoD acquisitions, and commercial vendors. Our findings revealed pain points within the process preventing some contractors from offering the maximum possible value to the DoD on their bids. Also, from the length of time it takes to get from acquisition requirements to bidding, technology may become obsolete. Additionally, private sector bidders identified an apprehension towards reopening acquisition requirements if a better solution was available to avoid lengthy renegotiation processes.

Private sector bidders on DoD acquisitions also named Lowest Price Technically Acceptable (LPTA), a method of analyzing bids and awarding contracts, as a potential deterrent from maximizing the value of their bids. Concerns over competitors undercutting them on price leads to bidders crafting proposals only to meet the minimum requirements and pass up delivering potential benefits to the DoD.

The team also found data to be a critical issue for all DoD acquisition stakeholders. The private sector uses first- and third-party data to inform ROI decision-making models. While the DoD has a new data management infrastructure that can be used to create a Single Source of Truth (SSoT) data lake, interviewees noted the data is not used or shared much. We believe that such SSoT data could be used to inform ROI decision-making for the DoD.

When assessing our findings in the context of ROI in DoD acquisitions, the team zeroed in on the problem of quantifying DoD "returns" or the benefits offered by acquisitions. This assessment is necessary to perform an ROI calculation, as procurement dollars need to be compared to some return. This issue is an area of continued research for the team and will inform the eventual realistic deployment of a potential DoD acquisition model. This model will need to be replicable and consistent, relying on standardized parameters and historical contract performance data to ensure valid and equitable results. This issue is another potential application for a DoD SSoT data infrastructure.

Based on our findings, the project research team believes that an ROI model can be built to encompass DoD objectives to enable the acquisition of superior systems and services and at the same time speed the contract process, better aligning bidders' interests with the DoD and addressing some of the acquisitions issues identified during our research. In short, when assessing the question of whether the DoD can benefit from an ROI acquisition model, the answer is yes, and our team is looking ahead to how this model will work and where it could apply within existing DoD processes.

Background

Return on investment (ROI), a calculation of the expected financial return on a given financial investment, is helpful for businesses to maximize the value of their capital expenditures and measure the performance of their assets. A metric for the financial performance of assets is useful for companies because it allows them to make objective decisions between acquisition options and to evaluate whether a particular project or endeavor is worth pursuing. The DoD today applies some business analytics processes in its acquisition process, including market research studies, investigation of alternatives, and historical pricing analysis for existing contractors (DoD, 2018). In some situations, the DoD does consider ROI through the cost savings from an acquisition to perform a specific function. This practice would be true for some acquisitions of commodities for enterprise use, such as staples like toilet paper, and for complex but well-characterized enterprise software systems such as payroll or accounting software. This process is known as Value Engineering (Gluck, 1976) and is often evaluated in the contracting process as Lowest Price Technically Acceptable (LPTA). However, since many DoD acquisitions do not result in revenue or direct cost savings, conventional wisdom is that no return-on-investment analysis is possible for contract evaluation. We propose to create meaningful, actionable metrics for the DoD to calculate ROI, based on how the private sector calculates ROI, but using DoD-specific metrics for return.

How Private Sector Businesses Use ROI

Private sector companies use ROI calculations to model business outcomes and test potential acquisition outcome scenarios. ROI models depend on input costs, investment schedule, and resulting revenue or cost reduction to determine a return on capital invested over time. These inputs rely on assumptions from estimating total costs, projecting schedules forward, and predicting future profit streams. These inputs contain two components, a dollar cost or time and a risk or uncertainty coefficient. These inputs and risk estimates can be based on historical data with contextually specific accommodations. Each of these inputs can be varied to see its impact on the performance of the acquisition, such as stress testing the model in the event of reduced future revenue or project delays. This flexibility to test potential scenarios and outcomes is a powerful tool for businesses making acquisition decisions.

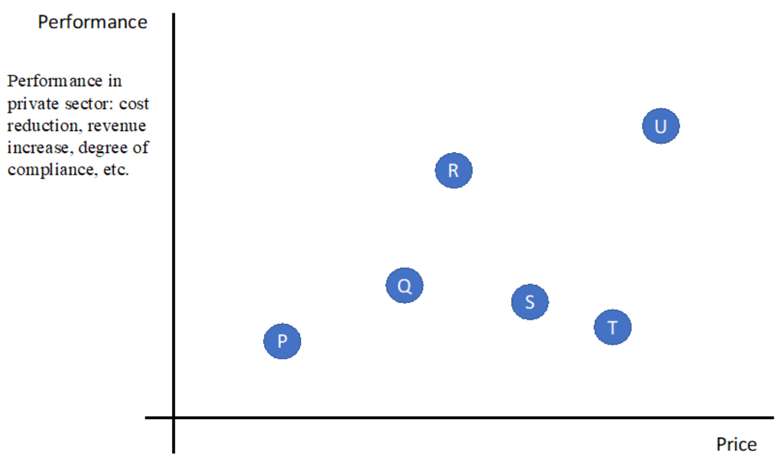


Figure 1. ROI as a Private Sector Tool for Acquisition

Figure 1 shows a hypothetical acquisition scenario for the private sector. Each of the various vendors P–U are responding to the RFP with products or services at various price points, delivering different value to the private sector. For most acquisitions, the value to the private enterprise is usually calculated as an improvement to profitability by increasing revenue or reducing costs. Note that there are other measures of value for a private enterprise. For example, in regulated industries, an investment in compliance solutions may not directly increase revenue. Being in compliance means the enterprise can be in business and thus make profits.

The figure shows that U delivers the most performance but at the highest cost. P is the least expensive but does not deliver much performance. In this simplified example, the private enterprise is most likely to select vendor R. It has the best-realized performance for the total cost, maximizing value and resulting in the highest ROI.

ROI provides a comprehensive performance metric for any acquisition or investment. This allows a business to compare different potential acquisitions and choose the most significant return or profit potential. ROI can also measure passive investments, comparing proceeding with a risky project versus allowing the investment capital to incur interest instead. One of the main reasons ROI models work for businesses as a decision-making tool is the profit-maximizing goal of a company and a desire to maximize the potential profit from available capital to be invested. With the correct ROI models, businesses can always choose the profit-maximizing option available to them.

Current Department of Defense Acquisitions and Application of ROI

The DoD has used various simplified forms of ROI analysis to inform acquisition decisions for decades. However, much of the focus of the acquisition process is spent specifying the deliverable to alleviate the need to compare value between different bids. While the private sector can reduce virtually everything to profit, the “return” in a DoD context uses a different set of goals—namely, the protection and promotion of U.S. interests on a global scale.

One challenge that arose from our research process was the broad nature of DoD acquisitions. There are many commodities and services acquired by the DoD that are handled well within the existing methods. For example, when acquiring something as simple as toilet paper, calculating the return on investment for this item is straightforward: buy the least expensive roll that wipes. Additional performance parameters are not a consideration. Similarly, when acquiring something a little more complicated—like computer hardware—there is still a general understanding of what is needed to create acquisition requirements. Does the new hardware provide faster access? How much faster? Does it reduce maintenance costs, and by how much per year? These are still straightforward ROI calculations. If the value offered by an acquisition for the DoD can only be measured in operational performance or risk reduction, non-monetary metrics for value will be needed for the DoD to measure the ROI of these acquisitions.

Currently, there is no reliable framework for ROI calculations that consider the unique mission values for DoD acquisitions. This report addresses this need by proposing an ROI tool for the acquisition process that emulates private sector ROI analysis in DoD contexts. Moreover, we hypothesize that a standard framework for evaluating ROI will enable acquisition personnel to accelerate the development, letting, and award of contracts overall with higher functionality and lower total cost. The purpose of this research is to identify opportunities in the DoD acquisition process where ROI calculations can be used to improve the performance of defense acquisitions in cutting-edge technology. By adapting the best practices of the private sector and non-DoD public sector’s ROI calculations to reflect the unique, non-monetary components the DoD considers as its “return,” acquisitions can better achieve the goals that improve the DoD’s return metrics.

Research Methods

In sourcing and reviewing research and associated articles relevant to the project, the following questions were points of focus. First, how does the DoD currently approach the acquisition process? Second, how does the private sector approach acquisitions? How is this different from how they sell to the DoD? Third, noting the importance of data analytics to estimating costs, risks, and value, we asked which established and emerging data analysis methods are showing the most significant efficacy within the private industry that may be applied to the DoD contract procurement process?

To best understand the current status of the DoD acquisition process and how private industry acquisition practices can play a more effective role, we began by reviewing industry standards for defining return on investment. Then we conducted interviews with industry professionals and defense representatives to gain boots-on-the-ground insight into current best practices, areas of issues, and potential solutions.

We conducted seven interviews with ten individuals from various components of the Department of Defense, an independent agency, and the GSA. From the private sector, we conducted 13 interviews with seven individuals from enterprise equipment companies, enterprise software companies, and defense contractors, including CRI Advantage, IBM, Oracle, Second Front Systems, an additional large enterprise systems manufacturer that services both the public and private sector, and one independent small business defense contractor.

Findings

The interviews we conducted produced interesting insights into the world of technology acquisitions. Throughout the discussions, key themes were raised for private sector companies in the context of working with the DoD and how that compares to how private sector companies work with others in the private sector. It was interesting to see the intersection of the perspective from private industry and the concerns of the DoD acquisition representatives and key program personnel. In developing a solution to guide the acquisition process, these commonalities present a possible opportunity to create process improvement.

Before we review the results of the interviews, the following two sections discuss the results of our brief literature review on DoD contracting.

Relevant Contract Types

When dealing with technology services and research and development acquisitions, many contract types are available. For this paper, we will focus on the general contract types associated with technology services acquisitions rather than the individual process for all subcategories of contract acquisitions. There are three contract types commonly used. The first is Firm-Fixed-Price, the second is Cost-Plus, and the third is Time-and-Materials. Firm-Fixed-Price (FFP) contracts provide a price that is, as the name suggests, fixed established on the object or service being acquired. Subcategories of FFP allow for price adjustments based on economic changes and other incentives. Cost-Plus is used in technology services acquisitions and is a variation of a cost-reimbursement contract. In these scenarios, there is typically a fixed base amount and an additional fee. That fee may be defined as a secondary fixed fee or a varied fee based on critical evaluation from the DoD. Time-and-Materials contracts are direct cost evaluations based on materials needed and time used based on hourly rates (FAR Part 16, 2021).

Expanding this analysis further, when considering new innovative products and services that may include significant research or development, FFP is typically not regarded as viable because this activity has considerable uncertainty as to effort and risk (FAR 35.006c). Cost-Plus contracts leave additional room for unforeseen costs to make the contracts fair to the DoD and financially viable for the contractor. Time-and-Materials can be a viable option; however, there is some debate whether the Time-and-Materials approach leaves room for contractors to “pad” their invoices and raise the overall price of the contract (DoD, 2018).

Interview Analysis

Several themes arose from the research we conducted. One common theme was the identification of barriers to the practical application of an ROI model. Additionally, the application of Lowest Price Technically Acceptable (LPTA) was discussed frequently by interviewees. Finally, the role of data application in analyzing and awarding contracts was discussed by interviewees.

Interview Theme 1: Barriers to Applying ROI Models in DoD Acquisitions

The DoD is not a business. It does not seek revenue derived from its investments. It is not seeking to maximize profit or obtain any financial return on the investment made. Instead, the DoD has other goals, such as expanding operational capabilities, improving life safety, establishing deterrent positions, and reducing risk. To apply ROI analysis for DoD acquisitions, finding substitutes for profit is necessary. Our preliminary research has identified the following challenges.

The first challenge is the process of identifying the requirements for a potential acquisition, releasing a request for proposal, and ultimately reviewing and awarding a contract is a barrier to the DoD acquiring the best solution for the problem at hand. Technical scopes, especially for technology procurement, are written one or more years before the DoD can send requests for proposals to the market. Often, the best technological solution can become obsolete before it is acted upon, leaving the DoD with a solution that is not the most effective option for the requirement. By the time the DoD negotiates contracts, technology products involved in the scope may be several generations obsolete. A common practice is to generate a change order upon contract award to update the procurement specifications. However, this gives contractors significant pricing leverage, resulting in inefficient procurement and further delays as terms are continuously renegotiated.

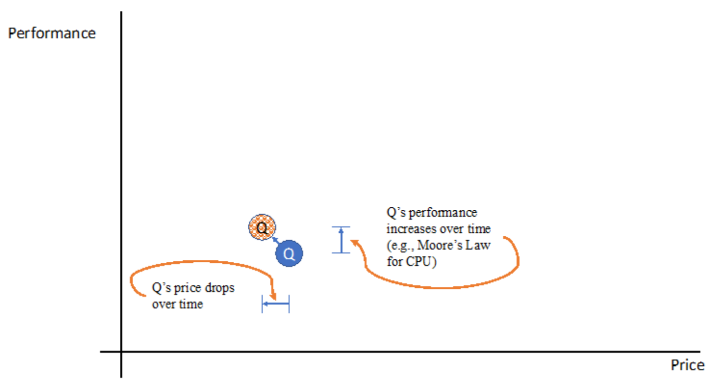


Figure 2. Impact of Long Contracting Cycles of Price/Performance

Figure 2 shows this scenario schematically. Assume the DoD selects vendor Q. We note the performance of Q's bid and pricing as the solid blue circle. However, in the intervening months or years since the RFP was written, released, and the contract was awarded, technology has progressed, and higher performance is available for a lower cost. This is typical for computer purchases. The DoD will want to use the more modern hardware. We note the performance of Q's system at award time by the hashed orange circle. The DOD will want the higher performance, so it will issue a change order to the contract. However, as a change order, vendor Q has little incentive to give the DoD the full reduction in cost—if it gives any of the reduction to DoD. Thus, the DoD leaves the potential value "on the table" by the delays from a long RFP cycle.

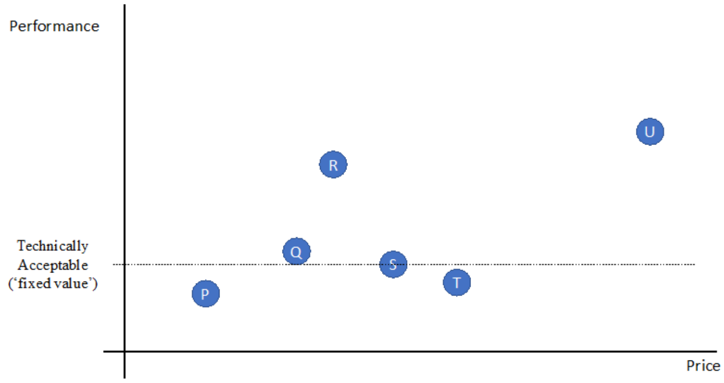


Figure 3. Impact of LPTA vs. ROI

Now consider LPTA operation, as depicted in Figure 3. The DoD would select Q at contract time and reject the other bidders based on either not being technically acceptable (P and T) or not being the lowest price (R, S, and U). Note this leaves the far superior value at a modest cost increment provided by R. However, the impact of LPTA truly comes to light if the RFP process is protracted. In the hypothetical example depicted in Figure 4 we keep the value/cost improvement shown by vendor Q from Figure 2. We also put out the hypothetical that vendor P's price does not change, but now it meets the basic requirements. Vendor R's price increases incrementally, but its value to DoD has significantly improved. Finally, Vendor U's performance holds, but its price drops dramatically. By eliminating all but Q in the LPTA process, the DoD forfeits access to these far superior alternatives.

The second challenge is a lack of clarity in scope and the ability to enumerate the actual needs of a contract. This creates issues within the acquisition process. Because an RFP specifies the minimum performance required by the DoD, companies may choose to bid the lowest cost technically acceptable solution, even though a significantly higher performance option may exist for a slight increment in cost. By focusing on minimum requirements and minimum price, the DoD contractors will deliver minimum performance that meets the requirements. That is fine for toilet paper or a bolt, but most likely a less than ideal goal for a complex weapons system.

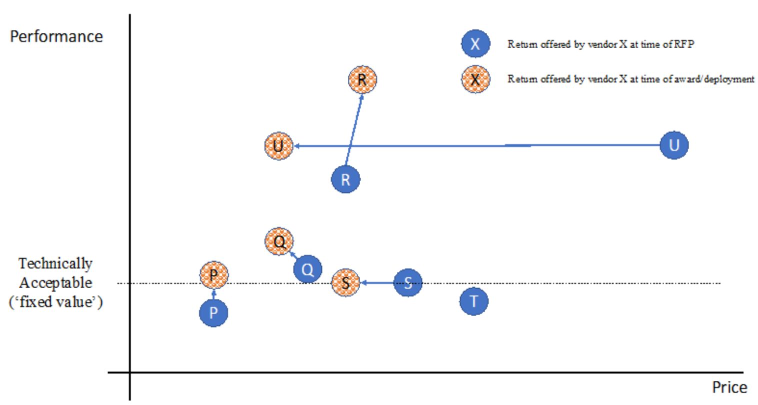


Figure 4. LPTA and Contract Delay

Interview Theme 2: Data Application in the Acquisition Process Creates Barriers to Effective ROI Calculation

A consistent message from our interviews with DoD personnel and private industry contractors was that applying existing data to current acquisition analysis was an issue. The DoD collects substantial data from internal resources regarding the performance of contracts, issues arising from established processes, and input from personnel on future needs. There are limited established processes to categorize and review the data efficiently regularly. Much of the data, historically, has lived in silos. As a result, applying past performance data to new technology or technology services acquisitions has been virtually impossible. While the DoD has invested in addressing the issue of data management, the application within the acquisition process has not been fully realized.

It is important to note that the DoD is a unique entity. It does not operate in the same fashion as a private enterprise because the DoD is not attempting to maximize profit over time. Instead, the DoD measures its success in less quantifiable areas such as promoting national defense, improving the life safety of service members, and reducing the costs and risks of its operations. Where private industry measures success in the fixed context of profit, the DoD measures success in the perpetually ambiguous goal of ensuring that U.S. interests are protected and promoted across the globe. So, the question becomes: Which data is necessary to make appropriate recommendations on return on investment?

The private industry has the flexibility to be very fluid and agile in the efforts to adapt to data best practices to help calculate value and total cost to determine the return on investment. The DoD is, by nature, an extensive, multifaceted organization that requires more touchpoints for the same goal. Therefore, it is an important contribution to the DoD acquisition process (beyond very basic acquisitions) to find an appropriate solution for establishing and implementing ROI calculation processes based on insight from the private sector.

When considering the role of data in the contract award process, a critical difference between private industry and the DoD is the tendency of unsuccessful bidders to contest the buyer’s decisions. When a private company purchases a cloud computing services contract, for example, the companies that did not win the business of the purchasing company have little to no recourse after the decision. So, private companies have a degree of autonomy in purchasing decisions. If a private company submits a proposal to the DoD and loses the bid, by contrast, they can contest the decision and require the DoD to justify why the contract was awarded to the successful bidder. In this manner, the DoD is subject to legal disputes that can last months or even years. During this time, none of the contracts in dispute can progress—so the requirement is not filled. As a result, the decisions must be backed by clear data. In many cases, a list of clear requirements and the lowest offered price is easy to defend, so LPTA tends to prevail. Where private industry can award contracts based on which company they believe will provide the best long-term performance, the DoD must have a provable decision-making process to justify every award.

While these differences between private industry and the DoD are important considerations, there were certain aspects of data management from the private sector that hold exciting possibilities for the Department of Defense with the overall goal of deploying an ROI model in the acquisition process. In conducting our research, the comments we received from interviewees consistently noted the complexity of the DoD as an organization. Therefore, we believe that it would be helpful to take a closer look at complex private industries to provide examples of possible improvements moving forward. Many companies find success with a streamlined data flow in their acquisitions processes, creating applicable formulas and strategies for collecting acquisition data, disseminating that data, and creating practical tools for computing return on investment on any given project. It should be noted that many of these companies—like Amazon, Netflix, Airbnb, Equifax, and more—leverage data obtained from third parties, or "big data," to make business decisions and forecast potential value on supply chain needs and marketing endeavors (Bozic et al., 2019). This applies to DoD acquisitions in new technology because the business intelligence data application necessary to properly identify the actual retrospective cost of a contract in this sector is similar in many ways to the process needed for determining the actual lifetime cost of an acquisition. The DoD can use this information to improve the accuracy of ROI calculations.

In our research, one process for acquisition data collection we identified is a "Single Source of Truth" approach, or a data strategy designed to centralize the flow of information into a funnel that supports a clear definition of contract goals, requirements, and pricing parameters (DalleMule & Davenport, 2017). One key element that is a focal point for private industry ROI calculations is applying existing data to support critical business decisions. Streamlining the flow of data would greatly support creating a comprehensive tool that will help establish a clear return on investment calculation for the DoD acquisition process. While the development and application of an ROI calculation process is not dependent upon a Single Source of Truth (SSoT) data management approach, it would make a more efficient ROI analytics process by ensuring easy access to data about prior acquisitions—thereby allowing acquisitions analysts to make more realistic forecasts in calculating ROI.

Speaking specifically toward acquisitions, the Truth in Negotiations Act (TINA) requires contractors performing government contracts to submit cost data that is truthful, accurate, and complete. TINA was enacted to prevent the DoD from becoming overly reliant on industry cost or pricing data (Tharp, 2020). While helpful in avoiding concerns of profiteering, TINA does not necessarily have the necessary data to help calculate the return of an investment. Further analysis of the utility of TINA data for ROI calculation can be a topic of further analysis.

The Department of Defense has implemented data analytics platforms to help with data management. Advana (Deputy Secretary of Defense, 2021) was designed in collaboration with Booz Allen Hamilton to organize data from financial, medical, human resources, logistics, and other parts of the DoD to drive decisions based on advanced analytics. The DoD has placed a strong focus on a "Single Source of Truth" data strategy for its organizational goals for 2020 and beyond (DoD, 2020). The application for this data strategy in reference to acquisitions could potentially open doors for more effective ROI calculations in technology acquisitions (Defense Business Board, 2020). We explore this in the proposed research section of this report.

Additional Insights

In addition to our findings regarding developing and implementing an ROI model into the DoD acquisitions process, we identified additional areas of interest. Our interviews opened the door to additional commentary on the acquisition process from private sector contractors and DoD personnel. While the following insights may not directly speak to ROI, they present interesting opportunities for future research.

Interviewees noted that if a contract's budget and scope are publicly available through Congress, companies have little incentive to underbid the publicized budget regardless of the true cost. We think that an ROI model can help in this situation. Given most bids will cluster around the published budget, an ROI model can help the DoD select the best system for that price. This is a potential area of additional research.

DoD interviewees noted a struggle with defining knowable outcomes to obtain funding for vital projects like cloud computing initiatives from Congress. While not specific to return on investment, the issues identified demonstrate a possible barrier to efficiency in the acquisition for the DoD. This issue would be an excellent opportunity for future research.

Another issue raised from interviewees within the DoD is the potential implications of ROI calculations for internal processes and purchases in addition to outside acquisitions. Specifically, key infrastructure investments like the Test and Training Enabling Architecture (TENA) with the Test Resources and Management Center (TRMC) can assist the DoD in fiscal efficiency and improve outcomes in the justification of funding needs. One interviewee within the DoD used the example of a change of testing standards. This can potentially create a situation where the DoD needs the equipment and infrastructure to update the testing environment. However, key personnel in this process struggle at times with how to effectively quantify the return for these updates. They are needed improvements, but there is a need for a cost analysis that will effectively articulate all the important factors that must be considered to an audience that may not have full understanding of the internal need. We explore this and similar internal use case examples in the Proposed Research section of this report.

Discussion

The concept of applying an ROI model to DoD acquisitions is not new. For example, as early as 1976, Gluck proposed using economic analysis, or value engineering, to help reduce costs for DoD acquisitions. However, value engineering focuses on cost reduction for the same result, not on the tradeoff of costs and benefits to any given mission. Likewise, a buy decision for diagnostic tools can use classical ROI calculations (Feldman et al., 2009), and another study identified DoD-centric returns (Oswalt et al., 2011). Still, the focus of these studies was on the limited domain of modeling and simulation. However, it is important to note that a scientific framework to calculate return on investment in the DoD context does not currently exist. Our initial research expanded on these past studies learned, from private industry, and examined current issues between private sector contractors and the DoD. It has been our goal in this initial discovery phase to determine if an ROI model can be designed and practically deployed in the DoD acquisition process in a reasonably efficient manner. We have determined that the development and implementation of this model is possible.

Throughout our research, we posed whether an ROI model could be employed in DoD acquisitions to improve decision-making and acquisition performance. However, as discussed, some critical elements of an ROI calculation as the private industry uses it do not have direct DoD equivalents. Primarily, profit measured by the private sector is not a quantifiable metric for the DoD. Contributions to improved operational efficiency and capability, reduction of life safety risks, and political and tactical deterrent value are challenging to quantify in specific dollar amounts. Yet, each costs the DoD significant dollar investments. That said, private industry formulates a dollar amount for complex acquisitions like technology services, cloud computing, cyber security, and research and development. With further research, we believe we can adapt those methods to the DoD for evaluating similar acquisitions.

For the DoD to make meaningful ROI calculations, metrics will need to be applied to these concepts through a scoring or classification system that can compare different proposals. This system would need to be repeatable and consistent to reduce contract adjudication and reduce the time taken by the protest cycle. One way to demonstrate repeatability and consistency is to collect historical contract performance data and then combine that with assumptions of what new research and technology can deliver. To thoroughly analyze this component of a functional DoD ROI acquisitions model would require more research to assess its feasibility and best approach. This is an area of continued interest for our team.

We recognize that to accommodate different contract types, additional research would be needed to provide insight into how to adapt the ROI model to the contract type for the requirement. As discussed earlier in this report, Fixed-Price, Time-and-Materials, and Cost-Plus contract types are all used for different acquisition needs. Each of these contract types has a different framework for assessing costs associated with a procurement. As a result, an effective ROI model would need to adjust for these unique parameters.

In addition, to be maximally effective, the use of the ROI model should not be limited to post-RFP proposal analysis. It has been noted in our research that the DoD acquisition process has many touchpoints. There are several personnel and considerations involved in establishing a scope of work, creating a request for proposal, analyzing contracts, and managing an awarded contract. A DoD-specific ROI model might vary from the perspective of DoD personnel in different phases of the acquisition. One area of research is to examine these different phases of the acquisition process and how the deployment of the ROI model would improve that phase.

Equally as important, if the ROI calculation model were to be used to establish the best possible value in awarding a contract, that model would need to be backed with enough traceable data to justify the decision in the case of an unsuccessful bidder contesting the decision. In the interviews we conducted, multiple DoD representatives noted that contract awards could be contested. The length of time these legal reviews take can range from a few months to more than a year. One of the reasons for choosing LPTA for proposal review is that LPTA provides clear reasoning for rejecting the other proposals, which protects the DoD from lengthy legal delays in disputes. To be truly effective in a DoD context, an ROI model must be based on provable data to make contract awards based on long-term performance outcome justifiable. To address this, we discuss additional opportunities for combining existing DoD data strategy initiatives and the proposed ROI model in the following subsections.

Finally, it is not uncommon for the DoD to seek out new technologies and innovative systems to promote the interests and protection of the United States. The challenge presented by these acquisitions is there is little comparable data to leverage in an ROI calculator because the technology in question may not have existed up to that point. Therefore, the ROI model for such acquisitions will need to accommodate forecasting based on similar technologies or the data from allied endeavors.

As we have noted, the DoD has different goals, objectives, and measures compared to private industry. As such, it is no surprise that ROI models for the DoD would factor dramatically different metrics for “value” in the ROI calculation. While the research and results from private industry can provide a foundation for the framework of an ROI model, additional testing would be required to see how standard practices would respond to real-life DoD acquisition scenarios. Armed with this information, a more comprehensive and tangible model could be produced to improve the acquisition process within the DoD.

ROI and Application with Single Source of Truth Initiatives

Complementary to an ROI model, the process could benefit from a new data-driven DoD acquisitions process, using a single source of truth data validation process. The following assertions associated with applying Advana’s Single Source of Truth (SSoT) platform to improve the efficacy of an ROI calculator are based on publicly available resources on the Advana platform, interviews with DoD personnel, and industry resources. Therefore, we assume that the Advana platform has the capabilities we mention in this paper. Our team has not had access to the Advana platform during this discovery phase of our research. To fully identify and create a comprehensive solution that could be an added value for the DoD's Data Strategy Initiatives, access to this acquisition data would be highly beneficial for the project's next phase.

As noted in this paper, one issue uncovered in the interviews was the challenge of establishing what "return" looks like for more ambiguous acquisition needs, like cybersecurity or cloud computing. These are more challenging than standard transactional acquisitions like hardware or office supplies because the technological opportunities and best practices often change within the timeframe of the standard DoD acquisition process. We found that the time it takes for information to make its way through an RFP, bidding, and analysis process can be long enough to cause specifications or acquisition objectives to become obsolete, often with better alternatives emerging. To counteract this issue, we propose leveraging existing DoD initiatives for a "Single Source of Truth" data management architecture in the Advana platform to provide a benchmark to measure future acquisitions and performance. By analyzing data on performance from previous, similar acquisitions, we can compare the results of an ROI calculation for a new acquisition. Since the DoD has voiced a focus on improved organizational data strategy, we contend that applying the Single Source of Truth data goal (Deputy Secretary of Defense, 2021) to the development of an ROI calculator would serve to improve the value of both efforts for the Department of Defense.

Our understanding is that the ROI input parameters available in Advana within the Single Source of Truth model fall into two categories: the programmatic data of costs, scope, and schedule of the acquisition itself, and the resulting capabilities offered by the contract. The costs encompass upfront and future costs in a normalized manner. The total cost of ownership models will vary depending on the type of procurement, and different timelines and future maintenance cost structures will need to be considered. Bidders input the scope of their proposals to demonstrate alignment with RFP requirements. The DoD can use these to identify whether bids fall short of, meet, or exceed RFP requirements. Bidders also enter schedule parameters to identify contract milestone delivery dates and assign a schedule risk factor (that may be openly negotiated in the contract term) that capture areas of potential delay ahead of contracting.

We believe that combining these sets of data can provide insight into how much value the DoD is getting out of a particular bid. If the capabilities can be meaningfully converted into dollars, then true ROI can be calculated. However, it may be more helpful or practical to consider the capabilities as a "score" or scalar value rather than a specific dollar amount. As new contracts are awarded in emerging technologies, continual collection and application of data within Advana will continue to support the efficiency of an ROI calculator that adapts to the changes within the DoD and the technology industry. While not a perfect science, the two practices of data application and forward-looking ROI calculations will help make the DoD more efficient in its acquisition process.

ROI and Application with Internal Infrastructure Investments

The efficiency of designing, implementing, and improving key infrastructure technologies within the DoD is a mission critical endeavor. A vital component of this efficacy is determining the cost and return of these technologies. This process goes well beyond the initial acquisitions process to a more cradle-to-grave approach to technology investments. Such an approach is often seen as an industry best practice in private corporations. In addition, once technology infrastructure has been established, the return can be increased through process improvement and analytics.

We've noted several infrastructure technologies that could benefit either directly or indirectly by the implementation of an ROI calculation and an improved data management process. The Advana database and the TENA middleware program have both been identified as potential examples that could benefit from our discussions in the process of creating this report. Beyond this, the long-term benefits of cyber security platforms, software, and cloud infrastructure could benefit from an ROI calculation model that effectively applies the output data already being mined by the DoD.

Armed with this information, the DoD could better identify areas for process improvement and cost efficiency. Application of an ROI model in this area could also make communication with different actors within the DoD funding clearer and easier to translate to a layperson. Finally, the benefits of applying an ROI model to existing technology infrastructure within the DoD would potentially play a powerful role when process improvement requires additional acquisitions. After all, the data gathered is only as effective as its application. An ROI model would create a clear and provable case study with which DoD personnel could seek the right technology or contractor for future acquisitions.

Conclusion

In conducting this research, the team set out to find aspects of the private sector ROI-driven acquisition model that could apply to DoD acquisitions and whether such a model makes sense for the DoD. Although private companies have quantifiable goals and performance metrics that usually translate into dollars, the DoD will need a substitute for profit when making ROI calculations. In our interviews, literature review, and analysis, such a substitute can exist. This issue is an area of the proposed research for the team moving forward.

Of the types of acquisition analysis the DoD currently performs, Lowest Price Technically Acceptable has the most significant potential to benefit from ROI analysis, allowing for analysis and selection of acquisition bids that exceed minimum requirements justifying slightly higher costs or offering lower total lifetime costs. By setting only minimum acceptable requirements, the DoD incurs additional burdens because it must spend inordinate effort to ensure that acquisition specifications cover all contingencies and provide the required performance. This process adds months or years to the RFP generation effort, meaning RFPs will be obsolete by the time they are eventually awarded. Moreover, by specifying minimum performance and asking for the lowest price, the DoD effectively limits private sector bidders from offering innovative or higher value solutions that could cost more than competitors bidding the minimum requirements.

One key difference between how ROI is applied in the private sector versus how it could be at the DoD is how to quantify value. Private companies seek to maximize profit, easily measured in dollars. However, the DoD's objectives are not always quantifiable. Finding a substitute method to measure acquisition performance is necessary to calculate an ROI. This issue is an area of continued research for the team and will be critical to successfully implementing an ROI model for DoD acquisitions.

In the private sector, the data used to make ROI calculations often includes the historical performance of comparable acquisitions to assess risk and evaluate potential benefits. In the DoD context, existing data sources, such as Advana, can serve this purpose and contain the necessary information for ROI evaluations.

In summary, the team believes the DoD can significantly improve acquisition value and performance by employing an ROI-driven decision-making model through improved information transparency, aligning private sector bidders' interests with the DoD's interests, and greater ability to assess solutions that do not need to be precisely specified. In the next phase of our research, we propose to explore how to build this model and quickly deploy it into the existing acquisition process. We also learned that the DoD itself can derive value from performing ROI calculations on its current and potential internal tooling acquisitions. We propose to explore the ROI of a select project or program to prove whether ROI calculations can improve internal investment decisions.

References

Bozic, K., & Dimovski, V. (2019). Business intelligence and analytics for value creation: the role of absorptive capacity. *International Journal of Information Management*. doi:10.1016/j.ijinfomgt.2018.11.020

Calisti, S. (2015). *Lowest price technically acceptable: Why all the debate?*. Department of Defense. https://apps.dtic.mil/sti/pdfs/ADA620543.pdf

Congressional Research Service. (2021). *Defense primer: Lowest price technically acceptable contracts*. https://sgp.fas.org/crs/natsec/IF10968.pdf

DaleMule, L., & Davenport, T. (2017, June). What's your data strategy? *Harvard Business Review*, 112–120. https://hbr.org/2017/05/whats-your-data-strategy?autocomplete=true

Defense Business Board. (2020). *Audit/performance data use in private industry*. https://dbb.defense.gov/Portals/35/Documents/Reports/2020/DBB%20FY20-02%20-Audit-Performance%20Data%20Study%2020201209.pdf

Deputy Secretary of Defense. (2021). *Memorandum for senior pentagon leadership: Creating data advantage.* https://media.defense.gov/2021/May/10/2002638551/-1/-1/0/DEPUTY-SECRETARY-OF-DEFENSE-MEMORANDUM.PDF.

DoD. (2018). *Market research: Gathering information about commercial products and services. Defense standardization program document SD-5*. https://www.dsp.dla.mil/Policy-Guidance/Key-Policy-Documents.

DoD. (2020). *DoD data strategy*. https://media.defense.gov/2020/Oct/08/2002514180/-1/-1/0/DOD-DATA-STRATEGY.PDF.

FAR § 16 (2021).

FAR § 35.006(c) (2021).

Feldman, K., Jazouli, T., & Sandborn, P. A. (2009). A methodology for determining the return on investment associated with prognostics and health management. *IEEE Transactions on Reliability, 58*(2), 305–316.

Gluck, M. (1976). *Value engineering in the DoD acquisition process*. Defense Systems Management College.

Kendall, F. (2015). *Memorandum for secretaries of the military departments: Appropriate use of lowest priced technically acceptable source selection process and associated contracted type.* Department of Defense.

Kendall, K., & Long, W. (2018). *Including cybersecurity in the contract mix*. Defense Acquisition University. https://www.dau.edu/library/defense-atl/blog/Including-Cybersecurity-in-the-Contract-Mix.

Oswalt, I., Cooley, T., Waite, W., Waite, E., Gordon, S., Severinghaus, R., Feinberg, J., & Lightner, G. (2011). Calculating return on investment for U.S. Department of Defense modeling and simulation. *Defense Acquisition Research Journal*, 123–143.

Tharp, G. (2020). Why you need to know about TINA, FAR, and ASPR. World Commerce and Contracting. Retrieved from: https://journal.iaccm.com/contracting-excellence-journal/why-you-need-to-know-about-tina-far-and-aspr

Avoiding the "I'll know It when I see it" Pitfall: Furthering a Choice-Based Conjoint (CBC) Model for Government Source Selections

First Lieutenant Brittany Thompson, USAF—is an active duty contract negotiator with 4 years of contracting experience in the U.S. Air Force. She graduated from Syracuse University with a bachelor's degree in management and marketing, then later received her MBA from the Naval Postgraduate School. She is currently stationed at the Air Force Life Cycle Management Center located at Wright-Patterson Air Force Base. [brittany.thompson.8@us.af.mil]

Lieutenant Colonel Daniel Finkenstadt, USAF—is an active duty contracting officer with over 20 years' experience in federal contracting. He graduated from the University of North Carolina at Chapel Hill with a PhD in marketing and has been an Assistant Professor in the Graduate School of Defense Management at the Naval Postgraduate School since 2020. [daniel.finkenstadt@nps.edu]

Abstract

The Department of Defense (DoD) current source selection methods are at an increased risk of experiencing sustained bid protests. During source selections, the government frequently contradicts itself between its advertised stated order of importance for acquisition evaluation criteria (pre-award) and its actual choice behavior during source selections (Butler, 2014). This paper provides a summation of research, conducted from 2021 to 2022, that explored the following research objectives: 1) Determine the degree of disconnect between stated preferences during pre-award acquisition phase and actual choice behavior in defense acquisition source selections, 2) develop a deep understanding of quality attributes in evaluating logistics-based service acquisitions, 3) provide a Choice-Based Conjoint (CBC) framework that the DoD could utilize to enhance source selection criteria development in both logistics and further categories of government spending. The research utilized methods such as interviews and spend analysis techniques to identify quality attributes of logistics-based acquisitions that would best discriminate as evaluation factors for award. Later, these attributes were used to develop a CBC exercise that enabled us to calculate attribute utilities and relative importance for each attribute. The summarized research in this paper provides a way forward to empirically deduce the relative importance for source selection evaluation factors, potentially reducing bid protest occurrences in future source selections.

Introduction

In its annual letter to congress, the U.S. Government Accountability Office (GAO) repeatedly reports that one its most common reasons for sustaining a bid protest: government agencies continuing to unreasonably evaluate technical, past performance, and cost or price evaluation factors during source selections (GAO, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021). Such unreasonable evaluations persist, and agencies cannot follow their own solicitation's evaluation criteria, ensuring a flawed source selection decision and increased chance of a GAO bid protest.

Additionally, the MITRE Corporation further substantiates the same issue in competitive source selections and evaluations, with its Contract Protest Diagnostic Tool (CPDT). The CPDT uses a heatmapping visual technique to show the exposure to protests within each phase of the federal acquisition phases (MITRE Corporation, 2022). Two of the most historically problematic "hot spots" indicate that the U.S. federal government is regularly exposed to protests because its agencies do not (1) perform fair and consistent evaluations that are consistent with the evaluation procedures described within solicitations or 2) solicit with evaluations factors in a properly weighted relative order of importance that matches how these same factors are evaluated during the source selection process.

Procurement agents throughout the DoD aim to deliver “quality and timely products and services to the Warfighter and the Nation at the best value to the taxpayer” (DoD, 2016). While source selections and their procedures offer a structured approach to these agents to obtain best value, the increased risk of bid protests created by these procedures means implicit consequences for the DoD. When faced with bid protests, the DoD must utilize valuable, finite resources to resolve said protests. In a time of increasingly varied global change and threats, losing valuable resources to preventative consequences places the DoD in a precarious predicament.

Past research conducted by one of this paper’s contributors finds further fault in current source selection procedures. In the graduate essay on “Perceived Service Quality and Perceived Value in Business-to-Government Knowledge-Based Services,” researchers argue that government agencies use Lowest Price Technically Acceptable (LPTA) procedures in an increased effort to avoid the risks of exposures such as those described in the above paragraph (Finkenstadt, 2020). The study goes on to provide some unique insights into the Business-to-Government (B2G) buyer and their choice behavior in simulated source selections by leveraging conjoint methods. For example, individuals often rely on theoretical deduction, or an a priori judgment, to predict the ordered importance of price and non-price factors instead of utilizing empirical reasoning (Finkenstadt, 2020). When presented evaluation factors in list form, individuals also have a difficult time in properly shaping the relative order of importance because a list does not provide them an opportunity to consider these nonprice and price factors when presented in a full set of offers or grouped together (Finkenstadt, 2020).

The following paper offers initial insights into how the DoD can address the illustrated disconnect between stated preferences during pre-award acquisition phase and actual choice behavior. These findings support the issues revealed in MITRE’s CPDT tool, GAO sustained protests, and past research. By quantifying the disconnect and better understanding how the DOD acquisition workforce and its customers evaluate products to meet their needs, there can be a subtle, yet significant shift in how the organization can better utilize its finite resources. Furthermore, the research summarized in this paper offers better understanding on how the DoD evaluates perceived attributes of logistics-based services. While these findings were supplemental in nature to the overall agenda of the research, such information has the potential to enhance future evaluation criteria in source selections for these logistics-based services. Finally, the insights offered from the research described in this paper may reduce the risk of acquisition protests, as it provides knowledge of perceived preferences, subconscious or otherwise, for these services. All ensure that acquisition professionals can better prioritize evaluation criteria during the contract pre-award phase ensuring the right solution, at the right time, and for the right customer.

Issues with Source Selection Methods

As outlined in FAR Part 15.3, source selections procedures enable acquisition professionals to determine which contractor proposal provides the best value, or “the expected outcome of an acquisition that, in the Government’s estimation, provides the greatest overall benefit in response to the requirement,” to the government (DoD, 2016). While the procedures provide a structured approach to obtain best value, the way source selections procedures stand now jeopardize the three goals of government procurement: transparency, value for money, and meeting requirements (Finkenstadt & Hawkins, 2016). This is because the procedures do not provide a way in which to state what really matters to the government and how best to quantify it. Instead, source selections teams are often left to define evaluation factors and an a priori ranking for those factors based on presumed importance. In short source selection guidance does not offer an empirical method to acquisition personnel that allows for both effective evaluation factor determination and their order of importance. Conjoint analysis, and more specifically, choice-based conjoint analysis can be that method.

Conjoint Analysis

Conjoint analysis is a tool that enables managers, companies, and acquisition personnel alike to "model the factors that underlie and drive consumer choice" (McQuarrie, 2016) through utilization of a product or service's "separate (yet conjoined) parts" (Orme, 2020). Through conjoint analysis, a product or service's attributes can be purposefully varied while respondents' reaction to the variability can be statistically deduced and these scores, or utilities and part-worths, for each attribute can help to define the value of the service (Orme, 2020). For reference, part-worths are fully defined as "the utility associated with a particular level of an attribute" and utility, in reference to conjoint analysis, "refers to a buyer's liking for (or the desirability of) a product alternative" (Orme, 2020).The advantage of conjoint analysis over other standard marketing techniques, like surveys, is that it is a "back door" method to develop insight into subconscious choice behavior when respondents are presented full product or service profiles (Orme, 2020). Figure 1 demonstrates further beneficial features of conjoint analysis.

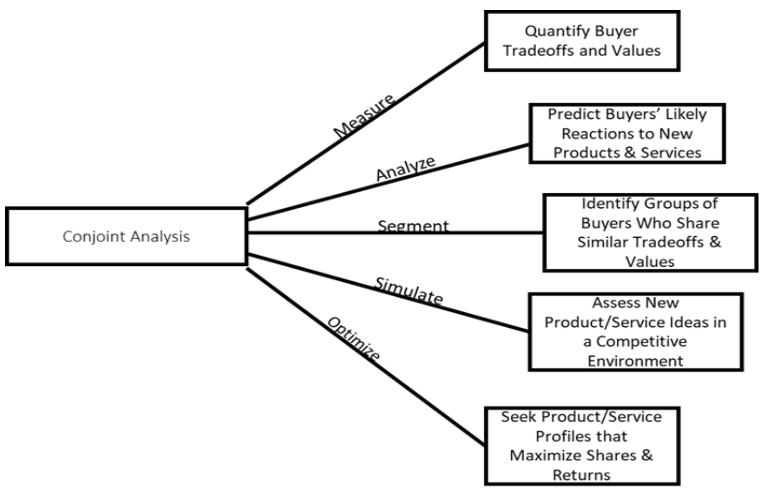


Figure 1. Features of Conjoint Analysis. (Thompson, 2022, as adapted from Rao, 2014).

While conjoint analysis offers far superior methods in terms of discovering consumer choice behavior, the simulated, hypothetical environment built from its use imposes a lack of real-life consequences to the respondents, preventing analysts from collecting the most realistic preferences and data from respondents (Ding et al., 2005). To help combat the consequences of a simulated environment, the incentive-aligned consequence of "expert scrutiny" was incorporated within this research's conjoint analysis exercise. This meant that respondents who participated in the choice exercise are "told to answer realistically because an expert in public procurement will analyze their responses for reasonableness prior to including it in any decision to change public acquisition methods or policy. This mimics the formal source selection review process found in many public agencies" (Finkenstadt, 2020, p. 101). Figure 2 displays what respondents for the CBC observed to add expert scrutiny to the exercise.

USTRANSCOM spends over $4.4 Billion a year on supplies and services enabling their logistic-focused mission. Many of its programs with industry partners are thoroughly tracked and publicly advertised by USTRANSCOM. Each contract value ranges from hundreds of thousands of dollars to hundreds of millions of dollars. Furthermore, much of the contract activity USTRANSCOM TCAQ initiates includes high spend activity that requires the best possible solutions for the taxpaying public and the warfighter.

With that, please treat the following survey as a real-world example. Make your choices as realistic as possible and answer to the best of your ability. Due to the impact the results will have in potentially changing DoD acquisition methods or policy, the results from your survey will be evaluated by public procurement/acquisition experts to determine response reliability.

Figure 2. CBC Expert Scrutiny Choice Exercise Condition

Finkenstadt (2020) discovered that expert scrutiny worked as well as other typical incentive-aligned CBC prompts for government acquisition personnel during an exercise in which over 600 personnel were randomly assigned to various prompt conditions. Though the outside option utility was much smaller in a Bayesian-truth serum condition, it was determined that it did not skew the relative importance ranking of factors (Finkenstadt, 2020). Finkenstadt recommends expert scrutiny due to its lower costs and time to employ. Therefore, this study settled on the use of expert scrutiny as the incentive-alignment prompt for respondents.

Software advancements have allowed conjoint analysis to expand in terms of its approaches and data that it gathers. What started as a method utilizing handwritten cards for product profiles in 1971 is now conducted on advanced statistical software that offers a multitude of options to its users depending on their research and what outcomes they hope to measure (Orme, 2020). Each conjoint analysis approach can be divided among the tactics researchers use within their exercise. A ratings-based approach has respondents ranking full-profile products, while choice-based conjoint techniques allow respondents to choose or trade-off among different product profiles. Other approaches utilize some form or combination of both techniques. Figure 3 details the types of conjoint analysis, but for the purposes of this research, CBC analysis and Sawtooth© Choice-Based Conjoint Software were utilized.

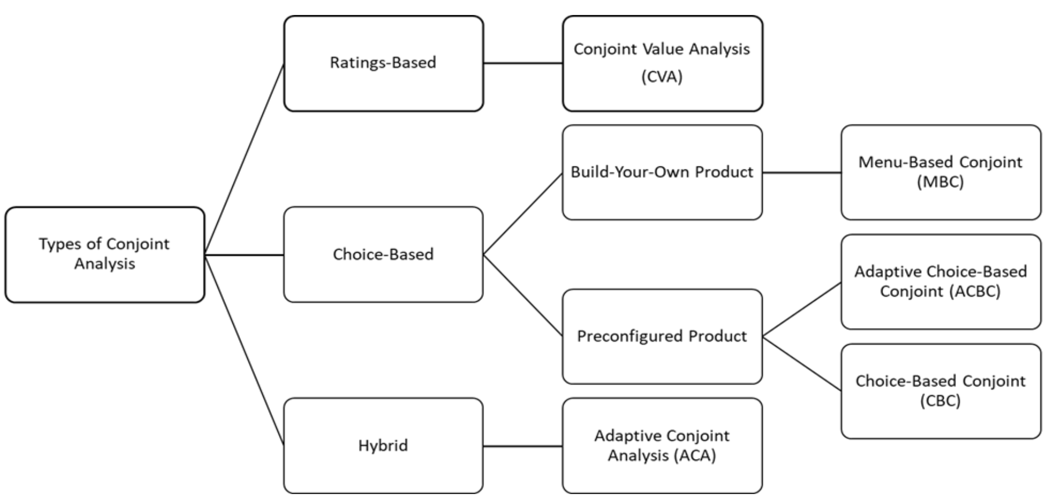


Figure 3. Types of Conjoint Analysis in Marketing. (Orme, 2020).

Choice-Based Conjoint

CBC presents a series of choice tasks, or questions, that ask respondents to choose from three to five product profiles (Orme, 2020). What sets CBC apart from other conjoint analysis techniques is that it provides respondents an option to choose none of the product profiles, as consumers realistically can choose none of the product alternatives when presented options in a real market environment. CBC utilizes several analytical methods to estimate respondent preference; however, for this research, Hierarchical Bayes (HB) analysis was utilized. HB estimation offers a model to estimate the part-worths at an individual-level, by iteratively collecting data from multiple respondents and finding a point of convergence (Orme, 2020). Figure 4 shows one of the 12 choice tasks presented in the CBC exercise for this research. The relative levels of each attribute displayed below are further explained within the methodology section of this paper.

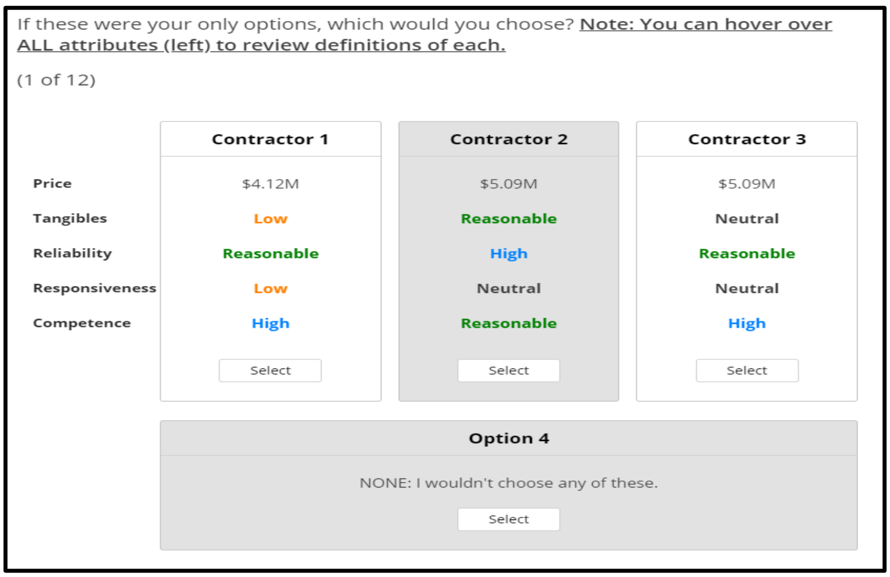


Figure 4. CBC Choice Scenario Example.

Real Property Maintenance

For conjoint analysis to be successful, it must only include a limited number of attributes per product/service profile; otherwise it risks unnecessary difficulties for respondents and possibly jeopardizing the results of the CBC. Ensuring the proper number of attributes and attribute levels is one of the most critical aspects in designing a successful CBC (Orme, 2020). To secure proper design of the CBC then, no more than eight attributes and five or fewer levels of attributes should be used (Orme, 2020). With that, the research presented in this paper determined that only *one* Product Service Code (PSC), under the Transportation and Logistics Service federal category of spend, would be used to determine the limited scope and attributes for the CBC scenario.

In order to select one specific PSC, spend and data analysis techniques were utilized in order to discover a PSC associated with the highest dollar spend under the Transportation and Logistics spending category level one. The U.S. Air Force Installation Contracting Center's (AFICC) Business Intelligence tool, AFBIT Lite, provided the spend data required to find this specific PSC. Within the category one level of spend, it was determined that among all 25 PSCs under that category, it was PSC R706 – Support Management: Logistics Support, that held the highest dollar spend at approximately $18.6 billion (AFICC, 2022).

There are many services associated with PSC R706, and so it was then decided that for the CBC to have the proper number of attributes, further narrowing of the PSC was necessary. Researchers concluded that only one service under that PSC would be the focal service that helped to develop the CBC exercise employed. To narrow it down from one PSC to a particular service associated with that PSC, the DoD's Project Management Resource Tools (PMRT) Enterprise Analytics (EA) application CON-IT application was used. Like the process utilized with AFBIT Lite, the service with the highest usage for the DoD was sought. This ensured the impact this research had was greater than if completed for a service not often utilized or contracted out for. Through a thorough examination of over 17,831 relevant Contract Line-Item Numbers (CLIN) data, Real Property Maintenance (RPM) was chosen as the selected service for the CBC exercise. The maintenance of real property is defined as "the upkeep of property only to the extent necessary to offset serious deterioration; also, such operation of utilities, including water supply and sewerage systems, heating, plumbing, and air-conditioning equipment, as may be necessary for fire protection, the needs of interim tenants, and personnel employed at the site, and the requirements for preserving certain types of equipment" (Real Property Policies, 2022). Real property can include "any interest in land, together with the improvements, structures, and fixtures located, and appurtenances thereto, under the control of any Federal agency" (Real Property Policies, 2022).

Methodology

Several steps were taken in advance to ensure the conjoint analysis techniques used in this research were properly conducted and represented a hyper-realistic situation that respondents could possibly encounter if participating in a DoD source selection. First, a literature review was conducted to educate, inform, and build a foundation for the study. Topics such as DoD source selection procedures, logistics, conjoint analysis and its use in the Business to Consumer (B2C), Business to Business (B2B), and Business to Government (B2G) markets were explored.

Second, once an initial backbone of knowledge was built, the researchers moved forward by interviewing logistics personnel and acquisition experts that aided in the determination of service quality attributes for logistics service. The six interviews conducted were with government personnel that had acquired logistics-based services and/or commodities, had a military logistics background, or participated in source selections for a logistics-based service. Questions proposed to interviewees focused on their organization's acquisition of logistics-based services, factors considered important when evaluating a contractor's proposal, and essentially, what was important to government customers, acquisition personnel, and logistics personnel when it came to a logistics-based service. Despite the diverse backgrounds of each interviewee, certain trends and patterns emerged among the responses provided to the researcher. Upon conclusion of the interviews, it was determined that the same evaluation considerations interviewees consistently mentioned were those indicators attributed to SERVQUAL, a popular model that aids in measuring the perceived quality of a service (Parasuraman et al., 1985). Five concise dimensions of service quality perception are highlighted through the SERVQUAL model:

Tangibles:	Appearance of physical facilities, equipment, personnel, and communication materials
Reliability:	Ability to perform the promised service dependably and accurately
Responsiveness:	Willingness to help customers and provide prompt service

Assurance: Knowledge and courtesy of employees and their ability to convey trust and confidence

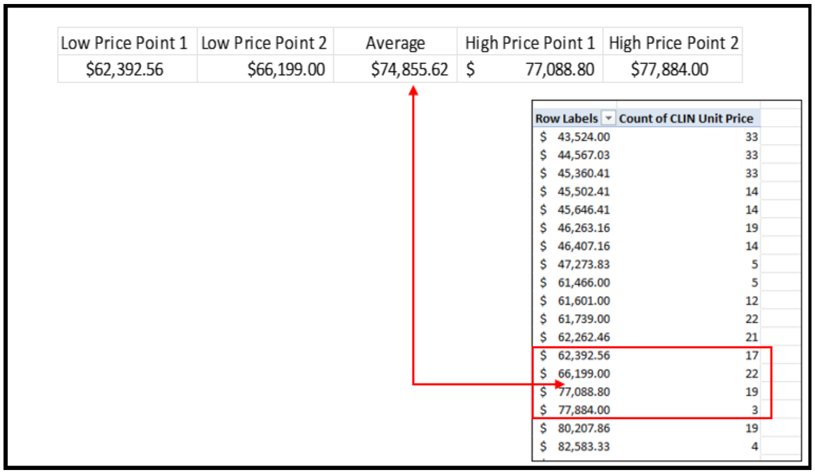
Empathy: Caring, individualized attention the firm provides its customers. (Parasuraman et al., 1985)

Interviewees consistently indicated that four of the five SERVQUAL service quality dimensions were important. These four dimensions were modified to represent the four attributes, besides price, that the CBC would include for the simulated logistics-based source selection. Table 1 displays the four attributes, besides price, utilized in the CBC.

Table 1. Selected Choice Exercise Attributes Modified from SERVQUAL Dimensions. (Parasuraman et al., 1985)

Attribute	Explanation from Interviews	Description to Respondents
Competence	Multiple interviewees stressed the importance that contractors needed to demonstrate capability and they have the capacity to perform the required service.	Real Property Maintenance firm's employees applied existing best practices to execute requirements on past contracts.
Reliability	Multiple interviewees stated they seek contractors that perform how they state they [contractors] can perform.	Real Property Maintenance firm demonstrated an ability to perform dependably and accurately on previous contracts
Tangibles	Multiple interviewees stated they need contractors that can accurately and demonstrably provide the manpower and materials required to perform the needed service.	Real Property Maintenance firm demonstrated they have the facilities, equipment, personnel, and communication materials needed to complete the service.
Responsiveness	Multiple interviewees stated that contractors chosen through LPTA evaluations failed to provide the needed qualitative, technical capabilities. Interviewees now aim to find those firms that understand the requirement and will take their service to the next level to meet that requirement, even if that means a higher price.	Real Property Maintenance firm demonstrated willingness to help customers and provide prompt service on previous contracts.

Third, and as mentioned in previous portions of this paper, a specific service was chosen through a tailored spend and data analysis utilizing AFBIT Lite and PMRT. This analysis helped narrow the scope of the CBC from a category of spend to the selected service highlighted within the CBC, RPM. Along with providing a high-use, high-spend service this analysis also enabled the determination of realistic prices to be used in the CBC as the fifth and final quality attribute of the RPM service. Through PMRT CLIN data, the average price per month for RPM services equated to $74,885.62. Once an average price was determined, a pivot table utilizing RPM CLIN monthly prices was created, and the average price previously determined was taken to identify four other price points to utilize in the CBC. Figure 5 represents that process and Table 2 shows all five of these prices when they were increased to reflect the price of a firm-fixed price contract with a 12-month base period, four 12-month option periods, and a 6-month extension of service clause if necessary.



Low Price Point 1	Low Price Point 2	Average	High Price Point 1	High Price Point 2
$62,392.56	$66,199.00	$74,855.62	$ 77,088.80	$77,884.00

Row Labels	Count of CLIN Unit Price
$ 43,524.00	33
$ 44,567.03	33
$ 45,360.41	33
$ 45,502.41	14
$ 45,646.41	14
$ 46,263.16	19
$ 46,407.16	14
$ 47,273.83	5
$ 61,466.00	5
$ 61,601.00	12
$ 61,739.00	22
$ 62,262.46	21
$ 62,392.56	17
$ 66,199.00	22
$ 77,088.80	19
$ 77,884.00	3
$ 80,207.86	19
$ 82,583.33	4

Figure 5. Price Point Pivot Table and Price Determination

Table 2. CBC Price Attribute Levels

Attribute Levels	Total Contract Price with 6-Month Service Extension [Description to Respondents]
Low Price (1)	$4.12 Million
Low Price (2)	$4.37 Million
Average Price	$4.94 Million
High Price (1)	$5.09 Million
High Price (2)	$5.14 Million

Finally, after the above steps were completed, the CBC was designed to provide 12 random choice scenarios to respondents utilizing the five attributes and price points determined through this research's additional methods of discovery. Along with the five attributes, four levels per attribute were created utilizing Table 3's scale ratings that were adapted from current DoD source selection procedures.

Table 3. CBC Attribute Level Ratings. (DoD, 2016).

Streamlined Scale Rating	**Adjectival Rating from DoD Source Selection Guide Table 5**	**Description to Respondents**
High	Substantial Confidence	Based on the offeror's recent/relevant performance record, the Government has a high expectation that the offeror will successfully perform the required effort.
Reasonable	Satisfactory Confidence	Based on the offeror's recent/relevant performance record, the Government has a reasonable expectation that the offeror will successfully perform the required effort.
Low	Limited Confidence	Based on the offeror's recent/relevant performance record, the Government has a low expectation that the offeror will successfully perform the required effort. [**NOTE**: A low rating does not mean the offer is unacceptable]
Neutral	Neutral Confidence	No recent/relevant performance record is available, or the offeror's performance record is so sparse that no meaningful confidence assessment rating can be reasonably assigned. The offeror may not be evaluated favorably or unfavorably on the factor of past performance.

CBC respondents included those government personnel that had held the role of contracting officer, contracting manager/administrator, contracting officer representative, quality assurance personnel, program manager, customer, and other positions directly involved with government acquisition. Respondents were guided to assume that all contract offers observed within each random choice task were technically acceptable, the prices provided were realistic, and the final evaluation determination they were selecting was based on the contractor's past performance and generated through a trade-off decision-making process between the price of the contract offer and the four service quality attributes (Finkenstadt, 2020).

The CBC was designed using Sawtooth© Choice Based Conjoint Software, tested for functionality at the National Contract Management Association (NCMA) Conference in July 2022, and finally released to collect data in August 2022. Along with the 12 random choice tasks presented to respondents (see Figure 4), respondents were also asked demographic questions regarding their experience in government acquisition and were also guided to rank order attributes of logistics-based services. These attributes represented the same as those presented in the CBC choice tasks; however, respondents were provided only the definition of these same attributes, and asked after the CBC choice tasks, to minimize the opportunity to "game" the system and memorize their choices in the CBC and match their rank ordered items similarly. Figure 6 displays the rank order choice exercise presented.

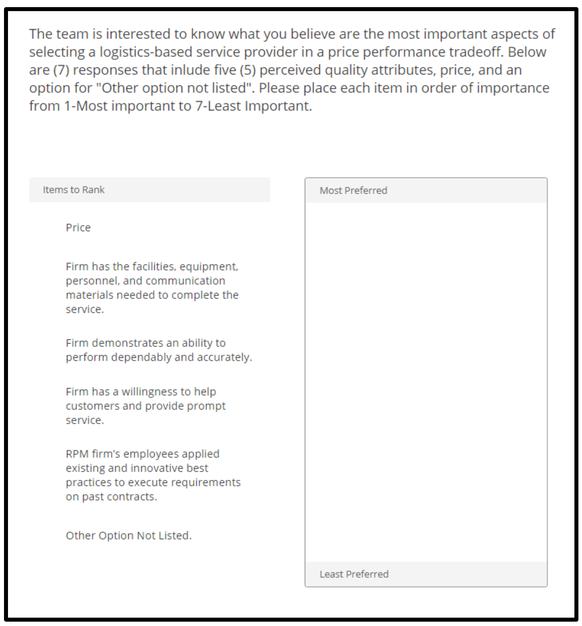


Figure 6. Rank Order Choice Exercise Question

Overall Findings and Contributions

The CBC choice exercise was open to respondents from August 1, 2022, to September 15, 2022. 30 respondents completed the choice exercise, meeting the standards "for investigational work and developing [a] hypotheses about a market" (Orme, 2020). The experience of those that completed the choice exercise varied in terms of the role held and their years of experience in said role. Each respondent was asked to select one or more of the acquisition-focused roles they had held and how many years they held that role. Table 4 and Table 5 show the experience demographics collected from the 30 respondents. The totals aggregate to greater than 30 as some respondents had multiple position experiences.

Table 4. Choice Exercise Experience Demographics

Position Held	Totals
Contracting Manager/Administrator/Specialist without RPM or Logistics-Based Services Experience	12
Contracting Officer without RPM or Logistics-Based Services Experience	11
Contracting Manager/Administrator with RPM or Logistics-Based Services Experience	5
Customer without RPM or Logistics-Based Services Experience	5
Other without RPM or Logistics-Based Services Experience	5
Contracting Officer with RPM or Logistics-Based Services Experience	4
Program Manager without RPM or Logistics-Based Services Experience	4
COR without RPM or Logistics-Based Services Experience	3
Contracting Officer Representative/Quality Assurance Personnel with RPM or Logistics-Based Services Experience	1
Other with RPM or Logistics-Based Services Experience	1
Program Manager with RPM or Logistics-Based Services Experience	0
Quality Assurance Personnel without RPM or Logistics-Based Services Experience	0

Table 5. Choice Exercise Experience Years

Role	Years of Experience
Other: NPS Faculty	32
Customer	28
COR Program Manager Customer	19
Program Manager	18
Contracting Officer Contracting Manager/Administrator/Specialist COR Program Manager Customer	18
Contracting Officer Customer	16
Other: Assistant Research Professor	15
Contracting Officer and Contracting Manager/Administrator	11
Contracting Officer Contracting Manager/Administrator/Specialist	11
Contracting Officer Contracting Manager/Administrator/Specialist COR	10
Contracting Officer	9
Other: Senior Lecturer	8
Contracting Manager/Administrator	7
Contracting Officer and Contracting Manager/Administrator	6
Contracting Officer Contracting Manager/Administrator/Specialist Program Manager	6
Contracting Manager/Administrator/Specialist	6
Other: OSI Agent	4
Contracting Officer Contracting Manager/Administrator/Specialist	4
Contracting Officer Contracting Manager/Administrator/Specialist Customer	4
Contracting Officer Contracting Manager/Administrator/Specialist	4
Other: Ship Division Officer	4
Contracting Officer	3
Contracting Manager/Administrator	3
Contracting Officer Contracting Manager/Administrator/Specialist	3
Contracting Officer Contracting Manager/Administrator/Specialist	3
Other: Company Commander	2
Contracting Manager/Administrator/Specialist	2
Contracting Officer Contracting Manager/Administrator/Specialist	2
Contracting Manager/Administrator	1
Contracting Officer Representative/Quality Assurance Personnel	1

Respondent's data was validated, in terms of response quality, utilizing several methods Sawtooth Software provides its researchers. Visual inspection of repeated choice patterns, review of completion times, and computation of the Root Likelihood measure were the three chosen methods used to validate quality. As a note, the Root Likelihood (RLH) is "an intuitive measure of how well the solution(s) fit the data. … [It] is an intuitive probability expression of how successful the utility scores are in predicting which items respondents pick" (Sawtooth Software, 2022). All three validation methods indicated that none of the 30 respondent's choices appeared randomly selected.

Research Objective I

In order to determine the degree of disconnect between stated preferences and actual choice behavior, the data collected from both the CBC and ranked preference exercise was compared for each of the 30 respondents. The CBC data offered individual importance scores for each attribute, while the ranked preference exercise allowed respondents to directly input what they believed to be most important to least when acquiring RPM services. Table 6 and Table 7 represent the collected data that was then compared against each other, while Figure 7 is a visual example of the comparison of stated and observed choices for one respondent.

Table 6. CBC Individual Importance Scores Per Respondent

Respondent	Price	Tangibles	Reliability	Responsiveness	Competence
1	15.35437	13.95127	26.18789	15.77734	28.72914
2	38.77005	14.19632	22.80028	6.8724	17.36095
3	20.34852	23.82053	19.7129	14.53701	21.58104
4	6.1063	17.51175	24.67448	26.1377	25.56978
5	23.19053	20.56684	27.44157	11.28664	17.51443
6	20.58427	22.19826	23.52144	14.5261	19.16992
7	7.72683	14.49259	28.9684	23.7424	25.06978
8	17.26002	15.67074	25.00742	16.16383	25.89799
9	28.85697	20.0963	21.16121	11.76638	18.11915
10	20.78097	28.06142	19.80186	13.71696	17.63879
11	11.41264	16.30745	21.56323	27.34676	23.36991
12	14.07932	13.28963	25.42101	16.69622	30.51382
13	21.07294	16.46564	20.89432	15.83543	25.73168
14	7.46573	9.06788	29.68934	24.47462	29.30243
15	22.47177	15.43122	23.63169	16.1193	22.34602
16	4.90415	14.53434	28.06384	30.51748	21.98018
17	8.15209	11.98993	26.55606	24.62871	28.67321
18	27.89499	20.61131	21.58292	11.01287	18.89791
19	6.48874	15.41981	26.19325	23.85643	28.04177
20	25.34969	23.40266	20.70524	8.7042	21.8382
21	21.06862	20.30179	24.06359	10.83193	23.73406
22	19.49001	14.73438	25.86596	17.39287	22.51678
23	21.73412	16.35209	28.65789	18.1412	15.1147
24	3.90716	16.17451	27.25348	26.2906	26.37425
25	24.26609	19.10173	24.00935	17.14051	15.48232
26	26.22331	21.61195	22.88639	10.1777	19.10064
27	6.91567	5.10399	33.39819	25.99038	28.59176
28	11.11214	13.50383	29.19329	20.76542	25.42532
29	14.24861	17.7801	22.91868	17.1422	27.91042
30	7.35924	15.18506	25.91598	23.41337	28.12635

Table 7. Stated Preferences of Choice Exercise Respondents

Respondent	1	2	3	4	5	6
1	Competence	Price	Reliability	Tangibles	Responsiveness	Other
2	Price	Reliability	Tangibles	Responsiveness	Competence	Other
3	Responsiveness	Tangibles	Price	Reliability	Competence	Other
4	Competence	Responsiveness	Price	Tangibles	Reliability	Other
5	Reliability	Responsiveness	Price	Competence	Tangibles	Other
6	Responsiveness	Price	Reliability	Tangibles	Competence	Other
7	Competence	Responsiveness	Tangibles	Reliability	Price	Other
8	Price	Tangibles	Responsiveness	Competence	Reliability	Other
9	Responsiveness	Reliability	Price	Competence	Tangibles	Other
10	Responsiveness	Price	Tangibles	Reliability	Competence	Other
11	Reliability	Tangibles	Price	Responsiveness	Competence	Other
12	Competence	Responsiveness	Tangibles	Reliability	Price	Other
13	Reliability	Responsiveness	Price	Competence	Tangibles	Other
14	Responsiveness	Reliability	Price	Competence	Tangibles	Other
15	Reliability	Competence	Price	Tangibles	Responsiveness	Other
16	Competence	Price	Tangibles	Reliability	Responsiveness	Other
17	Competence	Responsiveness	Reliability	Tangibles	Price	Other
18	Price	Tangibles	Reliability	Competence	Responsiveness	Other
19	Competence	Responsiveness	Price	Reliability	Tangibles	Other
20	Responsiveness	Competence	Price	Reliability	Tangibles	Other
21	Competence	Price	Tangibles	Responsiveness	Reliability	Other
22	Tangibles	Reliability	Price	Responsiveness	Competence	Other
23	Reliability	Responsiveness	Price	Tangibles	Competence	Other
24	Responsiveness	Competence	Tangibles	Reliability	Price	Other
25	Tangibles	Competence	Price	Reliability	Responsiveness	Other
26	Price	Tangibles	Reliability	Responsiveness	Competence	Other
27	Competence	Tangibles	Price	Reliability	Responsiveness	Other
28	Reliability	Responsiveness	Competence	Tangibles	Price	Other
29	Tangibles	Price	Reliability	Responsiveness	Competence	Other
30	Reliability	Responsiveness	Tangibles	Price	Competence	Other

Respondent 2	1	2	3	4	5
CBC	Price	Reliability	Competence	Tangibles	Responsiveness
Rank	Price	Reliability	Tangibles	Responsiveness	Competence
# Matched	2 of 5	Position(s) Held: Program Manager w/out RPM or USTRANSCOM-Related Svc. (18 Years)			
% Match	40%				

Figure 7. Stated Ranked Preferences vs. CBC Choice Behavior

Once all 30 respondents' stated preferences and CBC behavior was reviewed and match compared, the inverse of their match rates (the disconnect rate) could then be determined on an individual and aggregate level. The average match rate accumulated (as seen in Table 8) through all respondent match rates was 23%, leaving the average disconnect rate at 77%. In summation, in this simulated source selection, the disconnect between the stated preferences of respondents and actual choice behavior could be confirmed and measured at over three times the rate at which respondents, and their stated level of attribute importance, matched their choice behaviors.

Table 8. Match Rate Trends Among CBC Choice Behavior and Stated Preference

Overall Match Rate Trends:
0 of 30 Respondents got 100% Match Rate (5 of 5 Matches)
0 of 30 Respondents got 80% Match Rate (4 of 5 Matches)
5 of 30 Respondents got 60% Match Rate (3 of 5 Matches)
5 of 30 Respondents got 40% Match Rate (2 of 5 Matches)
10 of 30 Respondents got 20% Match Rate (1 of 5 Matches)
10 of 30 Respondents got 0% Match Rate (0 of 5 Matches)

In addition to analyzing exact match rates for respondents, the researchers also analyzed the collected data for the inclusive proximal match rate. This match rate reviewed choice behavior from both exercises and searched among all respondents as to if their CBC choices were off by one or two ranks in comparison to their stated ranked preferences. Simple 'if/then' formulas were utilized in Microsoft Excel to conduct this comparison process that not only checked for an exact match but also to examine whether the ranked attribute matched one ranking above or below that same attribute in the CBC choice behavior. Figure 8 displays the proximal match rate comparisons by attribute, with the green 'Yes' representing an exact match, the red 'No-Yes' representing the number of inclusive proximal matches, and the blue 'No-No' indicating a no match whatsoever. While there was an increase in match rate when utilizing the proximal match process, the rate at which respondents still presented no match was approximately 40%.

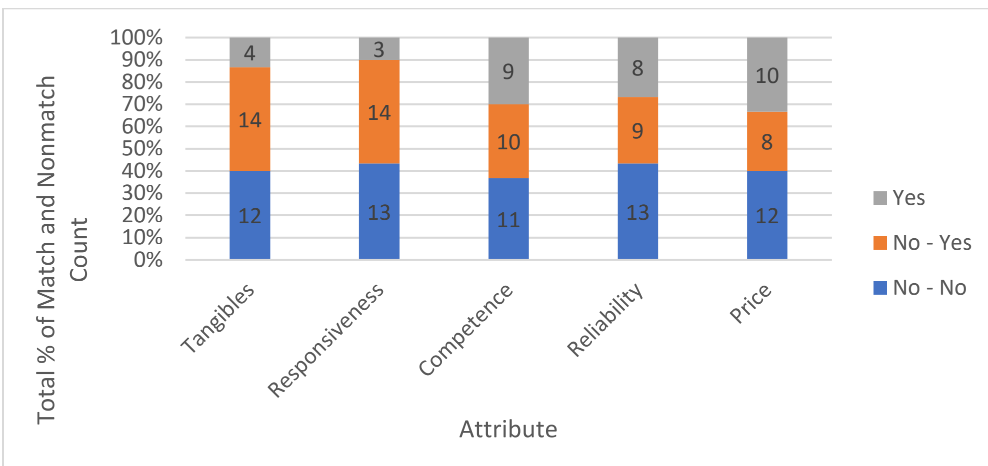


Figure 8. Inclusive Proximal Match Comparison by Attribute

Research Objective II

To develop a deep understanding of quality attributes that government buyers perceive when evaluating logistics-based service acquisitions, a series of semi-structured interviews were conducted with government personal that held various positions but had related experience in purchasing logistics-based services. These interviews highlighted several service quality indicators not associated with current measures and standards utilized in programs like the Contractor Performance Assessment Reports System (CPARS) or in guidance for Performance-based Logistics (PBL). Instead, the research offered some valuable insight into a potential issue regarding a dissonance between how the DoD is measuring the performance of logistics-based services versus how government personnel truly value the service itself and what they are looking for in terms of the contractors who provide it. With that, the research also provided four quality attributes (as seen in Table 1) that could offer a way forward in terms how the DoD measures quality for these services.

Research Objective III

The foundational knowledge and research collected through this project allowed for a procedural framework to be built that can improve DoD source selection procedures. This framework offers a path of empirical reasoning, as opposed to theoretical deduction when determining evaluation factors. Figure 9 represents the CBC framework as it is incorporated into current source selection procedures.

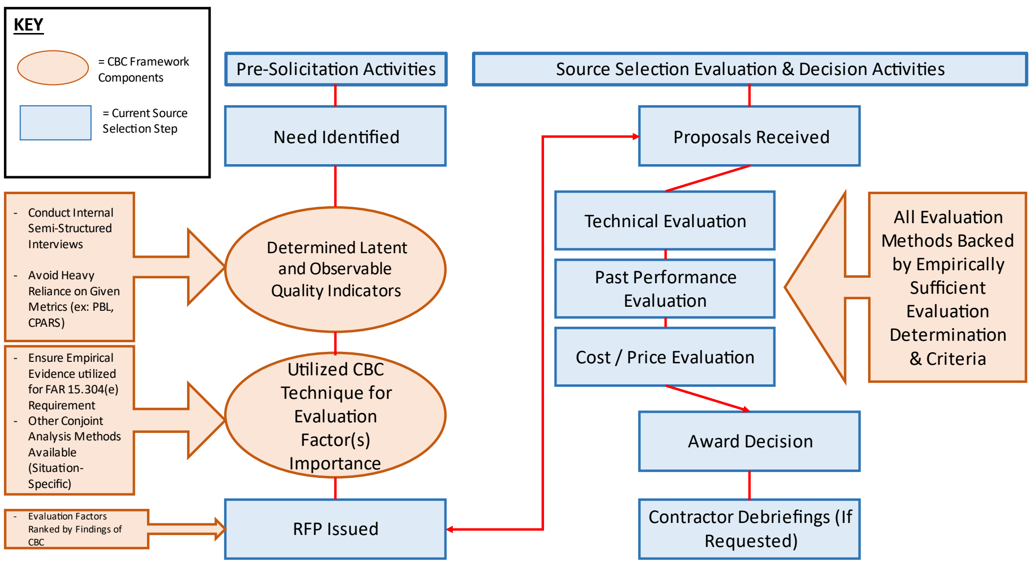


Figure 9. Source Selection Process with CBC Framework Incorporated. (Nicholas, n.d.).

With the CBC framework incorporated into source selection procedures, Source Selection Teams (SSTs) can develop latent quality indicators through the very methodology this research utilized (semi-structured interviews), transition these indicators and perhaps some objective indicators to evaluation factors, and finally rank these evaluation factors utilizing a CBC or other conjoint analysis technique. In utilizing this framework, SSTs avoid ranking evaluation factors on theoretical deduction, ensure they are examining grouped evaluation factors (as opposed to strictly list form), and later portions of the source selection are no longer compromised as early use of CBC ensures empirically sufficient evaluation determination and criteria.

Conclusion

As the DoD continues to operate with limited resources, witnesses rising tensions with geopolitical powers, and contends with an extremely accelerated technological shift, it is important it finds ways in which to effectively function and rapidly adjust to the changes these three factors present. The research presented in this paper provides opportunities to manage resources more effectively, avoid acquiring ill-suited acquisitions to meet the evolving geopolitical threats, and bring a technological advantage to avoid the risky, ad hoc status quo in DoD source selections. In essence, applying the CBC framework to current

DoD source selections offers a small, yet important, shift in how the DoD can deliver best value to rapidly protect and defend the United States of America (DoD).

References

Air Force Installation Contracting Center Strategic Plans and Strategic Communications Division. (2022). *AFBIT lite (Air Force business intelligence tool)* [Federal contracting spend]. https://public.tableau.com/app/profile/afbit

Butler, P. (2014). *Key case law rules for government contract formation*. Management Concepts.

Ding, M., Grewal, R., & Liechty, J. (2005). Incentive-aligned conjoint analysis. *Journal of Marketing Research*, *42*(1), 67–82. https://doi.org/10.1509/jmkr.42.1.67.56890

DoD. (2016, March 31). *Source selection procedures* (DFAR Supplement 215.3). https://www.dau.edu/pdfviewer/Source/Guidebooks/DoD-Source-Selection-Procedures-(SSP).pdf

DoD. (2022). *National defense strategy of the United States of America.* https://www.defense.gov/National-Defense-Strategy/

Finkenstadt, D. (2020). *Essays on perceived service quality and perceived value in business-to-government knowledge-based services* [PhD dissertation, University of North Carolina]. University Libraries: Carolina Digital Repository. https://cdr.lib.unc.edu/concern/dissertations/8910k095g

Finkenstadt, D., & Hawkins, T. (2016). *#eVALUate: Monetizing service acquisition trade-offs using the Quality-Infused Price© methodology* [Technical report, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/handle/10945/56388

GAO. (2013). *GAO bid protest annual report to Congress for fiscal year 2012*. https://www.gao.gov/products

GAO. (2014). *GAO bid protest annual report to Congress for fiscal year 2013*. https://www.gao.gov/products

GAO. (2015). *GAO bid protest annual report to Congress for fiscal year 2014*. https://www.gao.gov/products

GAO. (2016). *GAO bid protest annual report to Congress for fiscal year 2015*. https://www.gao.gov/products

GAO. (2017). *GAO bid protest annual report to Congress for fiscal year 2016*. https://www.gao.gov/products

GAO. (2018). *GAO bid protest annual report to Congress for fiscal year 2017*. https://www.gao.gov/products

GAO. (2019). *GAO bid protest annual report to Congress for fiscal year 2018*. https://www.gao.gov/products

GAO. (2020). *GAO bid protest annual report to Congress for fiscal year 2019*. https://www.gao.gov/products

GAO. (2021). *GAO bid protest annual report to Congress for fiscal year 2020*. https://www.gao.gov/products

McQuarrie, E. F. (2016). *The market research toolbox: A concise guide for beginners*. SAGE Publications. http://dx.doi.org/10.4135/9781483398228.n12

The MITRE Corporation. (n.d.). *Contract protest diagnostic tool*. Retrieved May 27, 2022, from https://aida.mitre.org/protest-tool/

Nicholas, R. E. (n.d.). *Source selection* [Presentation]. Oklahoma City Air Logistics Center. https://www.slideserve.com/odelia/source-selection

Orme, B. (2020). *Getting started with conjoint analysis - Strategies for product design and pricing research* [PDF version]. https://sawtoothsoftware.com/

Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1985). A conceptual model of service quality and its implications for future research. *Journal of Marketing*, *49*(4), 41–50. https://doi.org/10.1177/002224298504900403

Real Property Policies, 41 CFR § 102–71.20 (2022). https://www.law.cornell.edu/cfr/text/41/102-71.20

Thompson, B. (2022). *Stated intentions vs. actual behavior: Choice-based conjoint (CBC) in DOD source selections* [MBA project, Naval Postgraduate School]. NPS Archive: Calhoun.

Sawtooth Software. (2022). Lighthouse studio help [Digital Handbook].

PANEL 6. INVESTING IN AMERICA: DEFENSE INDUSTRIAL BASE

Wednesday, May 10, 2023	
12:45 p.m. – 2:00 p.m	**Chair: Justin K. McFarlin,** Deputy Assistant Secretary of Defense for Industrial Base Development & International Engagement ***How Not to Alienate Business Partners: A Framework for Addressing Factors Impacting Retention of Defense Contractors*** Moshe Schwartz, Etherton and Associates Michelle Johnson, Naval Postgraduate School ***Effective Competition and Market Concentration in the Defense Industrial Base and U.S. Federal Government*** Edward Hyatt, George Mason University ***Defense Industrial Base: DOD Should Take Actions to Strengthen Its Risk Mitigation*** Daniel Glickstein, U.S. Government Accountability Office

Justin K. McFarlin—currently serves as the Deputy Assistant Secretary of Defense for Industrial Base Development & International Engagement at the U.S. Department of Defense. In this role, Mr. McFarlin is responsible for Defense Industrial Base engagement strategy development and coordination, as well as the coordination and integration of all international agreements in the fields of research, development, acquisition and logistics, and foreign military sales. Specifically, he acts for the ASD(IBP) on matters concerning international programs while directing and monitoring the implementation of defense policies on international armaments cooperation within the Department. Mr. McFarlin oversees the Office of International Cooperation and the Office of Industry Engagement.

Prior to re-joining the U.S. Department of Defense, Mr. McFarlin spent almost two decades working in Aerospace & Defense. He was most recently a Director in the Corporate Strategy & Development group at L3Harris, where he shaped a corporate portfolio of businesses valued at over $40B. His work included managing special projects, leading internal deal teams, and serving as external coordinator for select M&A activities. Previously, Mr. McFarlin was a strategy and operations consultant at Monitor Deloitte and Censeo Consulting Group, working with Fortune 500 companies and U.S. federal agency clients. Mr. McFarlin began his career as an Army Officer, holding leadership and staff positions domestically and abroad, including Platoon Leader in a Patriot missile battery and Aide de Camp to a Deputy Commanding General of Multi-National Corps-Iraq. Mr. McFarlin earned the Defense Meritorious Service Medal, multiple Army Commendation Medals, and both the Chilean and U.S. Parachutist badges.

Mr. McFarlin received his B.S. in Computer Science from West Point, his MBA from Dartmouth College, and his MPA from Harvard University. He is a Term Member at the Council on Foreign Relations, a Security Fellow with the Truman National Security Project, and a Life Member of the Armed Forces Communications and Electronics Association (AFCEA).

How Not to Alienate Business Partners: A Framework for Addressing Factors Impacting Retention of Defense Contractors

Moshe Schwartz—is President of Etherton and Associates, a consulting and lobbying firm specializing in defense acquisition, industrial base, and cybersecurity policy. Prior to joining Etherton and Associates, Schwartz served as Executive Director of the congressionally mandated Advisory Panel on Streamlining and Codifying Acquisition Regulations and spent 15 years providing analysis and legislative support to Congress on acquisition policy and industrial base issues, including as a specialist at the Congressional Research Service and senior analyst at GAO. Schwartz also served as senior advisor to the Commission on Wartime Contracting in Iraq and Afghanistan, and as advisor at ISAF headquarters in Afghanistan. [moshe@ethertonandassociates.com]

Michelle Johnson—is Communications Manager at the Acquisition Research Program at Naval Postgraduate School. Prior to joining NPS, she was a research associate and communications manager for the congressionally mandated Advisory Panel on Streamlining and Codifying Acquisition Regulations (the Section 809 Panel). Johnson has a PhD in English Literature from Michigan State University. Her most recent academic position was assistant coordinator of composition and assistant professor of English at Francis Marion University in Florence, South Carolina. [shel.veenstra@gmail.com]

Abstract

The U.S. government and the Department of Defense (DoD) continue to add new social policy, regulatory, and legislative burdens to the federal contracting process, despite growing consensus that these practices have led to a sluggish and inefficient acquisition system that erodes our competitive advantage against adversaries. This dynamic is also driving companies to leave the defense marketplace in droves, despite efforts to recruit new businesses to sell to the DoD and encourage the use of alternative procurement processes. Our research provides a framework for how defense buyers and policymakers can improve retention rates for defense contractors, with specific recommendations for removing requirements that do not support critical national security needs. Fundamentally, defense acquisition should be governed by fewer requirements and checklists, freeing up acquisition professionals and leaders to develop and sustain long-term business relationships that take a win-win philosophy.

Introduction

Last year we presented a paper at the Naval Postgraduate School Acquisition Research Symposium entitled *The Slow Destruction of the Defense Industrial Base*, where we argued that despite the Department of Defense's unprecedented and increasing reliance on commercial technologies to conduct military and business operations, the National Security Innovation and Industrial Base (NSIB) is shrinking and "becoming detached from the greater U.S. economic base" because private industry "is choosing not to work with the federal government in general, and the Department of Defense (DoD) in particular" (Schwartz & Johnson, 2022).

We further argued that those companies who remain committed to working with the DoD "are hamstrung by statutes and government policies that inhibit innovation and adaption," putting these companies at a "severe disadvantage when competing with industry for high-skill talent critical to innovation, dedicating resources to R&D, and staying ahead of the technology and innovation curve."

The consequences of these two trends, if they continue, will have a significant impact on the DoD's ability to maintain a technology and capability advantage over potential adversaries, undermining our national security. The United States is already seeing its military advantage in a range of capabilities erode, to include hypersonics, where certain Chinese and Russian capabilities exceed the United States' (Tucker, 2023). Moreover, China is rapidly eroding U.S. naval overmatch and air superiority in the Indo-pacific region (Congressional Research Service, 2022).

The DoD needs a holistic reassessment of its relationship as a customer and partner with commercial industry, one built on respect, understanding the business needs of industry, open channels of communication, and sensible regulations that support national security without excessive bureaucracy.

This report asks, and identifies data to answer, four simple questions.

1. Is the NSIB continuing to shrink?
2. Are the DoD's efforts to reach out to industry and bring more companies into the NSIB working?
3. What about the acquisition regulations is driving the trend of shrinking the NSIB and hamstringing those companies that remain?
4. What can be done to reverse this trend?

Time is running out to prevent the United States falling behind in the race for technological and operational superiority. The DoD and Congress must heed the words of Reignier in Henry VI, and "Defer no time; delays have dangerous ends."

The NSIB Is Still Shrinking—But That is Only the Beginning of the Story

Last year we referenced a Government Accountability Office (GAO) analysis showing that from FY2011 to FY2020, the number of small businesses receiving DoD contract awards decreased by 43% even as obligations to small businesses increased by approximately 15% (GAO, 2021). But this is not a small business story—it is an industry-wide story. According to the same report, the number of larger businesses receiving contract awards fell by 7.3% annually over the same period, a more precipitous decline than the 6% annual decline in the number of small businesses receiving contract awards (GAO, 2021, p. 9).

> *Not too many years ago, we had five times as many contractors and there was more competition and there was more creativity.*
>
> – Representative Ken Calvert

The NSIB continued to shrink in 2022 across small business and larger businesses, DoD contracting, and government-wide contracting. According to Bloomberg analysis, the number of small and other businesses contracting with the DoD slid further in fiscal years 2021 *and* 2022, with small businesses decreasing by 5% and 7%, and other business decreasing by 1% and 5%, respectively (Nieberg & Murphy, 2023).

Table 1. Company Participation in the Defense Industrial Base. (Nieberg & Murphy, 2023).

	Large/Other Business	Small Business
FY18	14840	40752
FY19	14125	38434
FY20	13431	36705
FY21	13293	35036
FY22	12648	32681

A separate Bloomberg analysis takes a step back to reveal this pattern across all defense contractors, showing a drop in defense of 2,854 vendors from FY2021 to FY2022 (Murphy, 2023). A similar trend is playing out in civilian agencies (See Figure 1).

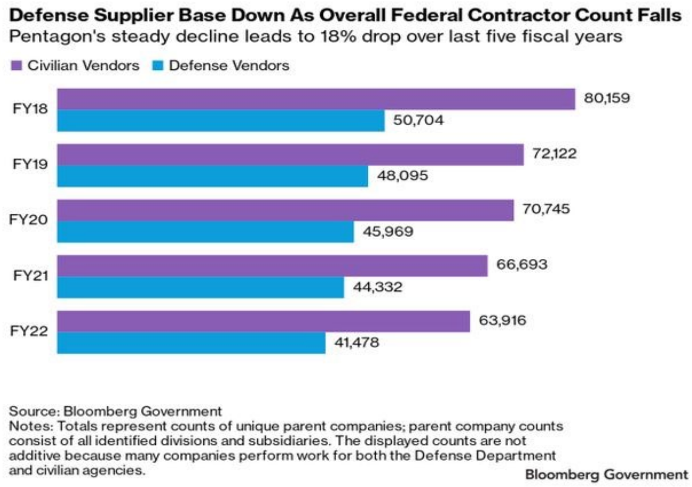


Figure 1. Defense Supplier Base Down as Overall Federal Contractor Count Falls. (Murphy, 2023).

Figure 2 depicts data from six different analytical trends of contractor participation in various segments of the government marketplace published by GAO, CSIS, Bloomberg, NDIA, and HigherGov. Each analysis of contractor participation shows a clear downward trend in contractor participation in the government marketplace.

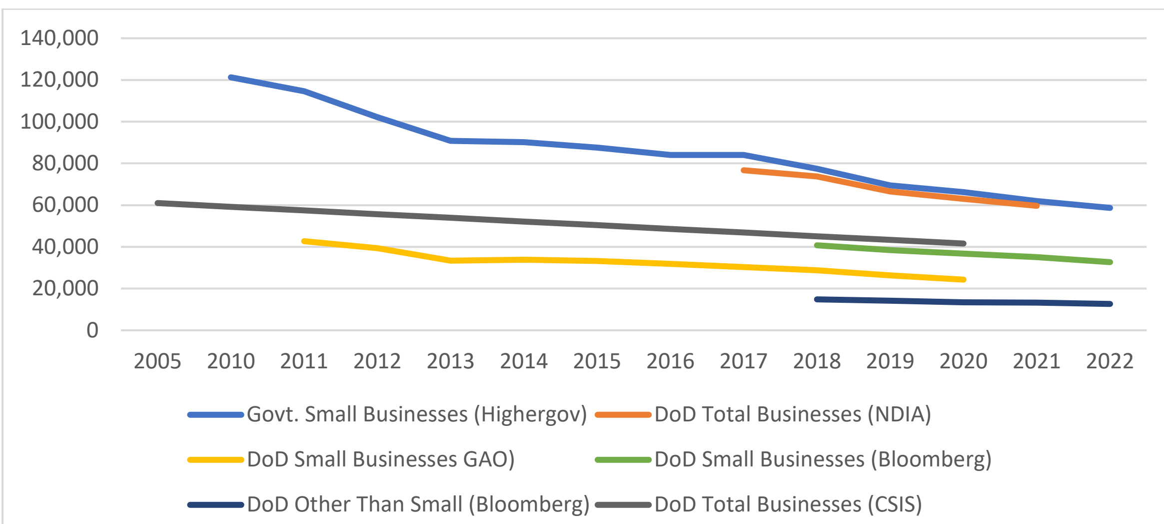


Figure 2. Contractor Participation in the Government Marketplace—Trends[1]

[1] See Appendix A for source data. The various data sources referenced in this report do not match. Such inconsistencies appear to be more related to differences in methodology and when analyses were conducted than a question of data. For example, because FPDS changed its methodology in 2015, CSIS removed from its analysis small contractors included in pre-2015 FPDS data that would not need to be reported under current rules. The Blomberg analysis "represent counts of unique parent companies" that consolidates all identified divisions and subsidiaries of a particular entity. In addition, FPDS is a dynamic source that updates data daily, returning slightly different results depending on when the data was run. Despite these inconsistencies, the overall trend identified by GAO, CSIS, HigherGov, Bloomberg, and others are all consistent.

Many analysts, and even the DoD's assessment of the health of the defense industrial base, have attributed this decline primarily to mergers and acquisitions. (See, for example, the 2022 DoD Report State of Competition in the Defense Industrial Base.) While mergers and acquisitions continue to occur in the defense marketplace, those numbers pale in comparison to the larger trends. A study from HigherGov found 433 mergers and acquisition in the aerospace, defense, and government sector in 2022 (Siken, 2023). Comparing this data to the Bloomberg numbers, this consolidation accounts for approximately 15% of the drop in defense contractors. The other 85% of consolidation would appear to come from vendors choosing to leave the defense marketplace.

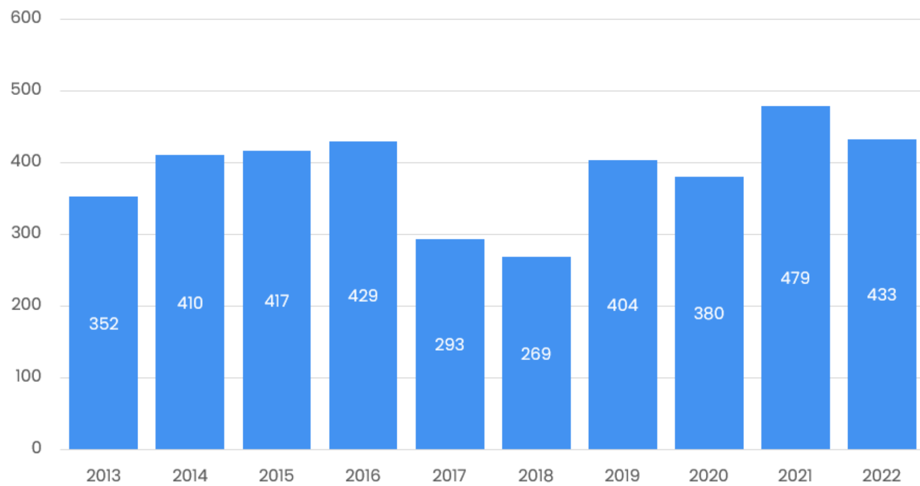


Figure 3. 10 Year M&A Transaction Volume Trend (Count).
(Siken, 2023).

Furthermore, mergers, acquisitions, and takeovers are not unique to the defense sector. They occur in the larger U.S. economy, which nonetheless continues to see growth over this same time period, both in dollars and numbers of businesses. Figures 4 and 5 convey a clear increase in GDP and the number of new companies joining the economy, respectively. U.S. GDP grew by 49% from 2011 ($15.6 trillion) to 2021 ($23.3 trilion), with a significant 10.7% increase ($3 trillion) from 2020 to 2021 (The World Bank, 2023). The total number of businesses in the U.S. economy increased by 7% from 2010 to 2019 (U.S. Census Bureau, 2021) and the number of applications for new businesses almost doubled from 2011 to 2022, from 2.58 million to 5.1 million new filing.

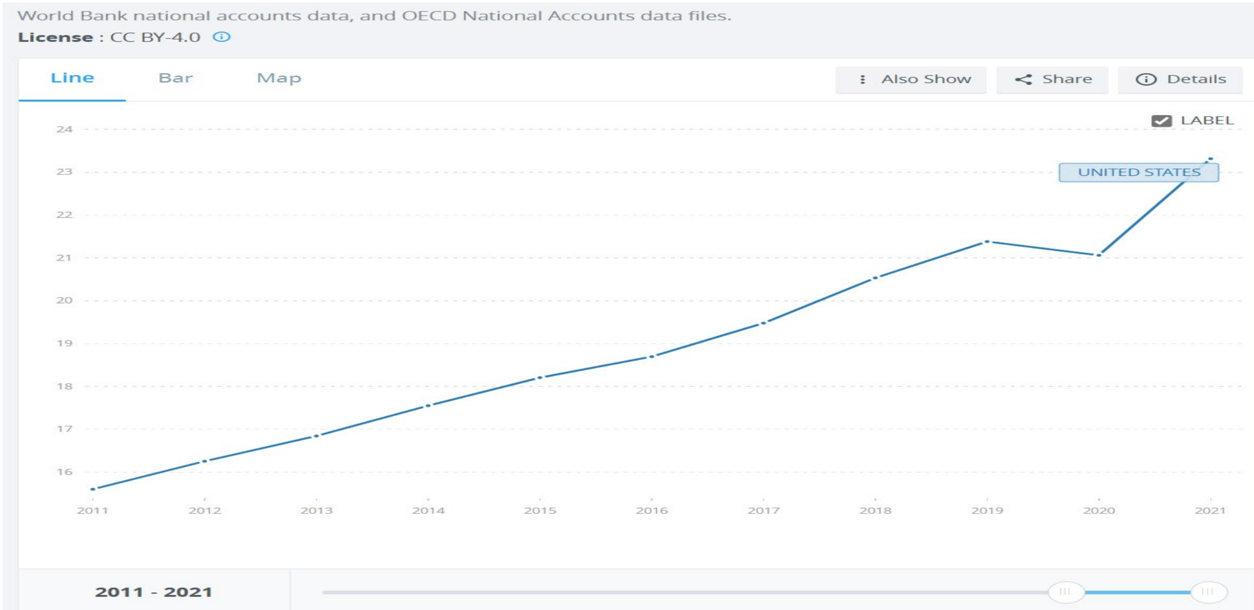


Figure 4. United States Gross Domestic Product, 2011–2021. (The World Bank, 2023).

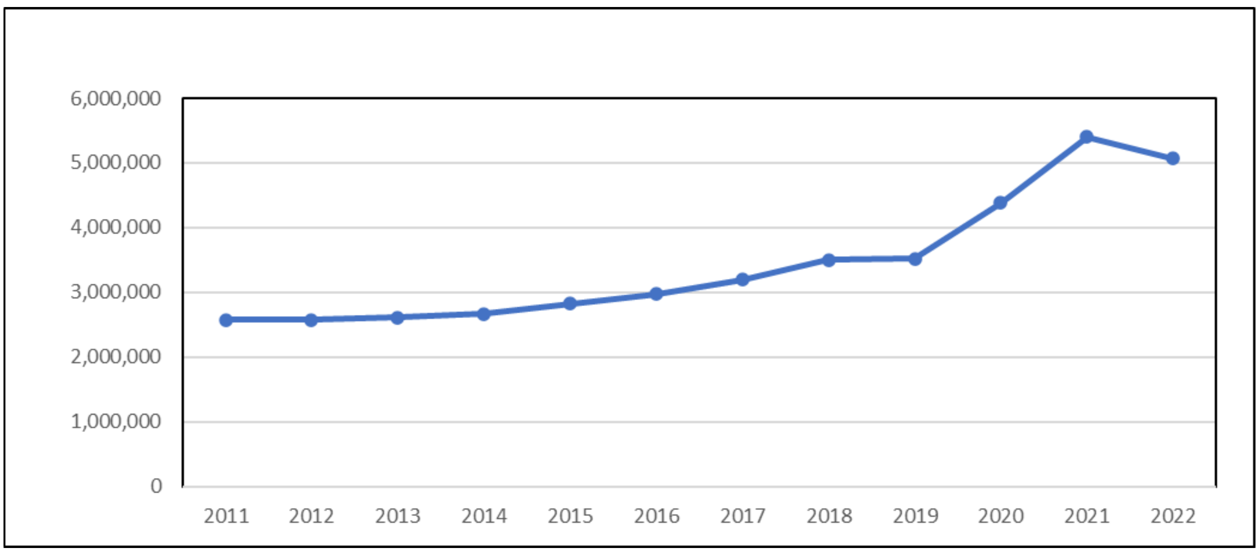


Figure 5: New Business Formation Filings (Seasonally Adjusted)

Data from the Small Business Administration reports a net increase of 180,528 businesses from March 2020 to March 2021 (U.S. Small Business Administration Office of Advocacy, 2022). The U.S. Bureau of Labor Statistics (2023) reported a net increase of 618,391 establishments in the United States from September 2021 to September 2022.

The DoD's Outreach Efforts Are Not Changing the Underlying Trend

Over the past decade, the DoD has made efforts to capture some of this growth in the larger marketplace, with a specific focus on recruiting nontraditional defense contractors and startup companies developing new technologies. In 2015 then–Defense Secretary Ash Carter established the Defense Innovation Unit (then known as DIUx) "as part of the Defense Department's outreach to America's innovative technology companies" (DoD, 2016). DIU's efforts are bearing some fruit. Between 2019 and 2022, DIU awarded 360 OT contracts to 321 unique vendors, many of which we believe are new to the NSIB. DIU, and its sister organization the National Security Innovation Network, are building a foundation for bringing in more companies in the future, generating proposals from companies that are not currently participating in the NSIB. (Defense Innovation Unit, 2022, pp. 8, 12).

But these recruitment efforts are focused on a small subset of the NSIB and are not (yet) reversing the larger trend. In fact, as the latest Vital Signs report from NDIA highlights, the rate of new companies entering the defense marketplace is also slowing. According to NDIA, from 2018 to 2021, the total number of companies entering the DoD marketplace decreased 17%, from 10,076, to 8,322 (NDIA, 2023, p. 13). Similarly, the GAO (2021) found that from 2016 to 2020, the number of small businesses contracting with the DoD decreased 22%, from 7,083 to 5,526 (see Figure 6).

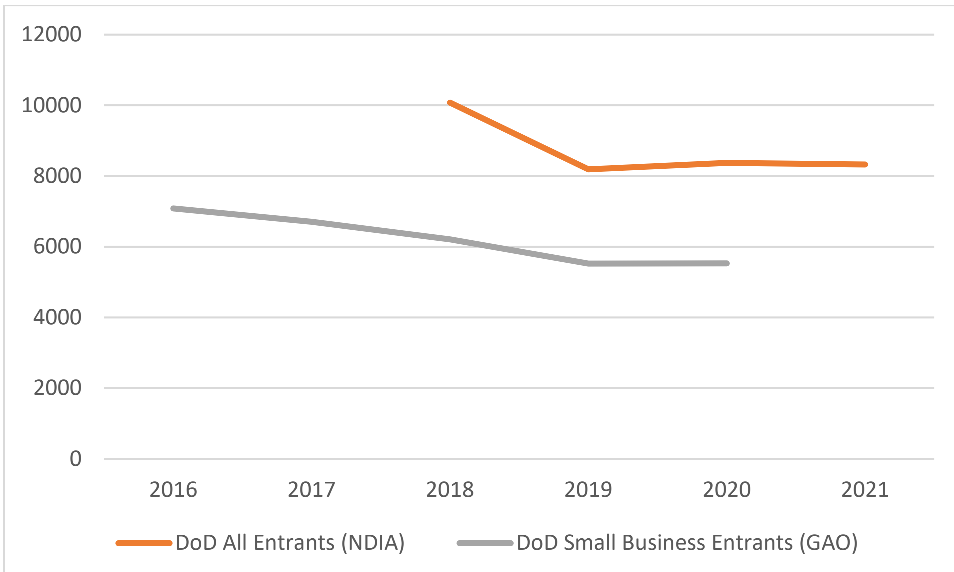


Figure 6. Fewer Firms are Entering the DIB.
(U.S. Census Bureau, 2023).

What Is Driving Industry Away from the NSIB (and Hamstringing Those that Remain)?

At two recent events we asked attendees “Has your company considered pulling out of any government markets?” Twenty-five percent of respondents said *their companies have considered pulling out of at least some government markets.* What is striking about this response is that both events were geared towards companies in the federal government market.[2] We then asked what factors most influence whether their companies participate in government contracts. Half of respondents cited “government-specific regulations that make it too hard or not worthwhile to work for government” as a strong or very strong consideration in deciding whether to contract with the government. Almost half of respondents cited “concerns over intellectual property integrity,” followed closely by “insufficient levels of cash-flow or profit margins.”

The polls we conducted were not scientific by any means.[3] However, a larger poll conducted by NDIA reinforced our informal findings. When asked by NDIA “What is the most

[2] The two events were the Practicing Law Institute’s *Government Contracts 2022* (October 26, 2022) and the NDIA Procurement Division Quarterly Meeting (January 10, 2023).
[3] We did not control for any outside factors and our sample size was small, ranging from 121–152 respondents.

pressing issue facing the defense industrial base," the burden of the acquisition process and paperwork was cited by 30% of those polled, ranking higher than concerns over budget stability, workforce, inflation, or any other issue (2023, p. 14). Respondents also indicated that it is much more difficult to do business with the DoD than other agencies. Eighteen percent of respondents said it was "very difficult" to do business with the DoD, compared to 10% for other government agencies, and 8% for non-government agencies (see Figure 7).

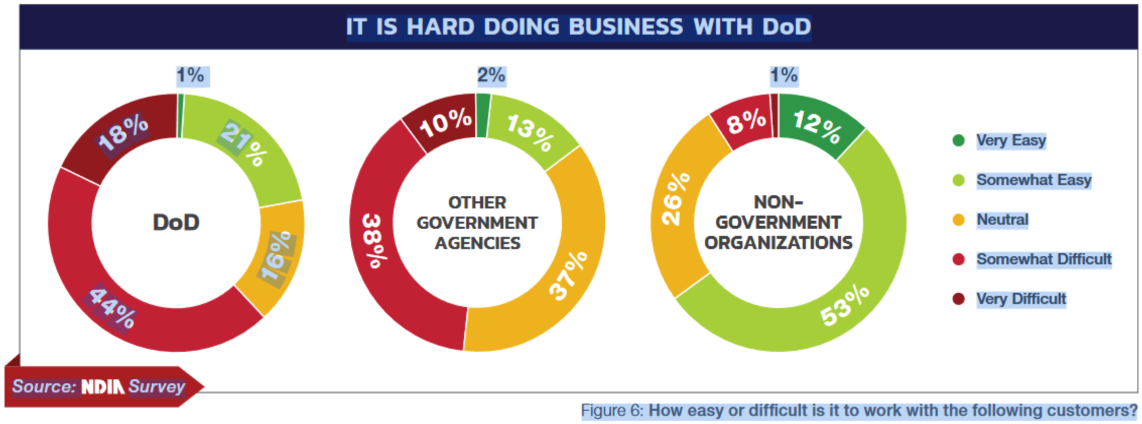


Figure 7. Views on Working with the Government

Companies Want to Work with DoD—There are Just Too Many Disincentives

There is another business model showing growth in the number of companies selling to the DoD. Data on the use of consortia and other transaction authority convey a sense that when the traditional procurement rules are altered, more companies seek out opportunities to work with the DoD. From FY10 to FY20, total membership in 12 consortia focusing on government contracting increased more than tenfold, from 365 to over 5,600. One consortium's membership increased from 161 members in 2010 to 900 members in 2020. Another consortium attracted over 900 members in its inaugural year in 2019 (Schwartz & Halcrow, 2022).

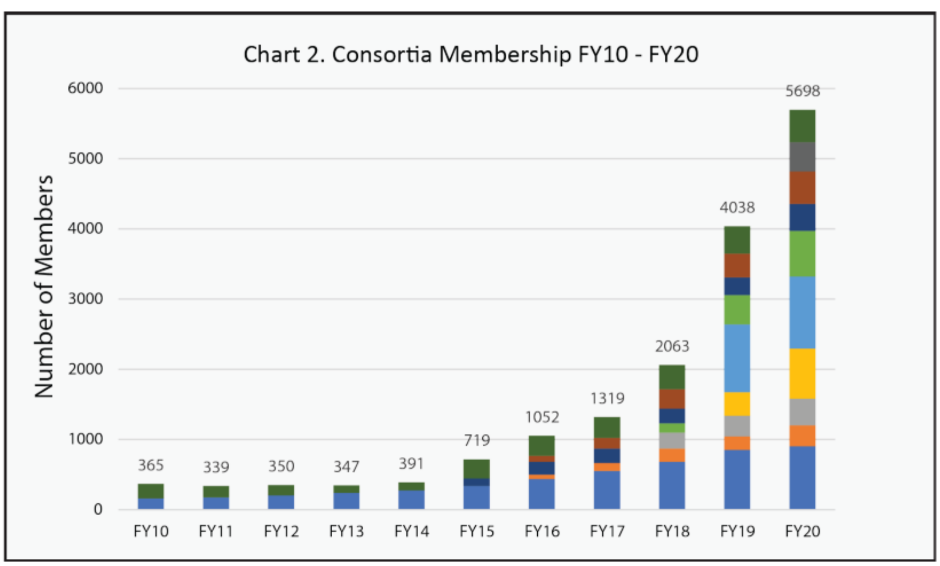


Figure 8. Consortia Membership FY10–FY20.
(Schwartz & Halcrow, 2022).

A large percentage of these businesses are nontraditional defense contractors, demonstrating the value of an arrangement that simplifies the process of working with the DoD and enhances the benefits of collaborating with others in similar areas of expertise.

What attracts companies to consortia and other transaction agreements is:

- An expedited and simplified method of contracting with the government—other transactions are not bound by the FAR or many other regulatory and legislative requirements.[4]
- Not having to deal with the government directly. According to the Executive Director on one company with 60 employees, "We would never have had this [contracting] opportunity without the consortia model" (Schwartz & Halcrow, 2022, p. 17).
- More communication and collaboration between government and industry—and within industry.

The benefits of working within consortia are similar to steps and recommendations being made by the DoD's outreach organization, DIU. DIU's Director of Acquisitions Cherissa Tamayori (2023) attributes some of their success to their use of simplified acquisition processes, notably other transaction authority and commercial solutions openings. Tamayori also suggests that to continue this trajectory, "We must ensure that government needs align with best commercial practices and do not require a company to create government-specific processes, develop costly proposals, or spend a year waiting to learn if it won a contract award." If the DoD and Congress simplified existing procurement rules and regulations and applied them more uniformly across the NSIB, a dramatic increase in numbers of defense contractors would likely follow.

Are Defense Procurement Regulations Really Different Than Industry Practices?

Commercial companies seeking to enter the defense market must ensure that their supply chains, software and hardware contents, sourcing, cybersecurity, accounting systems, and pay scale5 meet DoD and government-wide unique requirements. In combination, conforming to these requirements can be time-consuming and require significant upfront investment. Some of these government-unique regulations (such as domestic content requirements) can drive up the cost of goods and services provided by companies. Given that most companies in the defense industrial base sell into both government and commercial market, government-unique regulations that drive up the cost of products sold into commercial markets can threaten a company's ability to compete and survive outside of government contracts.

> *In purchasing power parity, they [China] spend about one dollar to our 20 dollars to get to the same capability. . . . We are going to lose if we can't figure out how to drop the cost and increase the speed in our defense supply chains.*
>
> —MG Cameron Holt, former Deputy Assistant Secretary of the Air Force (contracting)

A few case studies illustrate this burden and increased cost. At the April 2023 Sea Air Space expo, a representative from a midsize technology company that sells commercial goods to the U.S. Coast Guard stood up during Q&A to ask DIU's Cherissa Tamayori how industry can help the DoD better use its rapid acquisition authorities. Despite this company providing commercial goods, he claimed that none of his contracts had ever used FAR Part 12 ("Acquisition of Commercial Products and Services"). By his telling, accounting for the

[4] See 10 USC 4021 and 10 USC 4022.
[5] This requirement is primarily applicable to cost contracts.

extra and unnecessary burden of complying with the full FAR requirements drove up the costs for these supplies by 20%–30%.

Another example comes from a foreign supplier of an underwater camera to a defense prime. To account for the potential risk of accepting FAR clauses, conditions, and requirements they didn't understand, the sub doubled the cost of the camera from approximately $200,000 (commercial price) to $400,000 (Conversation with author, April 5, 2023).

To stay in the defense market, companies must absorb the cost of tracking constantly changing restrictions, prohibitions, and requirements of the procurement system, a task that is difficult for even the most sophisticated defense contractors—and an insurmountable challenge for many medium sized commercial companies. Appendix A is a list of prohibitions or restrictions currently working their way through the rule-making stage or recently implemented (as of March 1, 2023). These include:

<u>Restrictions on contractors using certain goods or services even if the goods and services are not used on a DoD contract:</u>

- Prohibitions on the use of Chinese telecommunications equipment
- Prohibitions on the use of Unmanned Aircraft Systems from certain foreign countries
- Prohibitions on the use of certain semiconductor products or service

<u>Other restrictions or requirements:</u>

- Disclosing to the DoD the source for certain permanent magnets in products or services
- Expanding the prohibition of procuring certain rare earths, strategic and critical minerals, or energetic materials from certain Chinese entities
- Prohibitions on certain items mined, produced, or manufactured in the Chinese Xinjiang Uygur Autonomous Region
- Prohibitions on certain printed circuit boards from China
- Requirements to disclose employees working in China on DoD contracts
- Expanding the prohibition on certain metals, to include materials mined, refined, or separated in China
- Cybersecurity requirements to contract with the DoD (CMMC)
- Gradually increasing domestic content requirements for the Buy American Act, increasing to 75% in 2029.

For private companies, particularly small or mid-sized companies, just tracking these changes requires significant cost, time, and expertise. Some of these regulations date back to legislation passed in 2018. In other cases, Congress passed laws to amend previous legislation whose regulations have still not been promulgated and issued.

These still-to-be-implemented rules are on top of current requirements, including

- The Berry amendment
- Specialty metal requirements
- Truthful Cost or Pricing requirements (formerly known as the Truth in Negotiations Act)
- Cost Accounting System requirements
- Wage caps for certain cost contracts

Incumbent defense contractors are often supportive of the larger goals of many individual requirements and have resources dedicated to complying with government-unique terms, conditions, and business processes. But even these long-term partners are growing weary of the ever-increasing complexity of doing business with the DoD.

In 2021, for example, three industry groups representing technology companies selling to the DoD wrote a letter to Deputy Secretary of Defense Hicks about the uncertainty surrounding CMMC—a requirement that was announced in 2019, evolved into version 2.0 in 2021, and has yet to be implemented. That letter expressed support for improved cybersecurity practices, but noted that this uncertainty of how CMMC will be executed is compounded by "the continued proliferation of federal cybersecurity requirements at the agency level . . . [and] causes operational impacts that result in procurement inefficiencies and contractual modifications that are passed on to the Government." This complexity also slows or stops efforts to modernize and comply: "contractors, subcontractors, and suppliers may defer substantial investments pending communication and greater certainty about the program's requirements" (Information Technology Industry Council, National Defense Industrial Association, and Professional Services Council, 2021).

One of the simple suggestions these groups make is better communication: "We believe [the] DoD and industry will achieve the best risk management outcomes when they engage in bi-directional information sharing and act transparently in their decision-making." Intentional and frequent communication between the DoD and industry has long been recognized as a best practice—yet efforts to embed more transparency in the acquisition process have been inconsistent and not widespread enough.

Recruiting and Retaining Companies Present Different Challenges, with Different Solutions

As with any relationship, the initial excitement of beginning something new can quickly fade as both parties settle into their routines. The steps the DoD has taken to attract new companies are insufficient to reverse the trend of a shrinking NSIB, in part because the Department—and the Federal Government as a whole—does not have an effective strategy for retaining companies once they join the national defense innovation and industrial base. The challenges they face are either unknown or deemed acceptable friction inherent to how the DoD conducts business. Before it can reverse the current industrial base trends, Congress and the DoD would benefit from a foundational change in how government thinks about the industrial base throughout the full life cycle of the acquisition relationship.

Acquisition is an Art Not a Science

Defense acquisition is too often executed as a mechanistic transactional process focused on checklists, regulations, and processes rather than a relational process focused on shared priorities, better outcomes, and mutual respect. Attempts to ensure consistent oversight and accountability across an enormous bureaucracy have produced a mechanistic approach that discourages individualized solutions, creative thinking, teamwork, and trust. But at its heart, acquisition is a human endeavor of building and sustaining relationships. More regulation does not produce greater efficiency and effectiveness. Rather, fewer regulations, more consistently enforced, coupled with empowering acquisition professionals to think, will reap greater acquisition rewards.

The DoD Should Get a Relationship Therapist

The relationship between the DoD and industry is dysfunctional (partly due to the third wheel of Congress—but that's another paper). While not relationship experts, our research and experiences have indicated that key to a strong relationship is

- Understanding the needs of the other party

- Having open and honest communication
- Seeking a win-win common ground that accepts compromise.

Understand Industry

The DoD generally does not have a solid understanding of how industry operates, what motivates companies, drives business decisions, and most importantly, prompts companies to leave (or not enter) the NSIB. The first step in developing a more beneficial relationship with industry is for the DoD to better understand their needs and priorities. DIU's Cherissa Tamayori (2023) makes one of her three suggested strategies for improved acquisition to "understand industry partners and align to common business practices." One of the differences the DIU team has found is that "many companies, especially those supplying software-based technologies, have pivoted to a service-based model." Tamayori admits that acquiring technology this way "requires a mindset shift" in defense acquisition.

Research on the differences between business-to-business (B2B) and business-to-government (B2G) processes provides additional some insight:

> The inflated cost of B2G exchanges outweigh the scale and efficiency benefits until the firm reaches a critical threshold. Firms with a stronger government customer emphasis also experience more performance volatility (as revealed in idiosyncratic and systematic risk) due to the difficulties of redeploying and safeguarding [transaction-specific investments] from unanticipated changes in government procurement activities. That is, firms face significant asset specificity in B2G exchanges because of the federal government's idiosyncratic nature, so the projected cash flows from B2G exchanges are more volatile. (Josephson et al., 2019)

We noted some of these characteristics of commercial businesses in our 2022 paper and add a few more: an unwillingness to relinquish all IP rights, the ability to operate with unlimited profit margins, and the potential for cashflow that evolves at pace with changing costs or other growth opportunities.

On a very simple level, the risks of selling to the DoD are increasing, while profits are decreasing:

> The traditional Wall Street view of the defense industry is that it should demand lower multiples than the technology industry as it possesses less revenue risk having the Department of Defense as its primary customer. However, with year-over-year variations in the defense budget and high-value transaction fluctuations in the Foreign Military Sales program, revenue volatility can actually be much higher than expected. Given that contract revenue volatility can result in lower margins, the major defense contractors seek alternative methods of revenue stability. . . . *Stabilized revenue generation and high margins are limited by fluctuating policies and budgets* while competitive advantages are disrupted by innovative new companies, so the primes utilize their balance sheets and respond with acquisitions and consolidation, *further reducing production capacity to save costs*. (Van der Colff, 2023, emphasis added)

Businesses don't thrive when the primary metric of success is low price. Nor do customers. The current challenge of replenishing supplies sent to Ukraine illustrates that an effective defense industrial base operates with redundancy, flexibility, and surge capacity. Leaders in the DoD and Congress are now admitting the weaknesses of just-in-time inventory strategies and are employing rapid acquisition strategies, especially for supplies considered necessary for national security. The establishment of the Joint Production Accelerator Cell in March 2023 begins a larger outreach to existing defense contractors to build "enduring industrial production capacity, resiliency, and surge capability" (LaPlante, 2023). As this and other efforts pick up speed, we are starting to see the potential of what it could look like when this relationship is nurtured around a shared commitment to mission. Such enhanced communication should be institutionalized as the rule, not the exception.

Better Communication

The key to any successful relationship is communication, listening, understanding the other's needs and perspectives, and working to find the middle ground that meets the needs of all parties concerned. This is not the DoD's strong suit. Many contracting officers opt not to have robust communication with industry, often out of fear of protest or violating a regulation. More robust communication has many advantages. A number of analysts believe that increased communication has helped reduce the number of bid protests (Konkel, 2022). One senior industry official told us that they prefer other transaction authority contracts because DoD contracting officials tend to be more communicative in negotiations.

The benefit of enhanced communication between industry and government/DoD is no secret. OMB's Myth-Busting memo #4 reminds acquisition professionals of all the channels of communication available to them and asks each agency to appoint an industry liaison (Field, 2019). More frequent and ongoing communication between industry and the DoD will help the DoD better understand commercial business processes and make clear where compromise can most effectively achieve the shared mission of ensuring national security priorities.

Build a Win-Win Relationship

Too often, in an overzealous effort to drive down cost, conduct oversight, protect DoD interests, or improve performance, the DoD takes a win-at-all-cost-on-every-issue approach. Such an approach may save some money, garner more IP rights, or facilitate a far-reaching oversight regime in the short-term, but the long-term consequences have contributed to a less robust, less resilient, and less dynamic NSIB. The DoD should embark on a win-win approach that focuses on nurturing its relationship with industry, recognizing industry needs, and being a more supportive partner with industry.

Progress Payment Rates: The Bigger Context

Progress payments help companies finance their work on long-term contracts without having to go to public markets for financing. The DoD increased progress payments rates during the pandemic to increase the velocity of funds flowing through the industrial base. Some officials have recently suggested that progress payment rates may be brought down to pre-COVID levels. In Congress, legislative proposals have sought to drop progress payment rates as low as 50%, with the possibility of increasing the rates if certain requirements are met.

Understand Industry: Cash flow is the lifeblood of industry. Elevated progress payments for work already performed is important to industry and does not increase cost to the government.

In March 2023, Bloomberg reported that small business are shedding jobs, in part due to higher interest rates, stating "U.S. businesses with less than 20 employees have eliminated 594,000 jobs since December 2021, while firms with 20 to 49 workers shed jobs for a second-straight month." This was attributed in part to interest rates because "Small businesses are often more sensitive to higher rates than larger ones, since they don't have the ability to lock in borrowing costs on the bond markets" (Tanzi, 2023).

Seek a Win-Win Approach: In a high-inflation economic landscape with increasing interest rates and an FY2024 budget request that does not have meaningful increases in spending (and likely does not keep up with inflation), the DoD should maintain progress payment rates at current levels. Maintaining the current rates is an easy way for government to support industry and pursue a win-win approach, giving industry incentives and benefits where it can.

As the current efforts from the Joint Production Accelerator Cell show, a healthy relationship with the defense industrial base involves compromising—here giving up some efficiency to get greater resilience. The White House has also invoked the Defense Production Act liberally since 2020, waiving many statutory requirements to meet national security imperatives. This productive relationship must continue.

Streamline the Relationship to Make it Less Beholden to Regulations and Easier to Navigate

The DoD should undertake a comprehensive analysis of what statutes, regulations, and policies are driving industry to leave the NSIB. Armed with such information, the DoD could then submit legislative proposals to Congress and initiate regulatory changes to the Federal Acquisition Regulation and the Defense Federal Acquisition Regulation Supplement that are aimed at rebuilding industry participation in the government marketplace while still maintaining the necessary oversight

Balancing Oversight with Industry Needs

We pulled all FPDS data that had "Certified Cost or Pricing Data" requirements for FY 2021. The current threshold is $2 million. Raising this threshold to $10 million would cut the burden on half the companies while still capturing 81.6% of dollars. The number of companies under the current $2 million threshold is 1,106, which reduces to 653 companies under a $7.5 million threshold and 557 companies under a $10 million threshold. A $10 million threshold would also drop the number of contracts affected by 62.6%.

If you moved the threshold down to $7.5 million, which is actually reasonable because that aligns with the threshold where companies would receive modified Cost Accounting Standards coverage, then the dollars covered is about 86% while contracts covered is 46%. Again, focusing time and auditing resources on where the biggest risks are (dollars) makes sense. Making this change would streamline business relationships while still maintaining important cost oversight.

Note: The data are not perfect; for example a competitive contract that then gets a sole-source modification >$2 million is actually TINA-covered but doesn't appear in the FPDS data. Moreover, there are contract values below $2 million that appear but are excluded from this analysis, perhaps because they are grandfathered in from a 2018 rule.

This review of existing statues, regulations, and policies should become a routine process that reevaluates requirements against the latest National Defense Strategy. Requirements that do not directly support these NDS priorities (such as domestic public policy priorities) should be removed. If this review occurs every four years, the effectiveness of this process would be inherently assessed and modified as necessary. If the loss of certain requirements created problems, that challenge would be resolved in the next iteration. This dynamic approach would solve the current bloated regulatory environment, which only adds requirements without taking a holistic view to the entirety of the compliance burden and the unclear priorities these diverse requirements convey to defense contractors.

As Pete Modigliani (2023) suggested, the DoD should survey the approximately 60 Program Executive Officers on the most significant bureaucratic barriers and regulatory impediments to operating with greater speed and agility and figure out how to remove these barriers (while maintaining absolutely necessary oversight). Such an effort could focus on repealing or eliminating those statutes and regulations whose value does not significantly outweigh the cost of an overly complex acquisition system, conducting a cost/benefit analysis to determine if certain thresholds should be raised.

Finally, the DoD should continue the progress made in reorganizing Title 10 and take the next step: harmonizing the cluttered notes that make a holistic understanding of the codified defense acquisition regulations nearly impossible.

The Times They Are a-Changin'

Bob Dylan wrote "Come senators, congressmen Please heed the call don't stand in the doorway don't block up the hall." He may not have been talking about defense acquisition but Congress has heeded the call and provided the DoD with acquisition authorities such as other transactions, commercial buying procedures, and expanded use of multi-year procurements. For its part, the Department is starting to change, driven in large part by the experience of Ukraine and by the commitment of current leadership. As Secretary of Defense (Acquisition & Sustainment) Bill LaPlante recently testified, "the Department continues to evolve our policies, processes—and most importantly—our culture" (LaPlante, 2023b). The DoD is also dedicating funding to address the industrial base challenge, including its use of Defense Production Act authorities and funds, and in the FY2024 budget request, "continuing widespread investment to strengthen the industrial base" to include roughly $6 billion into "foundational sectors such as microelectronics and castings and forgings to facilitate overall industrial base resilience."

These moves are setting the stage to reverse the trends in the industrial base outlined above. But this change must continue and expand to create a fundamentally new way of doing business.

Conclusion

In 1968, Robert Keller, the general counsel of GAO, provided his views of industry incentives and a particular regulation, the Truth in Negotiations Act. He testified:

> It has been said by some that the act will destroy contract incentives. I do not believe this for a moment. At the risk of repeating myself, the act was designed to achieve full disclosure at the bargaining table. Is such a purpose adverse to traditional contracting concepts? Will full disclosure at the bargaining table destroy the incentive of a contractor? We think not. In fact, it should increase a contractor's incentive to perform more efficiently. . . . GAO, for one, welcomes increased profits for the contractor if they are the result of efficiency in performance. (Keller, 1968, pp. 24–25)

In one sense, Mr. Keller is correct. The Truth in Negotiations Act, in and of itself, will not destroy the overall incentives to work with government. But in a larger sense, he is wrong. Taken in combination with all the other laws, regulations, and policies, the incentives have been significantly harmed. The current incentive structure (including the current formulation of the Truth in Negotiations Act) is driving vendors out of the government contracting market and discouraging new entrants. Current government acquisition rules are depriving the DoD from consistently getting the benefits of the best industry talent, the best commercial capabilities, and rapid transition and deployment of needed capabilities. If the regulatory burden and negative incentives are not addressed head on, no amount of outreach or training will bring businesses back into the defense marketplace—or keep them from leaving.

References

Congressional Research Service. (2022, December 1). *China naval modernization: Implications for U.S. Navy capabilities—Background and issues for Congress.* https://sgp.fas.org/crs/row/RL33153.pdf

Defense Innovation Unit. (2022). *Annual report FY2022*. https://downloads.ctfassets.net/3nanhbfkr0pc/5guJIhcMGwIgoop4z9r5QM/89f44fe62f981e5f0d28932618719196/DIU_Annual_Report_FY22_Final_0131.pdf

DoD. (2016, October 13). *DIUx official: Working at "speed of business" to bring tech to warfighters*. https://www.defense.gov/News/News-Stories/Article/Article/973315/diux-official-working-at-speed-of-business-to-bring-tech-to-warfighters/

Field, L. A. (2019, April 30). *Myth-busting #4—Strengthening engagement with industry partners through innovative business practices.* https://www.whitehouse.gov/wp-content/uploads/2019/05/SIGNED-Myth-Busting-4-Strenthening-Engagement-with-Industry-Partners-through-Innovative-Business-Practices.pdf

Josephson, B. W., Lee, J., Mariadoss, B. J., & Johnson, J. L. (2019). Uncle Sam rising: Performance implications of business-to-government relationships. *Journal of Marketing, 83*(1), 51–72. DOI: 10.1177/0022242918814254

Keller, R. (1968, September 12). *Role of the general accounting office in the enactment and implementation of Public Law 87-653—The Truth in Negotiations Act*. U.S. Government Accounting Office. https://www.gao.gov/assets/094490.pdf

Konkel, F. (2022, November 1). *Bid protests decline for 4th consecutive year*. Nextgov. https://www.nextgov.com/technology-news/2022/11/bid-protests-decline-4th-consecutive-year/379178/

LaPlante, W. (2023a, March 10). *Establishment of the joint production accelerator cell*. Under Secretary of Defense for Acquisition and Sustainment. https://subscriber.politicopro.com/f/?id=00000186-e659-dab2-a7b7-fedfab8c0000

LaPlante, W. (2023b, March 23.) *Testimony at HASC subcommittee on cyber*. House Armed Services Committee. https://armedservices.house.gov/sites/republicans.armedservices.house.gov/files/LaPlante%20Testimony.pdf

National Defense Industry Associations. (2023, February). *Vital signs 2023: Posturing the U.S. defense industrial base for great power competition*.

Nieberg, P., & Murphy, P. (2023, February 8). Labor shortages in U.S. hamper defense manufacturing efforts. *Bloomberg*. https://news.bloomberglaw.com/immigration/labor-shortages-in-us-hamper-defense-manufacturing-efforts

Modigliani, P. (2023, March 21). *Addition by subtraction in 2023*. https://defenseacquisition.substack.com/p/addition-by-subtraction

Murphy, P. (2023). *House panel to ask industry about declining pentagon vendor base.* Bloomberg Government. https://about.bgov.com/news/house-panel-to-ask-industry-about-declining-pentagon-vendor-base/

Schwartz, M., & Halcrow, S. (2022, July 18). *The power of many: Leveraging consortia to promote innovation, expand the defense industrial base, and accelerate acquisition* [White paper]. George Mason University Center for Government Contracting. https://www.gmu.edu/news/2022-07/power-many-leveraging-consortia-promote-innovation-expand-defense-industrial-base-and

Schwartz, M., & Johnson, M. (2022). The slow destruction of the defense industrial base. *Proceedings of the 19th Annual Acquisition Research Symposium.* https://dair.nps.edu/handle/123456789/4630

Shakespeare, W. (n.d.). Henry VI, act 3, scene 2, Reignier.

Siken, J. (2023, January 11). *Aerospace, defense, and government M&A review.* HigherGov. https://www.highergov.com/reports/year-end-ma-review-2022/

Tamayori, C. (2023, April). Becoming a fast follower: An acquisition perspective. *Contract Management Magazine*. https://www.ncmahq.org/Shared_Content/CM-Magazine/CM-Magazine-April-2023/Becoming-a-Fast-Follower.aspx

Tanzi, A. (2023, March 8). The smallest U.S. firms shed almost 600,000 jobs since end of 2021. *Bloomberg.* https://www.bloomberg.com/news/articles/2023-03-08/smallest-us-firms-shed-almost-600-000-jobs-since-end-of-2021

Tucker, P. (2023, March 30). What's next in U.S. hypersonic efforts as Air Force shelves ARRW. *Defense One.* https://www.defenseone.com/technology/2023/03/whats-next-us-hypersonic-efforts-air-force-shelves-arrw/384655/

U.S. Bureau of Labor Statistics. (2023). *Percent change in number of business establishments by state, total covered employment.* https://www.bls.gov/charts/county-employment-and-wages/percent-change-est-by-state.htm

U.S. Census Bureau. (2023, March 29). *Business formation statistics*. https://www.census.gov/econ/currentdata/dbsearch?programCode=BFS&startYear=2011&endYear=2023&categories[]=TOTAL&dataType=BA_BA&geoLevel=US&adjusted=1&notAdjusted=1&errorData=0#table-results

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

U.S. Small Business Administration Office of Advocacy. (2022). *2022 small business profile*. https://cdn.advocacy.sba.gov/wp-content/uploads/2022/08/30121338/Small-Business-Economic-Profile-US.pdf

Van der Colff, J. (2023, March 31). Building a new American arsenal. *War on the Rocks*. https://warontherocks.com/2023/03/building-a-new-american-arsenal/

Appendix A.

Contractor Participation in the Government Marketplace—Trends (Source data).

HigherGov (Siken, 2023). All Federal		NDIA, 2023		GAO, 2021		Bloomberg (Nieberg and Murphy, 2023)			Bloomberg (Murphy, 2023)		CSIS		
Small businesses	*dollars (in billions)*	*DoD Total*	*DoD total entering DIB*	*DoD Smalls*	*New entrants small*	*small DoD*	*Other DoD*	*Total DoD*	*DoD*	*Civilian*	*Total DoD*	*DoD small*	*DoD Other*
											61,000		
121,270	205.10												
114,618	102.20			42,723									
102,140	97.90			39,408									
90,767	90.20			33312									
90,255	97.00			33911									
87,570	96.10			33270									
83,987	104.10			31839	7,083								
84,029	109.10	76,723		30360	6,709								
77,459	123.90	73,820	10,076	28711	6,212	40,752	14,840	55,592	50,704	80,159			
69,490	132.50	66,576	8,189	26364	5,523	38,434	14,125	52,171	48,095	72,122			
66,223	148.80	63,022	8,369	24,296	5,526	36,705	13,431	48,750	45,969	70,745	41,600	26,600	15,000
61,886	153.80	59,678	8,322			35,036	13,293	48,329	44,332	66,693			
58,681	158.70					32,681	12,648	45,329	41,478	63,196			
-52%		-22%	-17%	-43%	-22%	-20%	-15%	-18%	-18%	-21%	-32%		

Appendix B.

List of all prohibitions or restrictions currently working their way through the rule-making stage or recently implemented (as of March 1, 2023).

Source: Open FAR Cases (https://www.acq.osd.mil/dpap/dars/opencases/farcasenum/far.pdf), Open DFARS Cases (https://www.acq.osd.mil/dpap/dars/opencases/dfarscasenum/dfars.pdf), Unified Regulatory Agenda, and an analysis of legislation.

Prohibitions and Unique Requirements in Process								
Prohibition	*Description*	*Public Law*	*US Code*	*Statute Implementation Date*	*Rule Status*	*FAR/DFAR*	*Case*	*Regulation Effective date*
Chinese Telecommunications Equipment and Services	Prohibits agencies from procuring covered equipment and services from Huawei, ZTE Corporation, Hytera Communications, Hangzhou Technology, or Dahua Technology (including subsidiaries or affiliates). Prohibits procuring from an entity that itself uses the covered items and services. No flowdown clause.	Sec. 889, FY19 NDAA	41 USC chapter 39: front matter, note	Subsection (a)(1)(A)—1 year from enactment [8/13/19] Subsections (a)(1)(B), (b)(1)—2 years from enactment [8/13/20]	Interim rule, drafting final rule for both	FAR	(a)(1)(A) - 2018-017 (a)(1)(B) - 2019-009	Subsection (a)(1)(A) - 12/13/2019 Subsections (a)(1)(B) - second interim rule, 10/26/20
Foreign-Made Unmanned Aircraft Systems	FY20 NDAA—Prohibits the DoD from operating or contracting to procure a UAS manufactured in China or from an entity domiciled in China; using flight controllers, radios, cameras, software, network connectivity and other specified items FY23 NDAA—Expands prohibition to include Russia, N. Korea and Iran; prohibits the DoD from contracting with an entity that operates equipment in performance of a DoD contract from specified sources or in/controlled/influenced by China, Russia, N. Korea, or Russia.	Sec. 848, FY20 NDAA Sec. 817, FY23 NDAA	10 USC 4871, note	FY20 NDAA—180 days after the FY23 NDAA enacted (as amended) issue policy FY23 NDAA—180 days after enactment issue policy	FY20 NDAA—Drafting proposed rule FY23 NDAA—no case yet	DFARS	2020-D020	FY23 NDAA – N/A
Certain Semiconductor Products and Services	Prohibits agencies from acquiring or contracting for electronic parts, products, or services that include covered semiconductor products or services, or procuring from an entity that itself uses electronic parts or products that include covered semiconductors. Covered semiconductors are from specified Chinese companies of are identified by the DoD.	Sec. 5949, FY23 NDAA	not placed yet	Five years from enactment	No case yet	FAR	N/A	N/A

Rare Earths and Strategic and Critical Materials	1) Requires contractors to disclose to the DoD sources for permanent magnets containing rare earths or strategic and critical minerals in delivered systems. 2) Expands the DoD prohibition of procuring from Chinese companies by expanding the Chinese entities included and by adding goods and services that are on the commerce control list that contain rare earths, strategic and critical minerals, or energetic materials used to manufacture missiles or munitions.	Sec. 857, FY23 NDAA	1) Provenance—not yet assigned 2) Prohibition—10 USC 4651, note prec.	1) Provenance—30 months after enactment and after the DoD certifies that gathering the data does not pose a relevant national security risk 2) 180 days after the DoD certifies that there are sufficient number of commercial providers outside China that can provide quality and quantity of needed goods or services, when needed and at U.S. market prices	Drafting proposed rule	DFARS	2023-D003	N/A
XUAR Region in China	FY22 NDAA: Prohibits procuring items mined, produced, or manufactured by forced labor in XUAR using funds made available for FY22 FY23 NDAA: Codifies and makes permanent the prohibition of the DoD to procure certain items from the XUAR and removes the certification clause.	Sec. 848, FY22 NDAA Sec. 855, FY23 NDAA	FY22 NDAA—10 U.S.C. 4651, note prec. (repealed in FY23 NDAA) FY23 NDAA—10 USC 4661 prec.	FY22 NDAA—90 days after enactment FY 23 NDAA—DoD to issue policy within 180 days of enactment	FY22 NDAA—Interim rule published 12/16/22, public comment period ends 2/14/23 FY23 NDAA—no case yet	DFARS	2022-D008	FY22 NDAA - interim effective 12/30/22
Printed Circuit Boards	Amends 10 USC 2533d by changing date of implementation, changing definitions of covered PCBs, and authorizing the DoD to issue exemptions.	Sec. 851, FY22 NDAA	10 USC 4873 (old 10 USC 2533d)	January 1, 2027 (extended from the previous date of January 1, 2023)	Drafting proposed rule	DFARS	2022-D011	N/A
Worker Transparency for Individuals Performing Work in China	Covered entities must disclose to the Secretary of Defense if employees will work in China on a covered contract—including the number of individuals and work locations. The Secretary will brief Congress semi-annually on these disclosures.	Sec. 855, FY22 NDAA	10 USC 363, front matter	1-Jul-22	Draft final rule under review	DFARS	2022-D010	N/A
Certain Metals	Amends 10 USC 2533c by replacing "material melted" with "material mined, refined, separated, melted" and by replacing "tungsten" with "covered material."	Sec. 844, FY21 NDAA	10 USC 4872, amendment	Five years from enactment	Drafting proposed rule	DFARS	2021-D015	N/A
CMMC (Cybersecurity Maturity Model Certification)	Measures a company's maturity and institutionalization of cybersecurity practices and processes.	Sec. 1648, FY20 NDAA	10 USC 2224, note	180 days from enactment of the FY22 NDAA (as amended by sec. 1526 of the NDAA)	2019-D041—Drafting proposed rules 2022-D017—Drafting final rule	DFARS	2019-D041 2022-D017	N/A
Greenhouse Gas Emissions	Requires contractors to publicly disclose their greenhouse gas emissions and climate-related risks and to set science-based emissions reduction targets.	n/a—proposed by the DoD, GSA, and NASA	n/a—proposed by the DoD, GSA, and NASA	Two years after publication of final rule	Drafting final rule	FAR	2021-0015	N/A

Effective Competition and Market Concentration in the Defense Industrial Base and the U.S. Federal Government

Edward (Ed) Hyatt, Ph.D.—is currently a senior research fellow at the Baroni Center for Government Contracting at George Mason University's School of Business. He has a decade of research experience and more than seven years of managerial experience in the public procurement profession. During this dual career he has earned several advanced degrees including a PhD in Business Management, served as a contracts and purchasing agent for multiple governmental institutions, and participated in the research and publication process on dozens of projects. His research values are aligned with the philosophical approaches of critical realism and pragmaticism, and he is committed to executing meaningful projects that create public value and serve our national interests. [ehyatt4@gmu.edu]

Abstract

The concept of a fair, open, and competitive marketplace is a cornerstone of the U.S. economy, and hence a core concern for government contracting. However, the defense industrial base has been shrinking for years with fewer companies acting as prime contractors, leading to concerns about undue increases in market concentration and a consequent decline in competition. Despite the rhetoric, what remains uncertain is whether the rates of effective competition and market concentration in the defense industrial base are unique or whether they are reflective of the broader U.S. federal government.

The following research conceptualizes the U.S. Department of Defense as a unique consumer of goods and services and combines the rest of the U.S. federal government agencies as a comparison group. Relying on a unique database containing 20 years of contract award data for all government agencies, effective competition (multiple commercial responses to competitive solicitations) and market concentration (relative market shares of companies within a marketplace) were calculated for 1) every market (i.e., product or service category), 2) all markets excluding research and development (R&D) services, 3) and a set of markets identified as not being overly dominated by any single government agency. Results provide tentative evidence that concerns for ineffective competition and market concentration in the defense industrial base may be largely overstated when compared to other government agencies. The primary importance of this research is that it contextualizes defense acquisition within the larger U.S. federal marketplace, thereby providing a clearer picture of the prevalence of certain trends.

Keywords: Defense industrial base, industry consolidation, competition, Herfindahl–Hirschman Index (HHI)

Background

Since WWII the U.S. government has steadily turned to the private marketplace to supply many of its defense-related goods and services. U.S. companies have been steadily consolidating in multiple markets for decades, and a trend of declining prime contractors in the defense industrial base (DIB) is a well-documented phenomenon (Adjei & Hendricks II, 2022; Bresler & Bresler, 2020; United States General Accounting Office, 2021).[1] The number of major prime contractors fell from 50 to six between 1993 and 2000, and today five companies receive the lion's share of U.S. Department of Defense (DoD) procurement dollars and contracts (Gansler, 2011). This is important because competition is a cornerstone of government acquisition, and industry consolidation is often implicitly or explicitly linked to lower levels of competition, greater risks for reduced supply chains,

[1] For the purposes of this study, the defense industrial base is defined as contractors with contracts awarded by the U.S. Department of Defense.

greater use of sole source contracting, and the potential for higher product markups. Therefore, the shrinking DIB and its potential deleterious impact on competition is often lamented in acquisition literature and remains a source of policy concern.

Competition is statutorily preferred in government contracting because it is generally assumed to be positively linked to a host of good outcomes for the government. The Competition in Contracting Act (CICA) of 1984 generally requires “full and open competition” for government procurement contracts (41 U.S.C. §253). Competition or the use of competitive procedures are highlighted within the provisions of many other regulations; for example, see FAR Subpart 6.1 titled “Full and Open Competition,” as well as other subsections such as in the administration of awards and contracts to small businesses (15 U.S.C. 14A §644(j)(1)). A 2016 Council of Economic Advisers report neatly summarized the government’s position on the value of competition and the danger of increasing industry concentration (Council of Economic Advisers, 2016). President Biden recently signed an executive order titled *Promoting Competition in the American Economy*, establishing a White House Competition Council as part of a whole-of-government effort to promote competition in the American economy (Biden, July 9, 2021).

The DoD is concerned with at least two distinct concepts related to overall competition: effective competition and market concentration. Effective competition is defined under the DoD’s Better Buying Power policy as a contracting situation where more than one offer is received in response to a solicitation issued using full and open competition procedures. Conversely, “ineffective competition” is a situation where only one offer is received for a competitive solicitation (United States General Accounting Office, 2012). The DoD has repeatedly voiced concerns about competition and has taken multiple steps aimed at increasing competition in general, and in particular at producing higher rates of “effective competition.”

Market concentration, the number of firms and their respective share of production within a market, is often used as a proxy for the degree of competition in a market. High market concentration represents low levels of competition and is therefore a concern of antitrust agencies when considering individual firm market power and the potential impact of horizontal mergers on consumer welfare. Higher market concentration may come about from a variety of sources, including mergers and acquisitions, especially since U.S. industries have been steadily consolidating for decades (Amiti & Heise, 2021; Autor et al., 2020; Ganapati, 2021; Grullon et al., 2019).

Critically, what is missing beyond the rhetoric is empirical evidence of whether a shrinking supplier base, ineffective competition, and market concentration are unique DIB phenomena or if they also exist in the broader U.S. federal government. Even though the DoD has a unique mission it would be illuminating to see how its trends compare to other federal government agencies. This would provide a more comprehensive picture of the prevalence of these issues, thereby allowing DoD officials to place their own situation and policies in a broader context. Therefore, the purpose of this study is to evaluate the trends of (in)effective competition and market concentration within the DoD and to make explicit comparisons to all other federal government agencies combined. Because this study is heavily reliant on secondary data, the procedures for analysis are extensively described followed by only a brief discussion of the results.

Given it is a central measure of market concentration the Herfindahl–Hirschman Index (HHI) will be reviewed in brief. This measure is arguably the most accepted measure of market concentration used by government agencies such as the U.S. Department of

Justice, Antitrust Division and the Federal Trade Commission.[2] Those agencies often use the HHI to help determine the effects of a proposed horizontal merger or acquisition of actual or potential competitors by firms within a market. It provides a numerical score of the overall level of market concentration based on the number of firms and their respective share of that market. The HHI is calculated by identifying a market and the firms operating in it, calculating the market share of each firm, and then squaring that market share value of each firm and summing the resulting numbers (United States Department of Justice, Antitrust Division, 2018). It is mathematically expressed using the following notation:

$\mathrm{HHI} = \sum_i^N s_i^2$, where *s* is the market share of firm *i*, and N is the number of firms in the market (Wallsten, 2019, 3, footnote 1).

The index ranges from a value of zero, when a market is occupied by many firms of relatively equal size, to a value of 10,000, when a market is controlled by a single firm (i.e., a monopoly). Therefore, a higher HHI value represents a higher level of concentration within a market and a presumed lower level of competition. According to the Horizontal Merger Guidelines, markets where the HHI is below 1,500 are defined as unconcentrated, between 1,500 and 2,500 points are moderately concentrated, and more than 2,500 points are highly concentrated. A key benefit of the HHI is that it considers both the absolute number of competitors in a market and their relative sizes, two features that are likely to be critical for characterizing the level of competition in a marketplace. The metric assigns proportionately greater weight to firms with larger market shares, thereby emphasizing the idea that larger firms matter more when considering concentration in a marketplace ecosystem. Therefore, even if a market has many firms, if one or more of those firms holds an outstanding amount of market share, it can be considered a more highly concentrated market than one with fewer firms.

Research Questions

Concerns regarding effective competition and market concentration within the DIB are well documented, but it is unknown whether the DoD is unique in its struggles or if similar patterns exist throughout the federal government. This study was exploratory in nature and driven by the perceived need to place the DoD's experience within greater context. As such, it was developed to address the following research questions:

RQ1. What are the competition and market concentration trends in the DIB over time? Specifically:

a. What proportion of spend is (non)competitive dollars?
b. What proportion of spend is (in)effective competition dollars?
c. How concentrated are the markets?

RQ2. How do the DIB trends compare to other federal government agencies? Specifically:

a. Are there similar proportions of (non)competitive and (in)effective competition in other agencies?
b. How concentrated are the markets in other agencies for comparable goods and services purchased from DIB suppliers?

[2] See the relevant section in the Horizontal Merger Guidelines at https://www.justice.gov/atr/horizontal-merger-guidelines-08192010#5c.

Method

Data

A unique dataset was developed based on files downloaded on March 1, 2023 from the Award Data Archive located at USAspending.gov. USAspending.gov is updated with contract data from the U.S. General Services Administration (GSA) Federal Procurement Data System (FPDS) on a nightly basis. Contracts whose estimated value is over the micro-purchase threshold of $10,000, along with any modification to that contract regardless of dollar value, must be reported in FPDS.[3] The downloaded files contain data for all federal government agencies for every fiscal year (October 1 to September 30) from FY 2001 to FY 2022. There are 285 possible data points (i.e., "fields") for every contract action record, including key information about the contractor (e.g., awardee, awardee parent company, Unique Entity IDs: UEI), contract (e.g., contract type, amount of monies obligated), industry (e.g., Product or Service Code: PSC, North American Industrial Classification System: NAICS code), and solicitation/award process (e.g., award type, use of competition procedures, number of offers received). Because there are often multiple actions involving each contract (e.g., additional work, change orders, close out), the number of contract actions vastly exceed the number of contracts. The number of contract actions varies for each fiscal year and averages roughly 3.5 million observations per year for all government agencies, and an average of just over 2 million observations per year for the DoD (see Table 1)[4]. This dataset represents a nearly universal set of contract transaction information between federal government agencies and private contractors; exceptions include some agencies are not required to report their contract data, confidential contracts with no reporting requirements are absent, and information pertaining to subcontractors is not included.

Procedure

Definitions and measures used in this study adhered as closely as possible to ones used in previous research and government reports. In all analyses the awarding agency was used rather than the funding agency because the former is the agency that creates and administers an award, thereby interacting most directly with a contractor, while the latter pays for the award.[5] Also, even though in most cases the awarding and funding agency are the same, there appeared to be far more missing data for the funding agency than the awarding agency. For example, for FY02, imputing the awarding agency for missing funding agencies resulted in an additional $14 billion (5.3% of total federal spend) that were previously unallocated and shifted the relative rankings of many agencies for total dollars obligated on contracts (e.g., USAID went from 30th place to 18th place). Given the research questions, dollars obligated to contractors on DoD contracts are considered to be the defense industrial base whereas dollars obligated on all other agency contracts are used as a point of comparison. Finally, all dollar values have been converted to FY19 dollars using a price deflator calculator provided by the U.S. Department of the Interior.[6]

Both sets of analyses, effective competition and market concentration, proceed through several levels of scrutiny. Each level narrows the markets (i.e., PSCs) under consideration, thereby becoming progressively more focused on the most comparable market situations between the DoD and other government agencies. Details for the two sets of analyses are provided below.

---

[3] See https://www.fpds.gov/wiki/index.php/FPDS_FAQ.
[4] Most tables and figures are included in the appendix due to page constraints.
[5] See https://www.usaspending.gov/analyst-guide.
[6] See https://www.doi.gov/sites/doi.gov/files/uploads/2021-pb-deflator.xls.

Effective Competition

Contract actions involving obligated funds are recorded in USAspending data via four types of awards: definitive contracts, purchase orders, BPA calls, and delivery orders (encapsulating delivery orders for supplies and task orders for services). Competition rates in this study were calculated using all four types of awards. Hereafter, “Contracts” refer to definitive contracts and purchase orders and “Delivery Orders” refer to BPA calls and delivery orders. A Contract is a stand-alone legally binding document between a government agency and a contractor. Delivery Orders reference a parent Indefinite Delivery Vehicle (IDV) that are themselves not generally considered contracts for most federal procurement purposes since they do not obligate funds but instead enable funded Delivery Orders with the contractor(s). Examples of IDVs include Government-Wide Acquisition Contracts (GWAC), Indefinite Delivery / Indefinite Quantity (IDIQ) contracts, Federal Supply Schedules (FSS), and Blanket Purchase Agreements (BPA).

The overall (non)competition rate was defined as dollars obligated via (non)competitive Contracts and Delivery Orders as a percentage of all obligations, relying on the “federal action obligation” field. Obligations made on competitive versus non-competitive Contracts were identified using several fields: “extent competed,” “solicitation procedures,” and “fair opportunity/limited sources.” For Contracts, several values in the “extent competed” field indicate competitive procedures whereas others indicate non-competitive procedures. For Delivery Orders, when more than one contractor has been awarded a parent award under an IDV, a fair opportunity to compete for ensuing delivery orders is generally afforded to each contractor. Therefore, when a Delivery Order indicated that it was subject to multiple-award fair opportunity in the “solicitation procedures” field, but it was ultimately awarded using an exception to fair opportunity as noted in the “fair opportunity/limited sources” field, this was counted as a non-competitive contract action. For Delivery Orders not subject to fair opportunity, such as those based on a single award IDV where further competition is rendered moot, the competition data was derived from the underlying IDV, thereby treating it more similarly to Contracts. This overall (non)competition rate includes all Contracts and Delivery Orders where (non)competitive procedures were used regardless of the number of offers received.

As mentioned before, under the DoD’s Better Buying Power policy, effective competition is a subset of competition defined as those situations when more than one offer was received in response to a competitive solicitation. Conversely, “ineffective competition” is a situation where only one offer is received for a competitive solicitation. The effective and ineffective competition rates were similarly defined in this study and computed for competitive contract actions using the “number of offers” field.

Analyses were conducted in a series of steps to make ever more meaningful comparisons between the DoD and other agencies. First, the effective competition, non-effective competition, and non-competed contract actions for all products and services were calculated for the DoD and all other federal agencies combined. Then, the analysis was repeated after removing research and development (R&D) services contracts so as to not include contracts likely to be related to the development of weapons systems, a unique DoD mission.[7] Finally, in an exploratory attempt to evaluate markets that are not dominated by a single agency, which is usually the DoD, the analysis was further restricted to only those selected markets (PSCs) for which no agency represented more than 90% of the dollars obligated to contractors in that market for each year. For example, in FY15, the U.S.

[7] See the following GAO reports for the basis of this rationale, although most of those reports also excluded products in their analysis: GAO-12-384, GAO-13-325, GAO-14-395, and GAO-15-484r.

Department of State represented 90.2% of the market for repair or alteration of museums and exhibition buildings (PSC: Z2JA), and in FY17 the DoD represented 97.4% of the market for combat ships and landing vehicles (PSC: 1905). Consequently, those two markets were excluded in the final analysis for their respective fiscal years. This was done to remove any potential monopsony effects and to approximate the level of competition for goods and products that are more widespread in the federal government. After all, everyone buys pencils, but only the U.S. Air Force buys F-15s.

Market Concentration

The "Product or Service Code" (PSC) field, a government-designed code that identifies the product or service procured, was used to define markets in each government agency. The PSC field was used instead of the "naics" field representing the North American Industrial Classification System (NAICS) code because the amount of obligated dollars attributed to PSCs was greater than those attributed to NAICS codes in every fiscal year (in some years, nearly 15% more obligated dollars). Relying on files available on the Acquisition.gov PSC Manual website[8] and other search capabilities and files provided by the handy Defense Pricing and Contracting (DPC) Office PSC selection tool website[9], wherever possible individual-level PSCs were consolidated into spend categories at the Level 2 category-level (e.g., "18.5 Technical Representative Services"). Many of the older PSCs still in use do not have a Level 2 categorization; in those instances, the PSC itself was used. Some PSCs have changed over time but most of them have retained their original codes and meanings as they have been updated; the ones used in this study are current as of April 2022.

Contract awardees and their parent companies were identified based on their Unique Entity IDs (UEIs) generated by SAM.gov for use across the federal government. This 12-character alphanumeric ID number has subsumed the nine-digit Dun & Bradstreet D-U-N-S Numbers historically used to identify companies prior to April 4, 2022. Since large contractors will frequently have multiple subsidiary companies, the parent company was used rather than contract awardees in market concentration analyses to gain a truer sense of the cumulative market share captured by a company's various subsidiaries. Additional steps were taken to consolidate parent companies that have multiple unique identifiers; these companies were identified by matching their Global Company Key (GVKEY) in the Capital IQ Compustat database for all firms in the S&P 1500 at any point from 2000–2021.

Dollars obligated using the "federal action obligation" field were used to calculate the market share of each contractor. Market share was defined as the revenues generated per parent company divided by the total amount obligated within each agency market, per fiscal year. However, many contracts continue year-to-year and in any given fiscal year a contractor may have net negative obligated dollars in a market, perhaps reflecting a close-out action or defunding action. As a reminder, the HHI captures the level of market concentration by summing the squares of the relative market share of each competitor. Therefore, only companies that had a net positive revenue in a market from the government were included in all analyses since it does not make sense to include negative market shares. Furthermore, squaring those results would make those negative values turn positive, leading to the inaccurate appearance of positive market share and erroneously contributing to the HHI calculation. The Herfindahl-Hirschman index (HHI) measure was then calculated to assess the level of market concentration within each agency market.

---

[8] See https://www.acquisition.gov/psc-manual.

[9] See https://psctool.us/.

Similar to the effective competition analyses, multiple levels of market concentration analyses were conducted to examine the trends of market concentration for the DoD and all other agencies combined. First, market concentration for all markets without restriction was examined. Then, the analysis was repeated twice, first without R&D services contracts and then with only the selected markets identified earlier. Since there are roughly 100 markets for every agency in each fiscal year, for presentation purposes this paper only shows a subsection of those selected markets, as follows. All selected markets for every year were ranked according to total obligated dollars and five PSCs rose to the top. These five PSCs (R425, R499, D399, 6505 and R408) ranked in the top five of total dollars obligated for every fiscal year since FY10, with three of the PSCs (R425, R499, and D399) ranked in the top five since FY01 and the remaining two PSCs (6505 and R408) still ranked in the top ten since FY01. These five PSCs cumulatively represented roughly 12%–15% of the total dollars obligated by the federal government each year from FY10–FY19.[10]

Table 2. Selected PSCs for HHI

PSC Code	Analysis PSC Description	Level 2 PSC Category
R425	Support-Professional: Engineering/Technical	Technical and Engineering Services (non-IT)
R499	Support-Professional: Other	Management Advisory Services
6505	Drugs and Biologicals	Drugs and Pharmaceutical Products
D399	IT and Telecom—Other IT and Telecommunications*	--
R408	Support-Professional: Program Management/Support	Management Advisory Services

Results

The research questions aimed to identify important acquisition trends like effective competition and market concentration in the DIB and to establish whether there are substantial differences between the DoD and other government agencies. Results are presented in several categories below, accompanied by a short conclusion detailing the importance of the results. Due to page constraints, only FY10–FY19 results are shown and discussed below, but similar results for FY01–FY09 are available from the author upon request.

As overview, Table 3 shows the trends in the contractor base for both the entire federal government and the DoD. The number of new DoD contractors has declined every subsequent year since FY05 with one exception (FY13 to FY14), which is reflective of the shrinking DIB trend noted in other research reports. However, the number of new contractors as a percentage of unique contractors with DoD contracts is in near perfect synchronicity with the entire federal contractor base (see Table 4). The rate of contractors exiting the DIB is also mirrored in the overall federal contractor base, although the absolute numbers for more recent years should be taken with a grain of salt since they are based on fewer ensuing fiscal years. Regardless, given that DoD contractors consistently represent less than half of all federal government contractors, these numbers demonstrate that the overall shrinking contractor base appears to be dispersed throughout the federal government and is not a phenomenon that is unique to the DoD.

[10] Only a handful of those PSCs dominated by a single agency (e.g., 1510: fixed wing aircraft), excluded from this analysis, accounted for similarly high obligated dollars. As such, these five PSCs are an excellent sub-group to use.

Table 4. New Prime Contractor Rate (% of Unique Contractors)

Fiscal Year	Total	DoD
FY10	19.1%	18.0%
FY11	17.3%	16.5%
FY12	14.1%	14.5%
FY13	12.5%	11.9%
FY14	13.2%	13.1%
FY15	13.0%	13.2%
FY16	12.8%	12.8%
FY17	12.7%	12.2%
FY18	11.9%	11.9%
FY19	10.9%	11.2%

Effective Competition

The results for the overall competition rates of the DoD versus all other agencies combined are shown in both dollar amounts (Figure 2) and percentages (Figure 3). Figures 4 and 5 show the same results for all contracts excluding R&D services contracts. Overall, in all years the proportion of contracts not competed is higher for the DoD than all other agencies; for the DoD it ranges from 37%–56% while for other agencies it ranges from 20%–34%. This is not surprising given the relatively higher rates of sole source contracting conducted by the DoD. The ineffective competition rate as a proportion of all contracts, however, is much smaller for the DoD than it is for all other agencies. For the DoD, it ranges from 7%–13% whereas for all other agencies it ranges from 11%–21%. When the R&D services contracts are removed, the competition rates for both the DoD and other agencies combined generally went up slightly. In short, this means that when contracts are competed by the DoD, they are more effectively competed than other agencies.

When considering the competition dollars and rates for the selected market only (Figures 6 and 7), a clear but relatively uninteresting pattern emerges. For example, for the DoD in FY19, an overall ineffective competition rate of 18.2% had improved to 15.6% when R&D services contracts were removed. However, when considering only the selected markets, the ineffective competition rate reverts to 17.6%. This same pattern is generally consistent in all the data for the DoD and other agencies, which means there is little value in examining markets less dominated by a single agency, at least based on the 90% threshold used in this analysis. As such the effective competition rate was not calculated for these selected markets.

Figure 8 shows the effective versus ineffective competition rates for all contracts for the DoD and all other agencies combined, followed by the same results for all contracts excluding R&D services contracts in Figure 9. When considering only the competed contracts, in almost every year (except FY03) the DoD's effective competition rate as a portion of its overall competed contracts is higher than all other agencies. This mirrors the result seen in the rates of all types of competition. When the R&D services contracts are excluded from analysis, from FY10–FY19 the DoD's effective competition rate increases, albeit slightly, while the effective competition rate of the other agencies remained roughly the same or slightly decreased.

The primary research question driving this part of the paper was: what are the key trends and how does the DoD compare to other agencies in terms of effective competition? In conclusion,

1. The DoD has a lower overall competition rate than all other agencies combined.
2. The ineffective competition rate as a percentage of overall obligations was lower for the DoD than all other agencies for every fiscal year. This means that when competed, the DoD has a better track record than other agencies at achieving the goal of competition with at least two bidders. While much attention has been focused on the DoD's non-competition rate, its higher effective competition rate is worth highlighting.
3. This result becomes starker when all R&D services contracts are excluded, providing a more relevant comparison between the DoD and all other agencies combined.

Market Concentration

As a way of obtaining an overall picture of market concentration in the DoD compared to all other agencies combined, averages were calculated based on the HHIs for every individual market and then weighted by the value of each of those markets against the total dollars obligated by the DoD and all other agencies. As demonstrated in Figure 10, when considering all contracts, with a few exceptions both the DoD and all other agencies exhibit HHI values mostly just below the moderately concentrated threshold of 1,500. The DoD consistently has a lower HHI value than other agencies for most of the FY10–FY19 time period, albeit only slightly in many cases. This means that the market concentration within the DoD is slightly better than it is for the rest of the federal government, which runs contrary to the rhetoric of a market concentration problem in the DIB. This result, however, largely reverses when all R&D services contracts are excluded (see Figure 11). In this instance, whereas both the DoD and the other agencies exhibit decreased market concentration, the DoD's decrease is not as great when compared to the rest of the government.

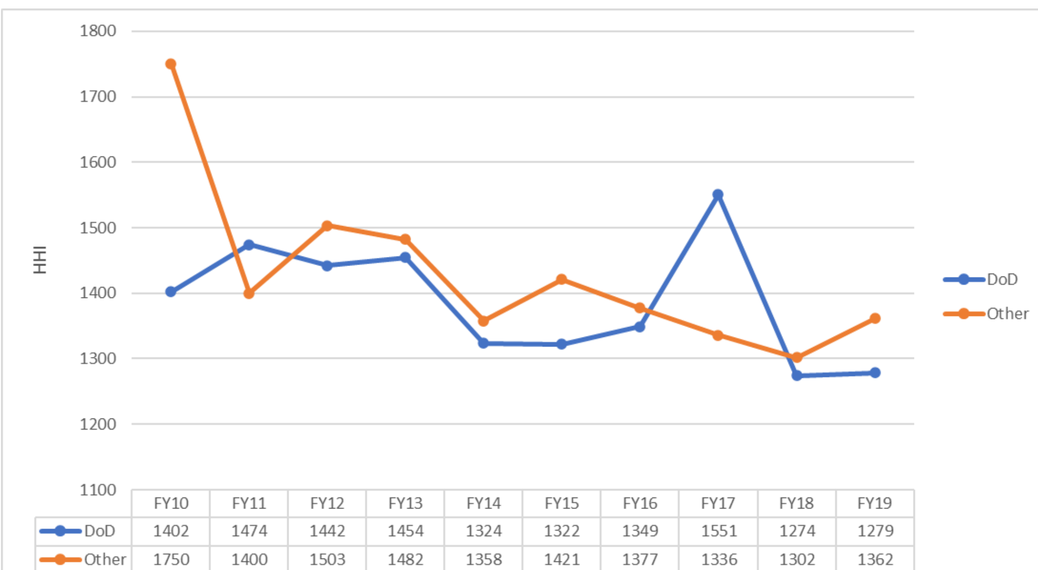


Figure 10. HHI (Weighted Average), All Contracts

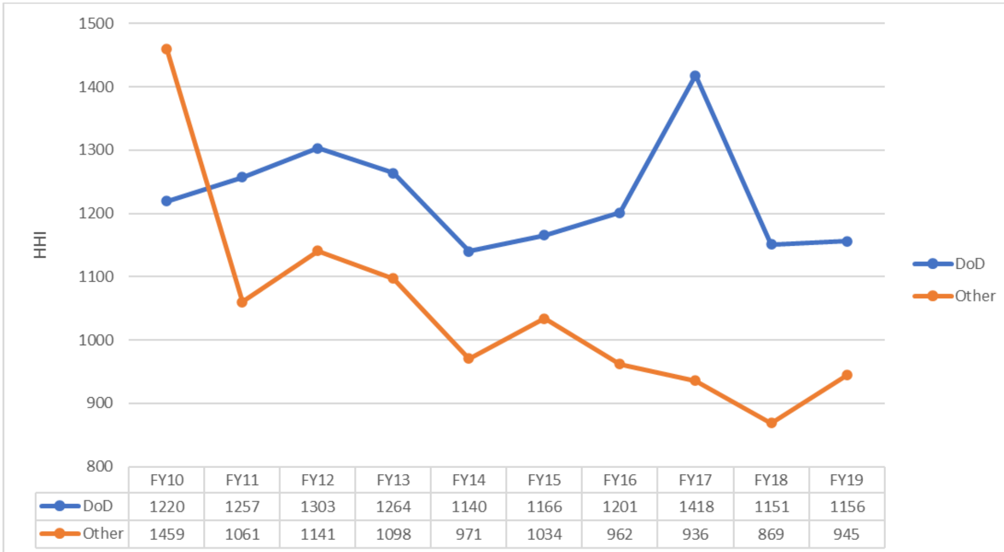


Figure 11. HHI (Weighted Average), R&D Services Contracts Excluded

The HHI results for the DoD and all other agencies combined for the five markets under direct examination in this paper are presented in Figures 12–16. The DoD has higher market concentration than all other agencies combined for almost every year in all five markets, with the exception of a few years in the largest dollar market (R425 Support-Professional: Engineering/Technical). This result reflects the general concern that the DoD has a market concentration problem. However, it is important to note that similar to the overall HHI, only one of those four markets (6505 Drugs and Biologicals) is at a level that would be considered highly concentrated. In fact, none of the other four markets would even be considered moderately concentrated as their HHI values are below 1,500. This means that while the DoD is more concentrated in comparison to other government agencies for these five markets, it still does not appear to rise to a high level of concern according to U.S. Department of Justice standards.

Contributions, Limitations, and Future Research

The contributions of this study are threefold. First, the trends identified advance our collective knowledge of the evolving situation within DoD acquisition. Specifically, the results provide insight into the potential effects of the shrinking defense industrial base on effective competition and market concentration in the DIB. Second, the study sheds light on how competition and concentration trends in the DoD compare to the rest of the federal government. This provides important context for certain debates regarding the overall standing of the DoD on important issues that concern the entire federal government. Third, the database developed for this study provides a strong foundation to contribute further to the sparse literature on government contracting. The Center for Government Contracting at George Mason University is already underway improving on this proprietary dataset and using it to facilitate additional research on important acquisition topics.

This study has several potential limitations, including that it majorly relies on USAspending.gov data. Contract information is manually entered by hundreds of different contract analysts across the federal government, so even with best efforts and training the information is undoubtedly incomplete in areas or contains errors that cannot be easily identified. Also, the data are limited in that only unclassified program information and prime contractor information is available. These concerns notwithstanding, the USAspending.gov data are regularly relied upon by other government agencies like the U.S. General Accounting Office. That office has generally noted in recent reports that system-wide changes implemented at least as of October 2009 have mitigated many previous errors and make the data suitable for analysis. The lack of classified programs is not likely to significantly impact the overall results, as Carril and Duggan (2020) reported that classified contract actions accounted for only 1.4% of contract obligations from 1985 through 2001. Finally, recent efforts at capturing more subcontractor activity in the Electronic Subcontracting Reporting System should bear fruit in the future. Therefore, it appears that for the time being USAspending.gov remains the single best, most authoritative source of federal contract information.

A logical extension of research focused on the concepts of effective competition and market concentration would be to examine their effects on outcomes like the quality of contracts, contract transaction costs, acquisition process costs, and overall program costs. For example, additional analysis can calculate what the HHI of a market in one year means for the contract awards of the following year(s) since the level of market competitiveness may be a predictor of the distribution of future awards. A few studies have done this type work to-date (e.g., Hunter et al., 2019; Josephson et al., 2019; Sanders & Huitink, 2018), and more research in this vein would be welcome. Other future research should probably examine specific aspects of the reduction of prime contractors in the DIB. The results of this study show that the number of new contractors has declined nearly every subsequent year since FY05, a phenomenon that has been similarly noted in other research. The barriers to entry experienced by potential new contractors are an important area that should receive more rigorous empirical investigation. Additionally, contractors exiting the DIB is another contributing factor to the overall reduction in prime contractors. This is usually attributed to DIB "consolidation," which implies mergers and acquisitions. While this activity undoubtedly contributes to the declining numbers of prime contractors, it is not likely to be the sole explanation. Other reasons for why contractors are exiting the prime supplier base should be investigated more thoroughly; otherwise, effective interventions cannot be designed to ameliorate the situation.

Conclusion

This study was exploratory and descriptive in nature, mostly concerning itself with DoD acquisition trends and comparing them with the rest of the federal government. The results of this study show that across many markets the DoD shows higher levels of effective competition and reasonable levels of concentration compared to other federal government agencies. Additionally, despite the decline in the number of prime contractors, the DoD's effective competition rate and level of market concentration do not appear to be negatively affected. This should be encouraging to DoD policymakers, and it likely means that future research efforts can focus on other fruitful areas of government contracting.

References

Adjei, S. O., & Hendricks II, C. O. (2022). *Increasing defense contractor competition in a predominately sole-source contracting environment* [Thesis, Acquisition Research Program]. https://dair.nps.edu/handle/123456789/4529

Amiti, M., & Heise, S. (2021). U.S. market concentration and import competition. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3847929

Autor, D., Dorn, D., Katz, L. F., Patterson, C., & Van Reenen, J. (2020). The fall of the labor share and the rise of superstar firms. *The Quarterly Journal of Economics*, *135*(2), 645–709. https://doi.org/10.1093/qje/qjaa004

Bresler, A., & Bresler, A. (2020, May 13). The effect of defense-sponsored innovation programs on the military's industrial base. *Acquisition Research: Creating Synergy for Informed Change*. Seventeenth Annual Acquisition Research Symposium, Online. https://dair.nps.edu/bitstream/123456789/4208/1/SYM-AM-20-059.pdf

Carril, R., & Duggan, M. (2020). The impact of industry consolidation on government procurement: Evidence from Department of Defense contracting. *Journal of Public Economics*, *184*, 104141. https://doi.org/10.1016/j.jpubeco.2020.104141

Cool, K., Röller, L.-H., & Leleux, B. (1999). The relative impact of actual and potential rivalry on firm profitability in the pharmaceutical industry. *Strategic Management Journal*, *20*(1), 1–14. https://doi.org/10.1002/(SICI)1097-0266(199901)20:1<1::AID-SMJ995>3.0.CO;2-X

Council of Economic Advisers. (2016). *Benefits of competition and indicators of market power*. Executive Office of the President. https://obamawhitehouse.archives.gov/sites/default/files/page/files/20160414_cea_competition_issue_brief.pdf

Ganapati, S. (2021). Growing oligopolies, prices, output, and productivity. *American Economic Journal: Microeconomics*, *13*(3), 309–327. https://doi.org/10.1257/mic.20190029

Gansler, J. S. (2011). *Democracy's arsenal: Creating a twenty-first-century defense industry*. MIT Press. https://books.google.com/books?id=b8zxCwAAQBAJ

Grullon, G., Larkin, Y., & Michaely, R. (2019). Are U.S. industries becoming more concentrated? *Review of Finance*, *23*(4), 697–743. https://doi.org/10.1093/rof/rfz007

Hunter, A. P., Sanders, G., & Huitink, Z. (2019). *Evaluating consolidation and the threat of monopolies within industrial sectors*. Center for Strategic & International Studies: Defense-Industrial Initiatives Group. https://www.csis.org/analysis/evaluating-consolidation-and-threat-monopolies-within-industrial-sectors

Josephson, B. W., Lee, J.-Y., Mariadoss, B. J., & Johnson, J. L. (2019). Uncle Sam rising: Performance implications of business-to-government relationships. *Journal of Marketing*, *83*(1), Article 1. https://doi.org/10.1177/0022242918814254

Sanders, G., & Huitink, Z. (2018). What does consolidation mean for performance? Concentration, competition, and defense contracting outcomes. *Journal of Strategic Contracting and Negotiation*, *4*(1–2), 30–57. https://doi.org/10.1177/2055563620921116

United States Department of Justice, Antitrust Division. (2018, July 31). *Herfindahl-Hirschman index*. https://www.justice.gov/atr/herfindahl-hirschman-index

United States General Accounting Office. (2012). *Defense contracting: Competition for services and recent initiatives to increase competitive procurements* (GAO-12-384). https://www.gao.gov/assets/gao-12-384.pdf

United States General Accounting Office. (2013). *Defense contracting: Actions needed to increase competition* (GAO-13-325). https://www.gao.gov/assets/gao-13-325.pdf

United States General Accounting Office. (2014). *Defense contracting: Early attention in the acquisition process needed to enhance competition* (GAO-14-395). https://www.gao.gov/assets/gao-14-395.pdf

United States General Accounting Office. (2015). *Defense contracting: DoD's use of competitive procedures* (GAO-15-484r). https://www.gao.gov/assets/gao-15-484r.pdf

United States General Accounting Office. (2021). *Small business contracting: Actions needed to implement and monitor DoD's small business strategy* (GAO-22-104621). https://www.gao.gov/assets/gao-22-104621.pdf

Table 1. Contract Actions and Obligated Dollars

Fiscal Year	Start Date	End Date	Contract Actions (Total)	Contract Actions (DoD*)	Sum of Obligated Dollars (Total)	Sum of Obligated Dollars (DoD)	DoD Obligations / Total Obligations
FY01	10/1/2000	9/30/2001	642,069	344,057	$313,055,709,309	$203,755,868,821	65%
FY02	10/1/2001	9/30/2002	830,653	498,343	$365,993,413,713	$236,975,665,973	65%
FY03	10/1/2002	9/30/2003	1,183,910	622,576	$440,758,210,394	$288,584,669,184	65%
FY04	10/1/2003	9/30/2004	2,001,920	751,042	$449,474,407,677	$306,219,578,319	68%
FY05	10/1/2004	9/30/2005	2,923,827	1,422,643	$502,664,325,983	$347,914,078,506	69%
FY06	10/1/2005	9/30/2006	3,798,103	1,365,909	$536,467,883,431	$374,089,479,051	70%
FY07	10/1/2006	9/30/2007	4,112,108	1,471,782	$569,581,606,299	$404,736,150,299	71%
FY08	10/1/2007	9/30/2008	4,505,579	1,598,235	$635,794,000,955	$466,632,357,828	73%
FY09	10/1/2008	9/30/2009	3,497,431	1,519,332	$634,184,321,975	$437,995,529,663	69%
FY10	10/1/2009	9/30/2010	3,543,595	1,568,107	$646,834,214,212	$424,823,840,472	66%
FY11	10/1/2010	9/30/2011	3,408,259	1,549,799	$608,717,931,604	$422,235,710,389	69%
FY12	10/1/2011	9/30/2012	3,129,370	1,462,380	$574,855,572,309	$401,574,270,801	70%
FY13	10/1/2012	9/30/2013	2,514,645	1,335,207	$503,749,329,286	$336,159,316,572	67%
FY14	10/1/2013	9/30/2014	2,528,295	1,349,267	$477,569,703,466	$304,501,785,864	64%
FY15	10/1/2014	9/30/2015	4,374,783	3,209,315	$468,146,197,631	$291,945,653,893	62%
FY16	10/1/2015	9/30/2016	4,821,448	3,668,472	$502,392,329,856	$315,366,246,225	63%
FY17	10/1/2016	9/30/2017	4,912,578	3,670,466	$530,671,054,531	$334,602,839,954	63%
FY18	10/1/2017	9/30/2018	5,617,867	4,508,657	$565,393,321,313	$365,629,889,690	65%
FY19	10/1/2018	9/30/2019	6,486,887	4,340,286	$590,177,739,500	$383,626,685,588	65%

Note. All dollar values adjusted for 2019 dollar values.

*DoD indicates any contract action where the DoD is listed as the awarding agency.

Table 3. Contractors

Fiscal Year	Unique Contractors* (Total)	Unique Contractors (DoD)	Exiting Contractors^ (Total)	Exiting Contractors (DoD)	New Contractors† (Total)	New Contractors (DoD)
FY01	70,242	33,949	12,961	5,415	--	--
FY02	82,616	45,406	15,109	7,712	38,310	22,875
FY03	104,549	57,396	21,409	10,211	45,098	24,516
FY04	135,122	68,522	26,792	12,921	58,882	26,147
FY05	164,870	84,009	33,522	17,808	61,452	29,058
FY06	171,401	80,388	31,781	15,361	49,227	19,768
FY07	176,588	82,090	32,522	15,579	41,672	17,673
FY08	179,443	81,274	36,066	15,697	38,796	16,438
FY09	173,626	80,825	31,872	16,062	35,880	15,783
FY10	174,579	79,043	33,239	16,050	33,330	14,255
FY11	170,803	76,014	37,093	16,013	29,476	12,573
FY12	155,025	71,023	30,973	15,345	21,871	10,275
FY13	142,634	63,913	26,445	12,633	17,762	7,626
FY14	138,816	61,529	25,379	11,501	18,292	8,055
FY15	136,835	60,844	25,914	11,928	17,797	8,043
FY16	133,984	58,756	26,746	11,673	17,084	7,496
FY17	137,850	56,920	34,167	12,110	17,481	6,939
FY18	123,962	54,386	29,580	12,754	14,794	6,476
FY19	113,650	51,099	30,223	14,474	12,417	5,731

Note. Each Fiscal year runs from October 1 through September 30, named for the year in which it ends.

*All Contractors hereafter reference parent companies of award recipients.

^Contractors with no contract records in ensuing fiscal years, through FY20.

†Contractors with a contract record from any previous fiscal year, starting in FY01.

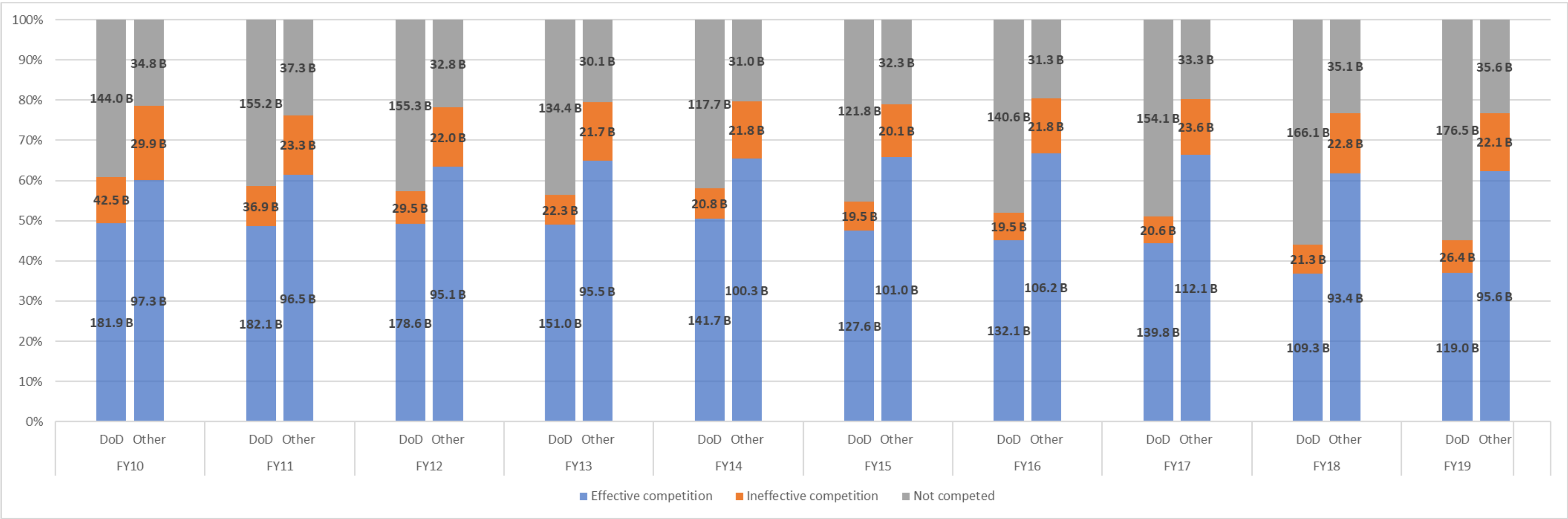


Figure 2. Competition Rates, All Contracts ($)

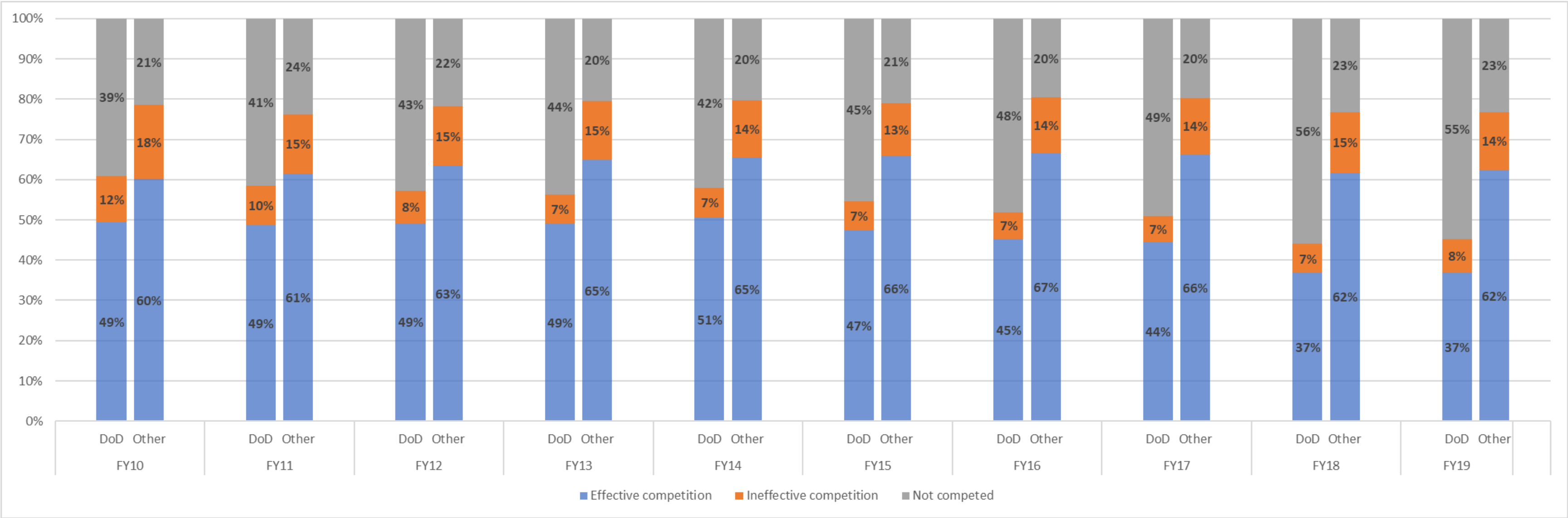


Figure 3. Competition Rates, All Contracts (%)

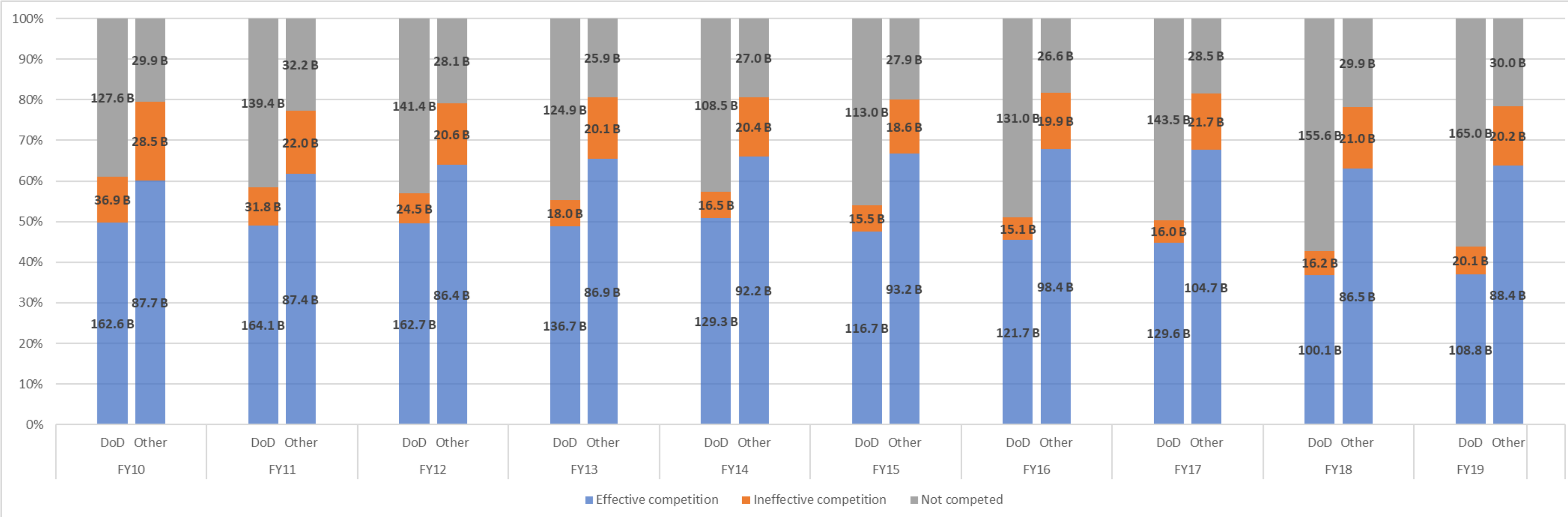


Figure 4. Competition Rates, R&D Services Contracts Excluded ($)

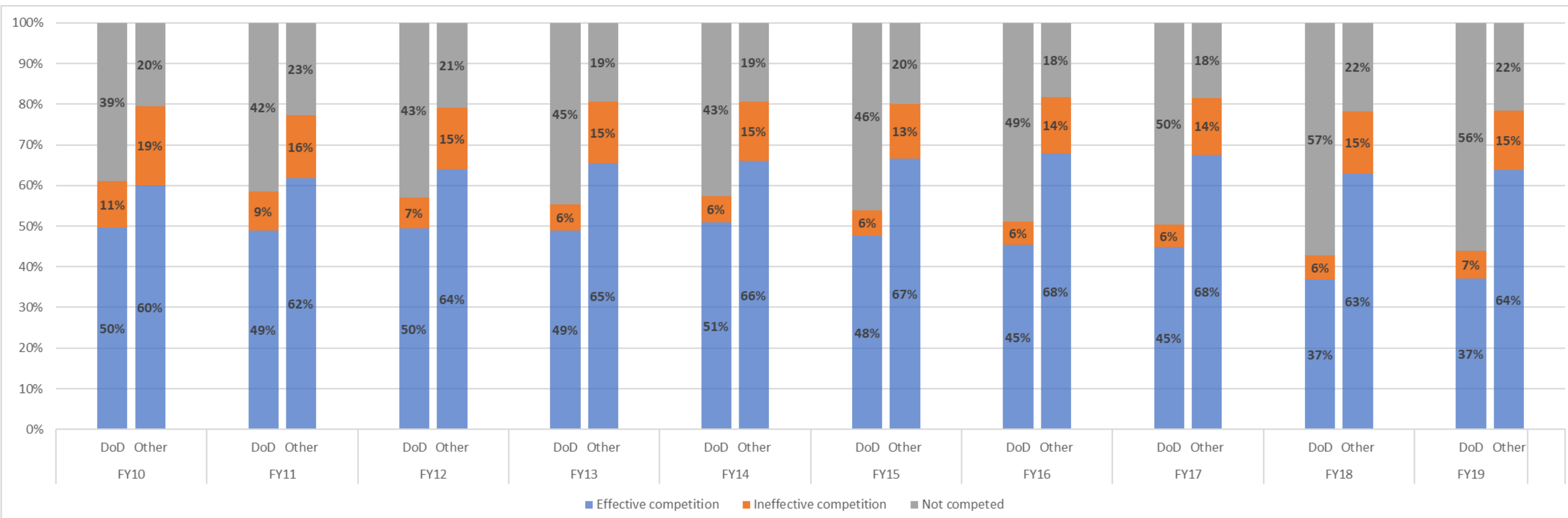


Figure 5. Competition Rates, R&D Services Contracts Excluded (%)

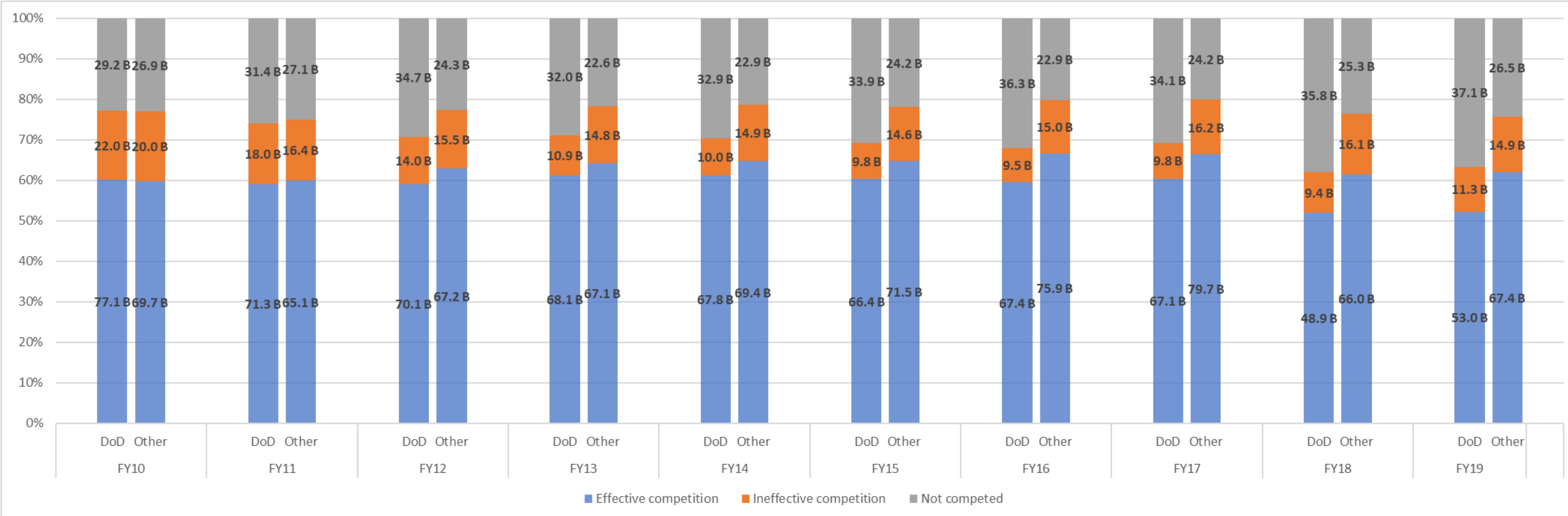


Figure 6. Competition Rates, Selected Markets ($)

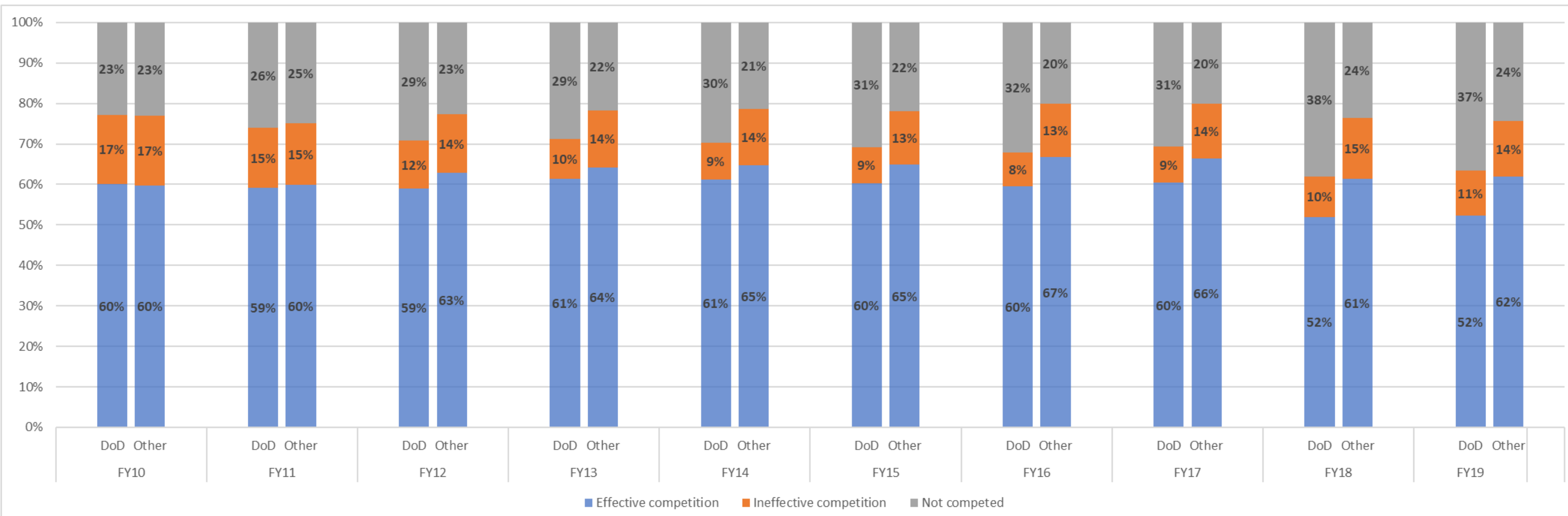


Figure 7. Competition Rates, Selected Markets (%)

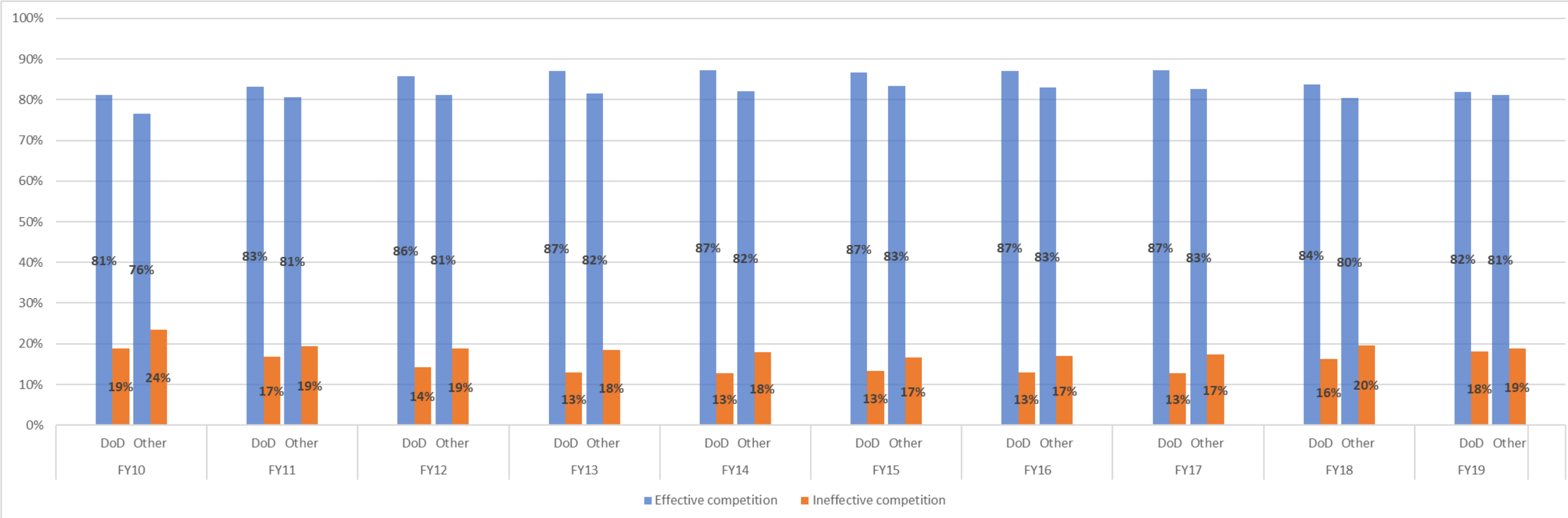


Figure 8. Effective vs. Ineffective Competition Rates, All Contracts (%)

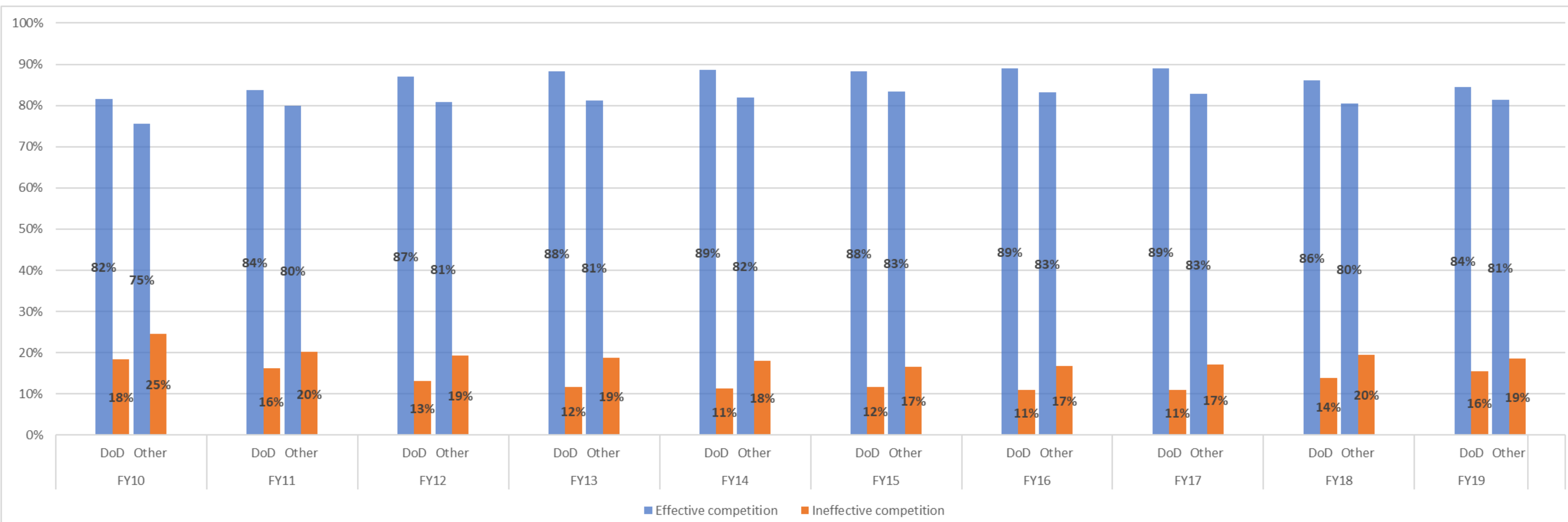
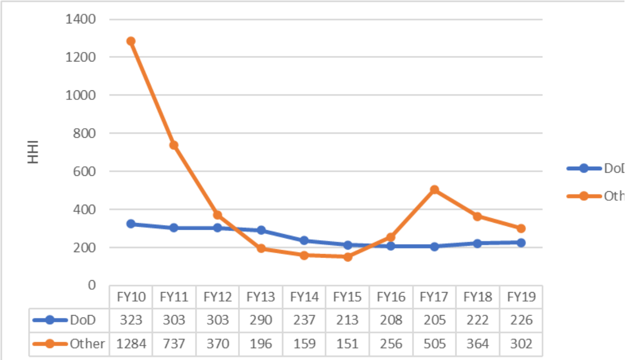
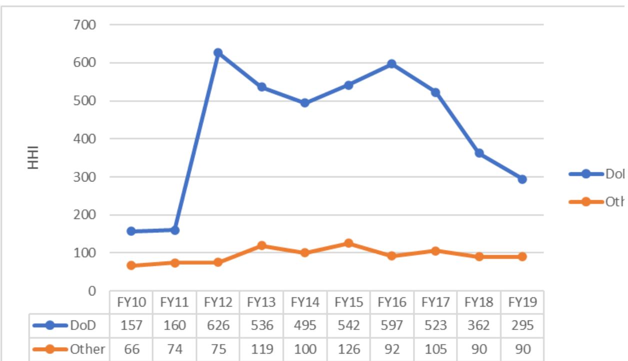


Figure 9. Effective vs. Ineffective Competition Rates, R&D Services Contracts Excluded (%)



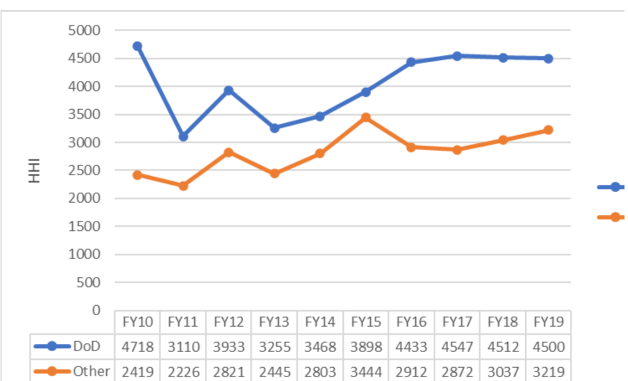
	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
DoD	323	303	303	290	237	213	208	205	222	226
Other	1284	737	370	196	159	151	256	505	364	302

Figure 12. R425 Support-Professional: Engineering/Technical



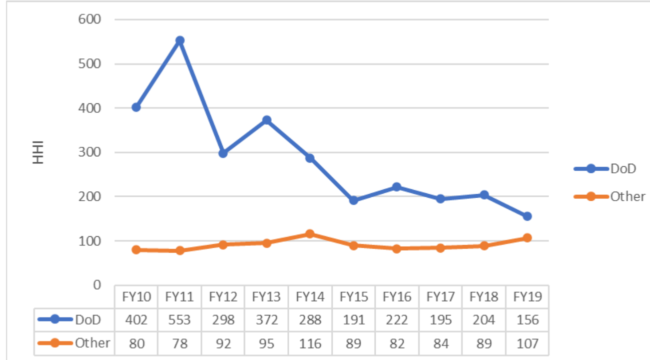
	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
DoD	157	160	626	536	495	542	597	523	362	295
Other	66	74	75	119	100	126	92	105	90	90

Figure 13. R499 Support-Professional: Other



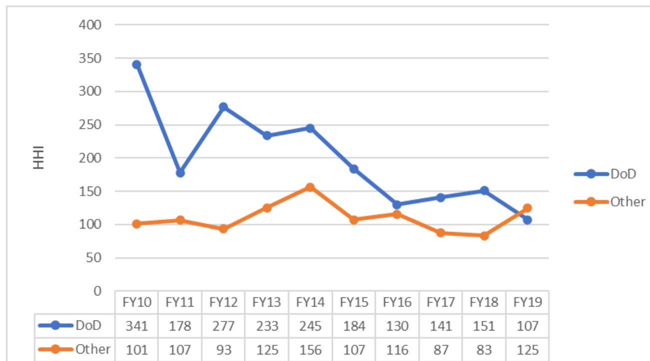
	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
DoD	4718	3110	3933	3255	3468	3898	4433	4547	4512	4500
Other	2419	2226	2821	2445	2803	3444	2912	2872	3037	3219

Figure 14. 6505 Drugs and Biologicals



	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
DoD	402	553	298	372	288	191	222	195	204	156
Other	80	78	92	95	116	89	82	84	89	107

Figure 15. D399 IT and Telecom—Other IT and Telecommunications



	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
DoD	341	178	277	233	245	184	130	141	151	107
Other	101	107	93	125	156	107	116	87	83	125

Figure 16. R408 Support-Professional: Program Management/Support

Defense Industrial Base: DoD Should Take Actions to Strengthen Its Risk Mitigation Approach

Daniel Glickstein— is a Senior Analyst at the Government Accountability Office in the Contracting and National Security Acquisitions team. Glickstein also spent 1 year detailed to the Senate Armed Services Committee. [Glicksteind@gao.gov]

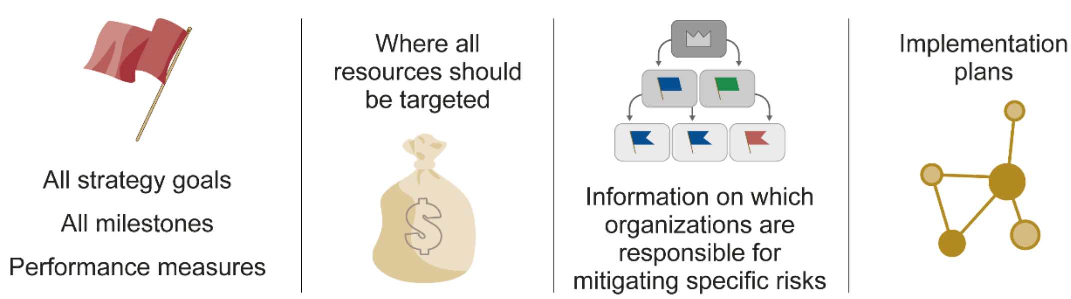
Abstract

A healthy defense industrial base is essential to meeting U.S. national security objectives. Multiple DOD reports have highlighted a need to maintain and grow the industrial base to foster innovation and support continued development of cutting-edge technologies and weapon systems. However, for decades, DOD has also reported on complex risks that the defense industrial base faces, such as relying on foreign and single-source suppliers for critical materials. The COVID-19 pandemic further highlighted vulnerabilities in the U.S defense industrial base.

DOD has multiple ways to identify and address industrial base risks. For example, the Office of Industrial Base Policy leads DOD-wide industrial base assessments and invests in projects that can help maintain or expand domestic production capacity. Another forum to discuss industrial base risks is the National Technology and Industrial Base (NTIB), a congressionally-created partnership between the U.S. and Canada. Congress added Australia and the United Kingdom in 2017, and directed DOD to develop and execute an implementation plan to integrate the defense industrial bases of these countries since then. This presentation highlights information from two GAO reports regarding (1) DOD's strategy for mitigating defense industrial base risks, (2) the extent to which DOD is monitoring and reporting its progress in mitigating risks, and (3) DOD actions to execute its NTIB implementation plan and reduce integration barriers between partner countries.

What the GAO Found

The Department of Defense's (DoD) Industrial Base Policy office does not yet have a consolidated and comprehensive strategy to mitigate risks to the industrial base—the companies that develop and manufacture technologies and weapon systems for the DoD. The office is using a combination of four previously issued reports that were created for other requirements because it devoted its resources to completing other priorities. Collectively, the reports do not include several elements the Government Accountability Office (GAO) has previously identified that would help the DoD achieve results, evaluate progress, and ensure accountability (see Figure 1).



Source: GAO-04-408T and GAO analysis of Department of Defense documents. | GAO-22-104154

Figure 1. Elements Not Fully Addressed in the DoD's Industrial Base Strategy

The DoD must update its industrial base strategy following the submission of the next National Security Strategy Report, which is expected to be issued later in 2022. By including all elements in a consolidated strategy, the DoD could better ensure that all appropriate organizations are working toward the same priorities, promoting supply chain resiliency, and supporting national security objectives.

The DoD is carrying out numerous efforts to mitigate risks to the industrial base. This includes more than $1 billion in reported efforts under Navy submarine and destroyer programs and $125 million to sustain a domestic microelectronics manufacturer. However, the DoD has limited insight into the effectiveness of these efforts and how much progress it has made addressing risks. For example:

- The Industrial Base Policy office and military services have not established enterprise-wide performance measures to monitor the aggregate effectiveness of the DoD's mitigation efforts.
- The DoD's annual Industrial Capabilities Reports do not include information about the progress the department has made in mitigating risks.

The GAO's prior work on enterprise risk management establishes that agencies should monitor and report on the status and effectiveness of their risk mitigation efforts. Without key monitoring and reporting information, the DoD and Congress do not have sufficient information to help determine whether industrial base risks have been mitigated and what additional resources or actions may be needed.

Why the GAO Did This Study

A healthy defense industrial base that provides the capacity and capability to produce advanced weapon systems is critical to maintaining U.S. national security objectives. The U.S. industrial base currently consists of over 200,000 companies. Mitigating risks—such as reliance on foreign and single-source suppliers—is essential for the DoD to avoid supply disruptions and ensure that the industrial base can meet current and future needs.

Since 2017, the White House has issued executive orders directing the DoD and other agencies to assess risks to the defense industrial base and high priority supply chains such as semiconductors.

Congress also directed the DoD to develop an analytical framework for mitigating risks and included a provision for the GAO to review the DoD's efforts. This report assesses (1) the DoD's strategy for mitigating industrial base risks, and (2) the extent to which the DoD is monitoring and reporting on its progress in mitigating risks. The GAO analyzed DoD policies and reports and interviewed DoD officials.

What the GAO Recommends

The GAO is making six recommendations, including that the DoD develop a consolidated and comprehensive strategy to mitigate industrial base risks, develop and use enterprise-wide performance measures to monitor the aggregate effectiveness of its efforts, and report on its progress in mitigating risks. View GAO-22-104154.

PANEL 7. UNCREWED, AUTONOMOUS VESSELS AND THE HYBRID FLEET

Wednesday, May 10, 2023	
12:45 p.m. – 2:00 p.m.	**Chair: James (Sam) Taylor, Jr.,** Mine Warfare Senior Leader, Program Executive Office Littoral Combat Ships ***Rising Demands and Proliferating Supply: The Future of the Global UAS Market*** Gregory Sanders, Center for Strategic and International Studies Alexander Holderness, Center for Strategic and International Studies ***Improving Precommissioning Assignments and Readiness on the U.S. Coast Guard Offshore Patrol Cutter*** Jennifer Lamping Lewis, RAND Corporation Aaron C. Davenport, RAND Corporation Brynn Tannehill, RAND Corporation Austin Lewis, Apple James V. Marrone, RAND Corporation Victoria M. Smith, RAND Corporation Barbara Bicksler, RAND Corporation ***Economic Tradeoff Analysis of a Product Line Architecture Approach Through Model-Based Systems Engineering: A Case Study of Future Mine Countermeasures Unmanned Underwater Vehicles*** LT Joao Franklin Alves, Naval Postgraduate School Alumni

James (Sam) Taylor, Jr., Ph.D.— was selected to a Senior Level (SL) Executive position in 2017 as the Mine Warfare Senior Leader for the Program Executive Office Littoral Combat Ships. He is responsible for the overarching leadership of the Mine Warfare portfolio within the PEO and works to ensure the seamless delivery of mine warfare capability to the Fleet.

Prior to joining PEO LCS, Dr. Taylor served as the Deputy Department Head for the Littoral and Mine Warfare Systems Department at the Naval Surface Warfare Center Panama City Division. There he provided technical, supervisory and managerial leadership for the for a 475-person department that was responsible for the development, testing, fielding, and life cycle support of littoral and mine warfare systems, including the LCS Mine Countermeasures Mission Package.

From 2011 to 2013, he was the Naval Surface Warfare Center Panama City Division Chief Technology Officer. As the Chief Technology Officer, Dr. Taylor was responsible for the development and implementation of a Science and Technology Strategic Plan for the command. This plan spanned all warfare areas at the command including littoral warfare, mine warfare, naval special warfare, diving and life support, expeditionary maneuver warfare, and unmanned systems.

Dr. Taylor has extensive experience in science and technology as a branch head in the Science, Technology, and Analysis Department at the Naval Surface Warfare Center Panama City Division. He has worked numerous projects for the Office of Naval Research and managed a Future Naval Capability Product line that developed technology for the Littoral Combat Ship Mine Countermeasures Mission Package.

In 2003, he took a one-year assignment as the Assistant Technical Director at the Deputy Chief of Naval Operations, Expeditionary Warfare Division (N75). In this position, he was provided science and technology leadership and direction in the areas of Mine Warfare, Special Warfare, Explosive Ordnance Disposal, and Sea Basing to the Director.

Dr. Taylor received his doctorate degree in Engineering from the University of Memphis in 1994 where his major was electrical engineering. He had received his bachelor's degree and master of science degree in electrical engineering from the same institution in 1990 and 1991, respectively. His awards include the Navy Meritorious Civilian Service Award and Commanding Officer/Technical Director Award for Engineering/Testing/Operations.

Rising Demands and Proliferating Supply: The Future of the Global UAS Market

Gregory Sanders—is a Fellow in the International Security Program and Deputy Director of the Defense-Industrial Initiatives Group at the Center for Strategic and International Studies (CSIS), where he manages a research team that analyzes data on U.S. government contract spending and other budget and acquisition issues. In support of these goals, he employs SQL Server, as well as the statistical programming language R. Sanders holds a master's degree in international studies from the University of Denver, and he holds a bachelor's degree in government and politics and a bachelor's degree in computer science from the University of Maryland. [gsanders@csis.org]

Alexander Holderness—is a Research Assistant with the Defense-Industrial Initiatives Group at the Center for Strategic and International Studies (CSIS). His analytical focus is on issues relating to national security, government acquisition, supply chain risk, and industrial capacity. Prior to joining CSIS, Holderness worked as an intern for the U.S. Army Futures Command, Joint Army Concepts Division. He holds a BA in government and history from the College of William & Mary. [aholderness@csis.org]

Contributing Authors: Rose Butchart, Astrid Price, and Dan Steinberg

Abstract

To understand the trends and implications of this proliferation, this report asks three questions: (1) What countries are driving the increase in demand? (2) How has the supply of military Uninhabited Aerial Systems (UAS) changed? (3) How is the U.S. defense industrial base positioned to support U.S. foreign policy goals in this new environment? The report addresses these questions with quantitative analyses of global UAS and loitering munition transfers and contract spending by the U.S. government on UAS, enabled by a groundbreaking labeling effort. Across these analyses, the paper reaches three broad conclusions. First, UAS and loitering munitions offer a wide range of capabilities to a growing range of states. Second, countries now have a range of alternatives for acquiring UAS and loitering munitions. Third, the United States has increased its exports of UAS but with a comparatively greater focus on wealthy trusted allies compared to other weapon platforms.

Introduction

The military use of powered Uninhabited Aerial Systems (UAS) has evolved since their inception in the 20th century. From the 1930s through the 1950s, the primary strategic case for UAS was for non-kinetic missions, including serving as practice targets and decoys (Hall & Coyne, 2014). The case for including reconnaissance capabilities evolved beginning in the late 1950s and first saw extensive use in combat during the Vietnam War, where the Lightning Bug UAS conducted 3,425 intelligence, surveillance, and reconnaissance (ISR) operations (Blom, 2010).[1] Innovation in the use of UAS was certainly not limited to the United States. Israel pioneered many of the Cold War–era UAS developments and remains a leading UAS exporter today; for example, in the 1983 Operation Peace for Galilee, it leveraged signal-emitting UAS to trick Syrian radar operators into expending missiles on decoys (Wezeman et al., 2021). For the United States, UAS became increasingly integrated into the use of precision guided munitions, proving critical for tactical level intelligence collection, battlefield damage assessment, and target validation during the Gulf War (Miller, 2013). After the dissolution of the Soviet Union in 1991, the strategic case for U.S. employment of UAS evolved again to address smaller asymmetric challenges. Humanitarian

[1] There were unsuccessful armed UAS attempts in combat during World War II (Hall & Coyne, 2014).

intervention in the former Yugoslavia combined with a constrained budget prompted the development of the long-endurance Predator UAS (Hall & Coyne, 2014).

UAS provide some advantages over inhabited aircraft that may lead a country to opt to acquire uninhabited vehicles. The U.S. military details in its *Unmanned Systems Integrated Roadmap FY2013-2038* that UAS are "preferred alternatives . . . for missions characterized as dull, dirty, or dangerous" (Department of Defense [DoD], 2013, p. 20). One such advantage, of course, is that it removes the risk to operators' lives; this in turn also enables operations that domestic audiences might not otherwise support. Another consideration is that UAS have lower personnel and operating costs per hour of operation compared to inhabited aircraft (Keating et al., 2021, p. 16). UAS also remove human limitations that burden human-piloted aircraft, such as flight endurance caps, human-centric safety requirements, and multidirectional maneuverability limitations of the human body (Fuhrmann & Horowitz, 2017).

The Obama administration's June 2015 National Military Strategy shifted the nation's strategic focus back to great power competition focusing on China, necessitating a new strategic concept for UAS (O'Rourke, 2020, p. 48). A mix of rapid technological developments and classified approaches makes summarizing that concept difficult. As the Unmanned Systems Integrated Roadmap noted, "over the last decade, the advancement of unmanned systems technology has exploded, and the extrapolated growth curve hints that by the time of the publication of this document, some unidentified emerging technology or issue will likely emerge to disrupt any path that a traditional strategy might lay out" (Performance Assessments and Root Cause Analyses, 2018, p. 4). That document did not outline a specific technology direction for UAS but put forward overall themes of "interoperability, autonomy, network security, and human-machine collaboration" (Performance Assessments and Root Cause Analyses, 2018, p. 4). Some analysts have forecast that UAS will be pivotal in future great power conflict, often invoking specific technological developments like swarming maneuvers (Work, 2015).

That said, the question of the use of UAS in conflict is not merely limited to great powers and innovators like Israel. Even the use of unarmed UAS for ISR purposes may lower the threshold for entry into combat, and the United Nations Office for Disarmament Affairs published a report raising five implications of armed UAS: (1) "altering incentives in the use of force"; (2) "tempting States to interpret legal frameworks to permit fuller exploitation of the expanded capabilities of armed UAVs"; (3) "use of armed drones by covert armed forces in ways that do not permit sufficient transparency or accountability"; (4) "increasing use by non-State armed groups or even individuals"; and (5) "automation and compressing the 'time to strike' process" (*Study on Armed Unmanned Aerial Vehicles*, n.d.) The Center for the Study of the Drone (CSD) reports that "at least 28 countries have deployed UAVs beyond their borders since the 1980s" (Gettinger et al., n.d., p. XIII).[2] Within or beyond their borders, "at least 10 countries—Azerbaijan, Israel, Iraq, Iran, Nigeria, Pakistan, Turkey, UAE, U.K., and U.S.—are believed to have used UAVs to conduct aerial strikes" (Gettinger et al., n.d., p. XIII).[3]

The operational utility of UAS has driven increased demand across the globe as shown in Stockholm International Peace Research Institute (SIPRI) data, with a nearly 60% increase in UAS delivered internationally and a 577% rise in loitering munition deliveries between the first and second decades of this century. While there are expensive high-end

[2] This number includes peacekeeping and coalition operations (e.g., 21 countries deploying UAS to Afghanistan).

[3] The CSD also noted that even when staying within national borders, UAS can be used to "quell domestic uprisings and suppress minority populations."

systems, affordable cost is a distinguishing feature of many UAS. The Teal Group estimates that the unclassified military UAS market will grow to $13.2 billion in FY 2032, a 41% increase over FY 2023 spending (Zaloga et al., 2022, p. 1). The industrial base is an increasingly global one, as different offerers—and different countries—specialize in different market niches. Teal finds “the US will account for 71.9% of the unclassified R&D spending on UAV technology over the next decade, and about 34% of the unclassified procurement through the forecast decade,” notable in both cases but smaller than the equivalent shares of military equipment in general (Zaloga et al., 2022, p. 2). Understanding the global UAS industrial base, the international arms trade, and the relevant regulatory regimes for these systems is key to understanding how they will achieve operational effects in future conflicts.

Key Concepts

There are several different classes of uninhabited systems that are used for warfighting effects. Traditional missiles are long-range, high-speed munitions aimed to strike a target. UAS missions range from ISR to employing other mission packages (including electronic warfare) and carrying and launching their own munitions. UAS are often remotely piloted and, if they survive the mission, can be recovered when it is complete. A last class—loitering munitions—falls between these two with some aspects of both. Like UAS, they can fly to the target area and stay aloft until a decision is made to use them. Like missiles, however, they have kinetic warfighting effects and are not intended to be reusable after striking a target; many models may not even be recoverable if they fail to find a target. In short, attritability is assumed for missiles and loitering munitions. For UAS, attritability is not the default assumption in most cases but is a lower cost option than the loss of an inhabited system.

The focus of this report is the latter two types. To capture the difference in both employment concepts and capabilities, this analysis uses three broad categories. The first category, unarmed UAS, participates in long kill chain and encapsulates the largest portfolio of UAS. “Long kill chain” means that for kinetic action to take place, targeting data first must be relayed to another system that is used to achieve that kinetic effect, typically after being transmitted back to a command post. While more organization capacity is required to make an effect happen, unarmed UAS platforms can be simpler. This trade-off means that unarmed UAS are the most ubiquitous platform and are often deemed to be lower proliferation risks.

The secondary category, armed UAS, have a short kill chain and are systems that can achieve kinetic effects from weapon systems mounted on the airframe. This simplifies the complexity of a kill chain and means that operators can surveil and strike a target from a single platform. These systems, however, are often larger and carry hefty acquisition and sustainment price tags relative to other UAS. This higher price tag typically comes with the ability to perform multiple functions or traits such as greater endurance, in addition to the fact that most armed UAS can support long kill chains in addition to their direct attack capability. Loitering munitions have self-contained kill chains, which is to say these systems have a warhead integrated into the airframe and can conduct surveillance of a target before striking it. From a proliferation concern perspective, the difference between a self-contained kill chain UAS and a missile is at times negligible.

Table 1. UAS and Loitering Munition Operating Concepts[4]

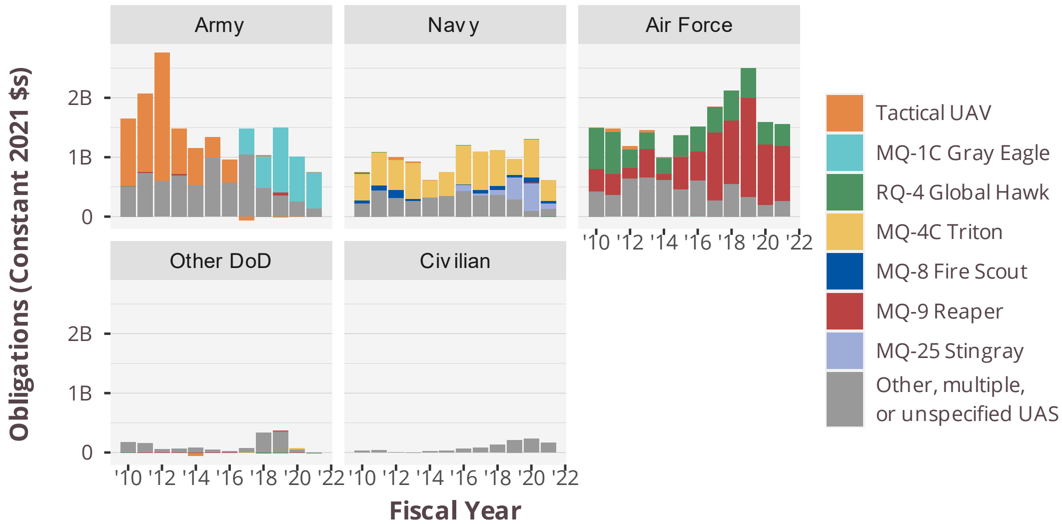
Category	Concept	Operational Complexity	Common Uses	Examples
Unarmed UAS	Long kill chain	High	Artillery spotting, battlefield surveillance	DJI Drones, Global Hawk, PD-2
Armed UAS	Short kill chain and long kill chain	Moderate	As above, as well as tracking and destroying targets needing long-term monitoring	Reaper, TB2
Loitering Munition	Self-contained kill chain	Low	Suppression of enemy air defenses, precision strikes requiring target verification	Switchblade, Harop

U.S. Contracting for UAS

The primary source for this information is the Federal Procurement Data System (FPDS), which includes all civil and defense government contract transactions, with a few notable carveouts mentioned below where relevant.[5] The FPDS tracks UAS spending with a code for "complete unmanned aircraft systems and subordinate air vehicles."[6] That tracking was expanded by the efforts of the study team as described below, and the analysis here is limited to UAS. Further, the FPDS only includes prime contractors (and classified contracts are not required to be reported), so next-generation systems such as the recently revealed Phoenix Ghost and speculated stealthy RQ-180 would not be included in the data. The Teal Group estimates the U.S. military UAS budget will be $10.6 billion in FY 2023 but only $5.4 billion, just 51% of that funding, will be unclassified (Zaloga et at., 2022, p. 3). While civilian agency data is included in this analysis, intelligence agencies do not report into the FPDS, although they have played a notable role in the development and use of UAS (Strickland, 2013, p. 6). To better capture the sector, CSIS has also searched through the major defense acquisition programs labeled within the FPDS to determine which of them qualify as UAS.[7] The study team further expanded the data set by searching through transaction descriptions from FY 2010 through FY 2021 associated with $10 million or more in then-year obligations to find which included UAS. This effort takes on a key challenge of analyzing UAS within the FPDS, which is that there is only the single aforementioned product or service code that covers uninhabited vehicles. The FPDS only tracks UAS as products and does not cover R&D—which is often grouped with aircraft research—or maintenance and repair and other services. Because loitering munitions are not explicitly covered as a product category and their programs are not large enough to be captured as a major defense acquisition program, they are only incidentally included in this data. Contracts that meet any of the three criteria of (1) using the product code for UAS, (2) being tied to a UAS major defense acquisition program, or (3) mentioning being for a UAS project in the description are all included in the data set, summarized in Figure 1.

[4] CSIS Defense Industrial Initiatives Group Data Analysis

[5] This paper applies OMB federal outlay deflators to adjust for inflation.
[6] The product or service code is 1550 "Unmanned Aircraft," which includes "only complete unmanned aircraft systems and subordinate air vehicles." The entry notes that "converted or modified guided missiles" are excluded, but the codebook makes no mention of loitering munitions in this or other categories.
[7] The DoD acquisition code field in FPDS is used to make these identifications. These codes capture the R&D through production of these systems as well as major upgrades. However, they are not designed to capture sustainment activity and so will miss out on operation and maintenance contracts. The projects included are as follows: QH-50, MQM-40/42 REDHEAD/ROADRUNNER, QM-107 GD MSL TGT SYS, UAV HUNTER (SHORT RANGE UAV), RPV (AQUILA), GLOBAL HAWK, MQ-8 Fire Scout, TACTICAL UAV, HAEUAV, QH-50 DASH, BQM-34 FIREBEE, BQM-74, BQM-74E SSAT, PREDATOR UAV, PIONEER UNMANNED AERIAL VEH, BAMS, MQ-9 Reaper, JTUAV, and MQ-1C Gray Eagle.



Source: FPDS; CSIS analysis.

Figure 1. Federal Prime Contracts for UAS, FY 2010–FY 2021 (FPDS, n.d.; CSIS, n.d.)

Totaling across all five DoD and civilian customers shown in Figure 1, unclassified spending on UAS had peaked at $5.3 billion in FY 2019 before falling to $4.1 billion in FY 2020 and then $3.0 billion in FY 2021. This total contract spending is in line with the Teal Group estimate that the unclassified budget for military UAS research, development, testing, and evaluation and procurement spending in FY 2023 is $5.4 billion (Zaloga et al., 2022, p. 3).[8] Trends varied across the military departments, with the Army having the highest spending levels before the FY 2013 budget caps. Army spending has been driven by Tactical UAVs, which include the RQ-7 Shadow and the MQ-1C Gray Eagle, a successor to the MQ-1 Predator. The Air Force had seen steady increases in contract obligations since FY 2014 before leveling off at $1.5 billion a year, slightly higher than the spending level at the start of the reporting period in FY 2010. The Air Force is planning the retirement of both systems receiving the bulk of its spending, the RQ-4 Global Hawk and MQ-9 Reaper, with classification limiting public discussion and cost reporting of any follow-on plans (Tirpak, 2021). The Navy has steadily spent on Broad Area Maritime Surveillance, which became the MQ-4C Triton, an upgraded RQ-4 Global Hawk. The dramatic drop in Navy spending, from a peak of $1.3 billion to only $0.6 billion, is driven in part by uneven annual obligations for the MQ-25 Stingray, which is still categorized as an R&D project with aerial refueling as a key mission. Meanwhile, civilian spending peaked at $222 million in FY 2020 before falling to $163 million in FY 2021, but despite that decline by more than a quarter, FY 2021 was still the third-highest year in the last decade for spending.

The majority of UAS contract obligations go to products (69% over the reporting period), as shown in Figure 2, and the decline in overall spending is largest in absolute terms in that category, falling by more than half from a recent peak of $3.44 billion in FY 2019 to $1.95 billion in FY 2020 and $1.55 billion in FY 2021—the latter two values each being new lows for this reporting period.

[8] While this is complicated slightly by multiyear procurement, budget figures should reliably exceed contract spending. That said, the Teal Group estimate does not include operations and maintenance spending, which is an important part of contract spending.

The proportion of UAS spending for R&D is remarkable. Across the reporting period, 11% of UAS obligations went to R&D, varying between 6 and 17%. For contrast, seven other defense system portfolios are included in Figure 2, which has a variable y-scale because remotely crewed systems are by far the smallest of the group.[9] While the UAS R&D rate is below that of space systems (55%); electronics, comms, and sensors (14%); and air and missile defense (25%), it still exceeds that of aircraft (7%), ships and submarines (2%), land vehicles (4%), and ordnance and missiles (4%).[10] UAS R&D spending did drop from $0.6 billion in FY 2020—the highest level since FY 2012—to only $0.18 billion in FY 2021, but both the high and low can be attributed to the uneven annual distribution of contracts for the MQ-25 Stingray.

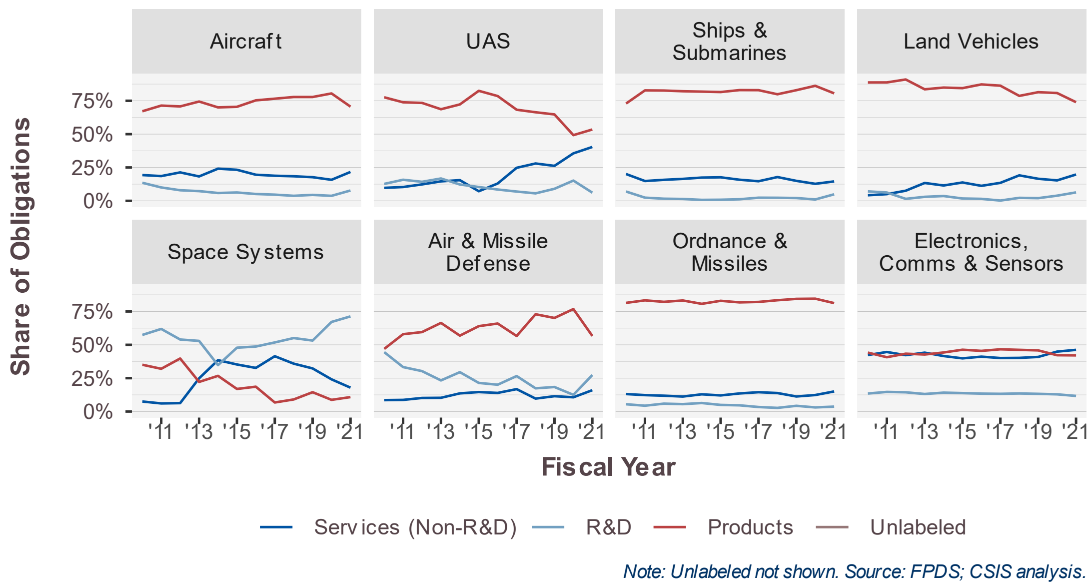


Figure 2. Defense System Platform Contract Obligations and Share of Obligations by Product, R&D, and Service, FY 2010–FY 2021
(FPDS, n.d.; CSIS, n.d.)

Turning to services, a review of some of the descriptions of major service UAS service contracts found some examples of UAS ISR as a service, but far more common is contractor logistic support that is focused on keeping these systems in an operational state. Twenty percent of UAS contracting spent on services, while likely a conservative estimate, is also greater than that of most vehicular categories—but largely comparable to that of the aircraft sector (19%), lagging slightly behind space systems (23%) and well behind electronics, comms, and sensors (42%). Notably, however, that last sector incorporates a range of information and communications technology services that includes business system support. While spending on UAS services declined from $1.41 billion in FY 2020 to $1.17 billion in FY 2021, that lower level of obligations was still higher than any year from FY 2010 to FY 2016, when annual spending averaged below $0.5 billion.

[9] This graph does not include those platforms less tied to a particular defense system: other products, other services, other knowledge-based and R&D, and facilities and constructions.
[10] As was discussed above, there are no product or service codes dedicated to R&D for UAS. However, the comparatively high rate of R&D contract spending for this portfolio suggests that CSIS's layered labeling approach is overcoming that limitation.

Federal Acquisition and the Commercial UAS Market

The federal and defense acquisition system has a range of tools that are oriented to accessing commercial or emerging technology in addition to tools for developing technology within the traditional defense industrial base. The total value for of civil UAS is estimated by the Teal Group to be $7.2 billion in 2022, smaller than the value of military UAS but still a major source of innovation (Gertler & Zoretich, 2022, p. 1). Commercial acquisition contracting authorities loosen some of the restrictions on acquisition with the intent of employing commercial market discipline and benefiting from technology investments not made for government purposes.

In commercial-adjacent sectors like the UAS industrial base, many technological advances are not government funded and are sold to a wider market. The traditional federal contracting system has tools for accessing products and services that are commercially available, which this paper refers as commercial contracting.[11] As seen in Figure 3, commercial contracting represents only a few hundred million of the billions spent on UAS each year. That amount has risen for the Army, Air Force, and civilian agencies. That said, any such use is still nascent or under-labeled, as the last 4 years have seen an average of 5% of federal contract dollars for UAS use a commercial approach, compared to higher average levels for aircraft (7%), space systems (9%), and ships and submarines (14%)—let alone the 26% of land vehicle obligations spent using commercial contracting approaches. This rate in recent years does exceed that for ordnance and missiles or air and missile defense (2.1 and 0.5%, respectively), showing that rates do exceed that of exclusively defense-focused sectors.

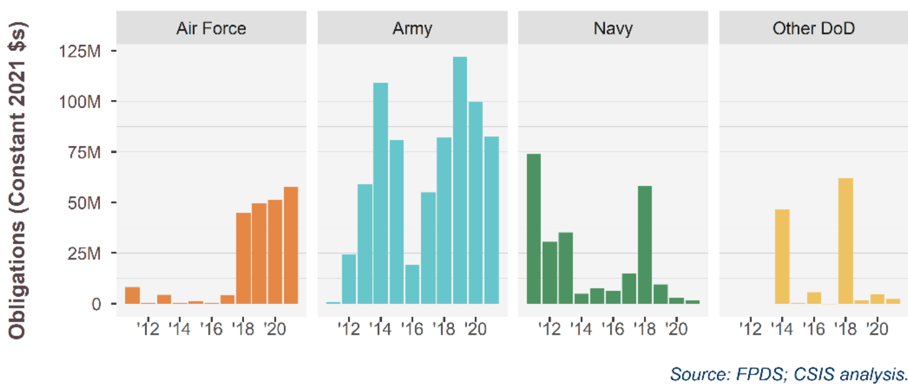


Figure 3. Federal Obligations for UAS Using Any Commercial Authorities, FY 2011–FY 2021 (FPDS, n.d.; CSIS, n.d.)

Structure of the U.S. UAS Industrial Base

The UAS industrial base is a niche within the larger U.S. defense industrial base. Across the reporting period, the inhabited aircraft sector was over 20 times its size and the ordnance and missiles sector more than five times larger. Analyzing those sectors also benefits from better labeling, which makes it more straightforward to capture if the government is directly contracting for an engine, electronic suite, or warhead to be placed

[11] For this paper, "commercial contracting" refers to federal contract procedures for items that are commercially available according to the definitions in Federal Acquisition Regulation 2.101. The authorities available for commercial contracting are available in Part 12 of the Federal Acquisition Regulation. In FPDS, there are multiple relevant fields, and this paper treats as commercial any transactions using *Commercial Item Acquisition Procedures*; that qualify as commercial under the DoD-focused *Information Technology Commercial Item Category*; or that employ less demanding test procedures allowed by *Simplified Procedures for Certain Commercial Items.*

on the platform. With those caveats in place, the data nonetheless reveal two central trends about the UAS industrial base, both shown in Figure 4. First, when measured by obligations as shown in the chart on the left, the sector is undergoing consolidation resulting from merger and acquisition activity as well as from some UAS programs finishing production without follow-on work for the vendor in question. Second, when looking at count, a wider range of vendors is participating even if their revenues are modest. Despite a small decline in FY 2021, the number of vendors has grown most years since FY 2014, even when the trend in the larger U.S. defense industrial base has been one of stability or decline; for example, in FY 2020 the number of defense vendors across all sectors fell by 10% even as the number of UAS vendors rose (Office of the Under Secretary of Defense for Acquisition and Sustainment [OUSD(A&S)], 2022; Sanders et al., 2022).

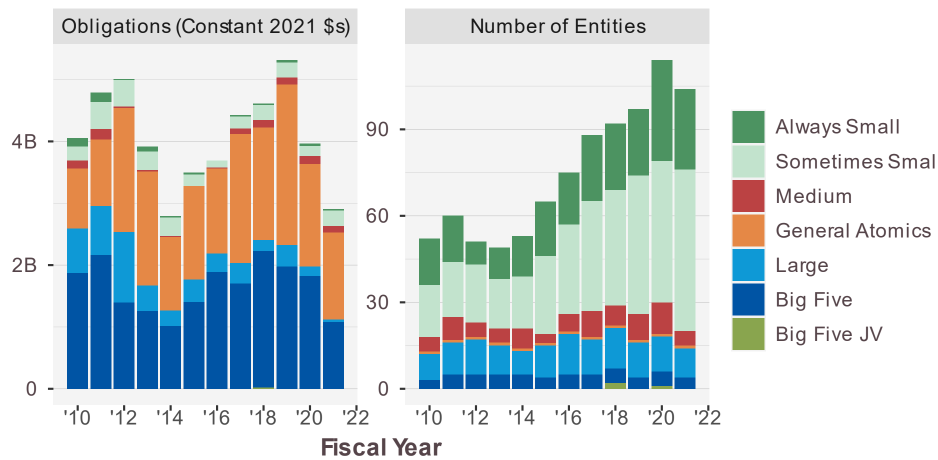


Figure 4. Count and Contract Obligations to Federal UAS Vendor by Size, FY 2010–FY 2021 (FPDS, n.d.; CSIS, n.d.)

When looking at market share, the “Big Five” contractors—Lockheed Martin, Northrup Grumman, Boeing, Raytheon, and General Dynamics—collectively commanded 40.5% of the market during the period, with midsized specialist General Atomics receiving a slightly smaller 40.0% share. At the peak in FY 2019, the Big Five received $2.0 billion in obligations, and this dropped to only $1.1 billion in FY 2021 although their share of the market remained the same (37%). General Atomics, since FY 2012, has held a 37 to 49% share of the defense UAS market and went from receiving $2.7 billion in FY 2019 to only $1.4 billion in FY 2021, despite only a slight reduction in share (49 to 48%). That said, the Big Five defense primes do specialize in defense-unique items, including stealth technology such as that employed by the F-35 fighter and B-21 bomber. As a result, they likely play a prominent role in any expenditures for classified systems not included in this chart.

Large entities—defined as those vendors with $3 billion or more in revenue, including from non-federal sources, which are not among the Big Five—have steadily lost market share over the period. They received only $344 million in obligations in FY 2019, and that number reduced by an order of magnitude to $35 million in FY 2021. Instead, the growth in count has been in medium and small vendors, even though (setting aside General Atomics) their collective share of the market has not grown. The biggest jump has been for vendors that are sometimes categorized as small.[12] Across the past decade, the number of small

[12] “Sometimes small” means that in a given year, one contracting officer labeled them as other than small within their sector, and another contracting officer in an earlier year or working in a different sector perhaps made the judgment that they met the small business criteria when the contract started.

and medium vendors went from 60 in FY 2011, to 75 in FY 2016, to 104 in FY 2021. In dollar terms, the share for these vendors has been comparatively small, dropping from a peak of $758 million in FY 2011 to only $127 million in 2016 before partially rebounding to $376 million in FY 2021.

Table 2 takes a closer look at the individual contractors that received the greatest share of defense obligations. The two largest providers of UAS during this period are General Atomics and Northrop Grumman, which cumulatively received $19.5 billion and $13.6 billion in obligations, respectively, from FY 2010 to FY 2021, with Northrop Grumman holding the lead in FY 2010 and FY 2011 and General Atomics thereafter. In addition to Northrop Grumman, three other members of the Big Five defense contractors, Raytheon, Boeing, and Lockheed Martin, place in the number three, five, and seven spots, respectively. The largest overall defense contractor, Lockheed Martin, is also the second-largest provider of civilian UAS, with $339 million in the reporting period, of which $64 million was spent in FY 2021 alone, compared to $501 million in the reporting period and $78 million in FY 2021 for General Atomics.

Table 2. Top 10 U.S. Federal Prime UAS Vendors for Contracts, FY 2010–FY 2021

Rank	Contractor	Obligations (Constant 2021 $ Millions)			
		History 2010–2021	Prior Decade 2010–2019	2020	2021
1	General Atomics		16,503	1,662	1,407
2	Northrop Grumman		11,727	1,126	775
3	Boeing		3,461	584	178
4	Textron		3,543	51	3
5	Raytheon		1,265	82	133
6	Aerovironment		1,074	34	68
7	Lockheed Martin		336	17	(0)
8	Kratos Defense & Security		245	30	75
9	Navmar Applied Sciences		312	(0)	-
10	Composite Engineering		222	-	-
All Other			3,402	379	267
Total			42,091	3,964	2,905

Turning to other large companies, as Figure 6 shows, these firms have been in relative decline in the reported data. Textron has undergone the largest change, with peak obligations in FY 2012 at over $1.0 billion. The remaining vendors fall within the medium to small tiers. AeroVironment stands out as a producer of multiple systems transferred to Ukraine via drawdowns, including the Puma unarmed UAS and the Switchblade loitering munition. Kratos Defense & Security is also notable as an example of consolidation within this sector, as it purchased the 10th-ranked Composite Engineering.

Arms Control Agreements and Regulations

While this report looks primarily at the advantages offered by uninhabited systems, U.S. arms control agreements and export laws primarily regulate those systems by their capabilities. The foundation of U.S. export controls is domestic law, notably 1976’s Arms Export Control Act. The executive branch enforces this law and goes further to regulate arms and dual-use exports, with the Departments of State, Defense, and Commerce each having an important role. The executive branch can also give guidance through the conventional arms transfer policy and more specific policies such as the 2015 and 2019 updates to UAS export policy. There are multiple relevant international agreements, including the Wassenaar Arrangement, but one of the most important agreements for UAS has been the Missile Technology Control Regime (MTCR). The initial MTCR-based regulations introduced in 1992 considered all UAS as potential delivery platforms for missile technology—with a threshold based on speed and carrying capacity for stricter regulation.

The MTCR includes rules on UAS that set a major brake on higher-end UAS exports, although that was not the original focus of the agreement. The G7 states signed the MTCR in 1987 after initial discussions started in 1983 (van Ham, 2017). Today, the MTCR has 35 member states (Alberque, 2021). The MTCR was created to form "rules and norms that could be used to address sales of nuclear-capable missiles by the Soviet Union and China" (Alberque, 2021). It divides missile-related capabilities into two categories. Category I includes "complete rocket and unmanned aerial vehicle systems . . . capable of delivering a 500-kg warhead to 300 km," their launch vehicles, and "major complete subsystems," among others (Bureau of International Security and Nonproliferation, n.d.). The MTCR Annex includes the full list (MTCR, n.d.). Category I items face a "strong presumption of denial" for export and should be rarely exported under MTCR guidelines. Category II items include dual-use items, less-sensitive components, and "other complete missile systems capable of a range of at least 300 km" and are more freely exported. The MTCR is nonbinding as an international agreement, although its member countries may (and do) create binding laws on a national level (Bureau of International Security and Nonproliferation, n.d.). Instead, it operates through "export controls, meetings, and dialogue and outreach," putting the "burden for compliance onto the seller rather than the buyer" (Bureau of International Security and Nonproliferation, n.d.; Alberque, 2021).

The MTCR was expanded in 1992 to counter the spread of chemical and biological weapons of mass destruction (WMDs), in addition to the nuclear warheads it was originally designed for (Bureau of International Security and Nonproliferation, n.d.). 1992 also saw the MTCR expand to UAS, applying the same categorization rules that apply to missiles. This has caused widespread discussion. Some have touted the addition of UAS as one of the MTCR's "notable successes," demonstrating that the MTCR can expand to include new technologies as additional types of platforms that are capable of delivering WMD-like payloads. This line of thought puts that the MTCR should continue expanding toward an even larger scope (Alberque, 2021). The primary contrasting view in the literature focuses on UAS' capacity for reuse, positioning them closer to aircraft—which are not regulated by the MTCR. This line of thought holds that UAS inclusion under the MTCR is *counterproductive*, a distraction from the primary purpose of the MTCR (Schneider, 2020).

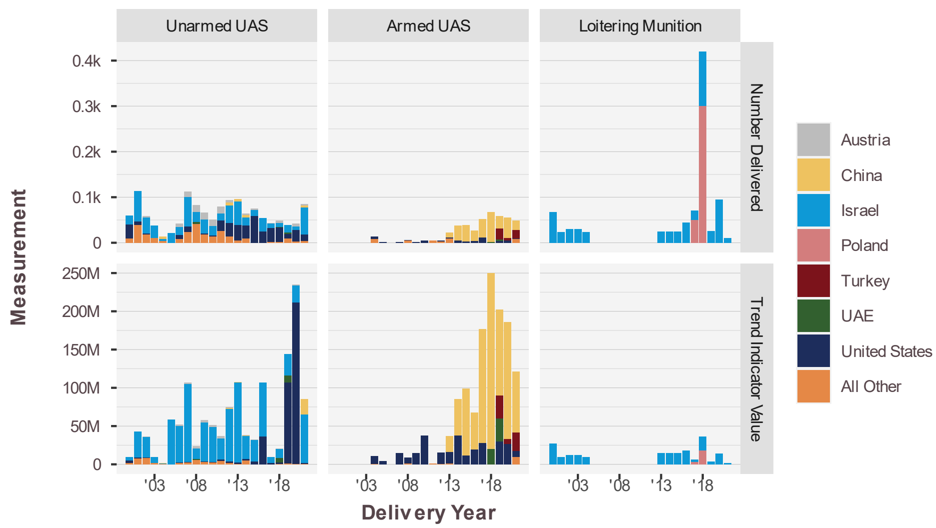
The inclusion of UAS as a Category I system inherently puts the brakes on the widespread export of systems capable of carrying 500 kg at least 300 km. The United States reinterpreted the MTCR to move systems with an airspeed of less than 800 km/h into Category II in June 2020 (Schneider, 2020). Opening opportunities for broader export—cited as a U.S. priority in the release—may make the regime more appealing to potential MTCR additions (Office of the Spokesperson, U.S. Department of State, 2015). Shifting UAS into Category II removes the strong presumption of denial for export, making the threshold to export UAS systems more like that of other arms. Critics warned that making this change on a non-consensus basis risks undermining international norms and standards and opening the door to future other countries to unilaterally reinterpreting international regimes (Kimball, 2020). As of August 2022, neither the Department of State's MTCR Fact Sheet nor its International Traffic in Arms Regulations (ITAR) had been updated to reflect the new carveout for systems under 800 km/h, although the Department of Commerce's Export Administration Regulations (EAR) was updated in 2021 (Bureau of International Security and Nonproliferation, n.d.; Code of Federal Regulations, 1993; Federal Register, 2021). ITAR and EAR will be discussed further later in this section, but the former was most recently revised in June 2022. Israel, an MTCR signatory, produces a UAS with a 450 kg payload, carefully below the MTCR's 500 kg limit (van Ham, 2017). Russia and Ukraine are MTCR signatories, as is the United States; Armenia and Azerbaijan are not. China, now the largest exporter of armed UAS (all nominally below the capacity thresholds), is a self-proclaimed adherent of the MTCR but has not formally joined (Alberque, 2021).

How, then, should UAS exports be controlled? The 2013 Arms Trade Treaty (ATT) does not specifically mention UAS but does include combat aircraft as one of its categories and so "does implicitly apply to drones" (*The ATT | Arms Trade Treaty*, n.d.; Stohl & Dick, 2018). In this, the ATT draws a distinction that the MTCR does not—not on the craft's crewing and theoretical potential to deliver a warhead, but on its strike capabilities, a different set of priorities than the MTCR that places more emphasis on compliance with the laws of war. The United States and Ukraine have signed but not ratified the ATT; Armenia, Azerbaijan, and Russia have neither signed nor ratified (NTI, n.d.).

The 2015 U.S. Export Policy for Military Unmanned Aerial Systems also emphasized the laws of war. Despite its name, the policy applies to both military and commercial-origin UAS. It evaluates transfers on a case-by-case basis; its principles for evaluation cite the MTCR, humanitarian law, "lawful basis for use of force under international law," proper training, and avoidance of unlawful surveillance or force (Office of the Spokesperson, U.S. Department of State, 2015). The 2016 Joint Declaration for the Export and Subsequent Use of Armed or Strike-Enabled Unmanned Aerial Vehicles (UAVs; Office of the Spokesperson, U.S. Department of State, 2015; Bureau of Political-Military Affairs, 2017). The United States sought to build support for the latter on the occasion of an ATT conference and has a similar hope for multinational agreement around both exports and imports (van Ham, 2017). Ukraine has signed on to the United States' declaration; Armenia, Azerbaijan, and Russia have not. The United States again revised its export policy in 2019, which listed "increases trade opportunities for U.S. companies" first among its five objectives (*U.S. Policy on the Export of Unmanned Aerial Systems*, 2019).

The 2016 declaration and 2019 export policy draw a strike versus non-strike distinction, which captures armed and strike-enabled UAS that would fall beneath the MTCR's capacity thresholds. These smaller UAS have become a growing part of arms transfers in the past decade. In examining these four together, the strong suggestion is that UAS will increasingly be regulated according to their combat capabilities. Examining the Department of State's International Traffic in Arms Regulations (ITAR), which regulates U.S. exports and transfers to third countries, finds a broad but capability-based distinction: it regulates "aircraft, whether manned, unmanned, remotely piloted, or optionally piloted" (Code of Federal Regulations, 1993). These characteristics are not related to whether they are uninhabited, but by their relation to defense or to the MTCR. ITAR separates aircraft and UAS only when regulating UAS launch vehicles or swarm-capable UAS—two capabilities without inhabited system parallels. Its missile-related language reflects the MTCR, referencing "MT [missile technology] if usable in rockets, SLVs [space launch vehicles], missiles, drones, or UAVs [unmanned aerial vehicles] capable of delivering a payload of at least 500 kg to a range of at least 300 km" (Code of Federal Regulations, 1993). Missile technology here designates the MTCR. ITAR outlines a policy of denial for "defense articles and defense services" to Russia, except for some commercial and government space capabilities (General Policies and Provisions, n.d.). No ITAR policy of denial applies to Armenia, Azerbaijan, or Ukraine, but all four countries are controlled countries under the Department of Commerce's EAR (Definitions of Terms as Used in the Export Administration Regulations [EAR], 2022). The EAR bases its reasons for controlling *nonmilitary* UAS technology in part on missile technology; however, its restrictions on "unmanned 'airships'" are much broader than the MTCR or ITAR. While still tied to capabilities, the EAR restricts craft by speed, range, and altitude rather than solely by strike capability (Commerce Control List, n.d.).

UAS Arms Trade Trends



Source: SIPRI Arms Transfers Database," June 12, 2022, https://www.sipri.org/databases/armstransfers; CSIS analysis.

Figure 5. UAS and Loitering Munitions Deliveries by Exporter, 2000–2021 (SIPRI Arms Transfers Database, 2022; CSIS, n.d.)

From 2011 to 2020, SIPRI tracked 1,734 transfers of UAS and loitering munitions, compared to 736 in 2001 to 2010. Armed UAS and loitering munitions were largely responsible for this growth: armed UAS took off from 30 transfers in the first decade to 368 in the second, while loitering munitions exploded, growing sevenfold from 108 units transferred in 2001–2010 to 731 in 2011–2020. As can be seen in Figure 9, this growth was driven in large part by China's emergence as an exporter, going from less than 10 units exported in the first decade to nearly 300 in the second. In the first decade, Israel had a commanding lead, with 73% of UAS and loitering munition exports as weighted by estimated production cost.[13] In the second decade, however, China was on top, with 43% of estimated production costs; the United States adjusted its arms exports policy and grew to account for 28%, and Israel dropped to only 22%. That said, according to CSD, in 2019 the United States still provided UAS or loitering munitions to a plurality of countries:

> Nineteen countries have exported drones that are currently in active military service. Most foreign-made systems are acquired from China, Israel, or the U.S. Aside from the military services in these three countries, a total of 79 countries—83 percent—operate at least one active drone type made in China, Israel, or the U.S. Thirty-two countries operate at least one drone made in China, 39 countries operate at least one from Israel, and 49 operate at least one from the U.S. (*The Drone Databook*, 2019, p. IX)

[13] Trend indicator value (TIV) is often more useful for measuring UAS proliferation because estimated production costs weigh the value of larger and more lethal or otherwise capable systems far higher than other platforms. While proliferation of the number of platforms is certainly important, the proliferation of capabilities lends greater insight into the state of the global market and the status of export controls.

Across the entire 2000–2021 period, Israel and China are, by a healthy margin, the largest exporters of UAS by estimated production cost. Israel has long been an exporter of midsize UAV surveillance systems and has notably made the choice not to sell armed systems (with the exception of loitering munition transfers). China, on the other hand, is a relative newcomer to the market and has seen most of its sales with high-end armed systems, often selling to nations limited in their ability to buy U.S. armed UAS because of U.S. humanitarian and arms control concerns. In Israel, the Israeli Defense Force's armed UAS capability was until recently treated as an important enough state secret that discussion was censored, which still applies to advertising capabilities to potential international customers. These rules did not limit discussion of loitering munitions, however, and "arms-capable UAVs have been reportedly sold to Germany and India under special agreements" (Fabian, 2022). The United States occupies a distinct position in the export market, since while it has some of the most advanced capabilities on offer, it sells relatively few of them. Because of how advanced U.S. systems are, they have much higher estimated production costs, meaning that while the United States exports relatively few systems, these represent a substantial portion of global capability.

There is a significant step down from the three largest exporters to the runners-up, the UAE and Turkey, both of which sell larger armed platforms. While the UAE and Turkey do not export the volume of systems that some larger exporters do, they do export armed UAS capabilities (based in part on Western technology) and could be major players in the global market depending on how foreign policy concerns shape different states' willingness to export systems (Sabbagh & McKernan, 2019). The last two countries with notable exports in the period are both niche players. Poland is a relatively limited proliferator of capabilities, only exporting the Warmate loitering munition.[14] Of the top seven exporters shown in Figure 9, Austria makes up the smallest portion of the global export market, selling only a single surveillance UAS. The CSD lists Austria as the fourth largest provider by number of countries served. In addition to those mentioned here, the CSD also notes exports by Denmark, France, Germany, Iran, Italy, Russia, Slovenia, South Africa, South Korea, Spain, Sweden, and Switzerland (*The Drone Databook*, 2019, p. IX).

Implications

The Chinese and Israeli dominance of the market likely has to do with both political and military concerns. On the military side, Israeli and Chinese systems offer lower unit costs than their often-larger U.S. counterparts. On the political side, both Israel and China are willing to sell to states with mixed human rights records where U.S. companies are often barred from selling advanced long-range weapon systems. China in particular is willing to sell large armed UAS to countries without regard to whether the country has a history of respecting humanitarian and human rights concerns with their use of precision munitions. Since these states are driving demand, this can make it difficult for U.S. companies to export systems, given the government's legitimate export concerns. The United States has, however, made some recent gains in the global market, with long-planned sales of the Global Hawk platform which, while unarmed, had fallen under stringent MTCR category I controls.

[14] SIPRI's TIV system assigns a much lower value to loitering munitions than other armed drones. This is likely because of follows from their low production cost and limited use nature. So, while Poland sold more systems than any other country in some years, in terms of proliferating capabilities, other states that sold more reusable and larger systems will have higher exports by TIV.

Major Importers and Regional Import Trends

The Near East and Africa were the most prominent source of the increase in UAS and loitering munition demand in the 2011–2020 period. Because of domestic manufacture, this trend does not align with overall regional spending on military UAS. The Teal Group reports that the United States is the largest spender, followed by Europe and the Asia-Pacific region.[15] As seen in the top portion of Figure 6, the Near East is responsible for the largest share of UAS and loitering munitions by value (accounting for $719 million in Trend Indicator Value [TIV], compared to $665 million for second-place Europe and Eurasia). The leading two purchasers, Saudi Arabia and the UAE, account for two-thirds of the TIVs for the region and are the number one and number five importers, respectively, for the entire 2000–2021 period, as seen in Table 6. The growth in African imports was driven by Nigeria and Sudan, which, while representing a much smaller portion of global demand, also displayed a striking increase that followed similar dynamics as the Near East. Algeria, Egypt, and Iraq also appear on the top 25 importer list from the Near East, and all seven nations covered here have turned to China as their plurality source of UAS, although Algeria notably turned to the UAE as well.

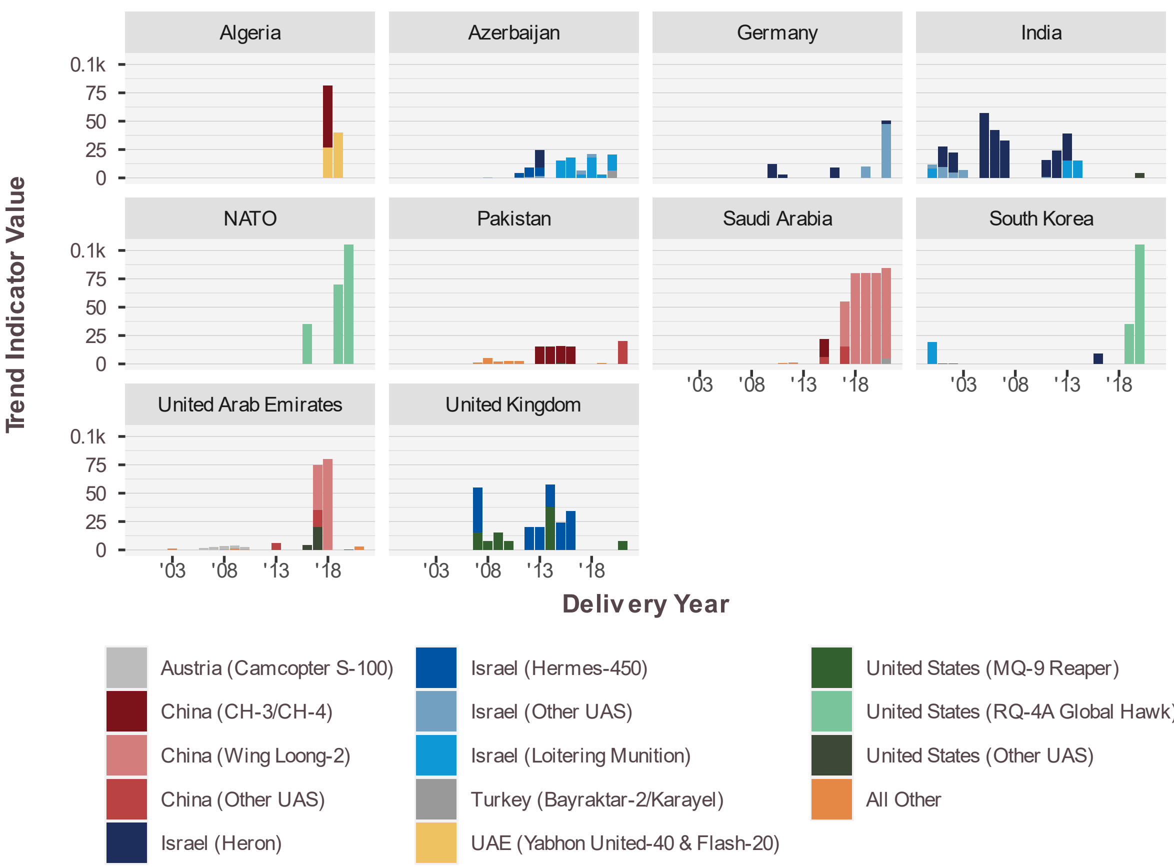
Here China's entry as a supplier provides a straightforward explanation for the greater than order of magnitude rise in demand. Most of the Near East and African buyers are unlikely to buy from Israel because they do not have formal diplomatic ties to that country (with the long-standing exception of Egypt, partially joined by Sudan and the UAE in 2020). This cut them off from the largest supplier of UAS in 2001–2010, and while many of these Near East nations are major importers from the United States, a presumptive denial policy for larger UAS limited their range of options. Interestingly, as with Azerbaijan, funding from oil dollars is a notable part of this story. As seen in the bottom half of Figure 6, UAS and loitering munitions do not stand out as a proportion of total Near East weapons imports; they only comprise 0.7% on average from 2011–2020, with a peak of 2.2% of the region's estimated production costs for import in 2018.

Europe and Eurasia are the second-largest regional importer in estimated production cost terms but also have been a fairly persistent source of demand throughout the entire period. The United Kingdom and NATO are the number three and four importers across the period, with Azerbaijan and Germany in the top 10, and Turkey, France, Italy, Spain, and ultimately Ukraine appearing in the top 25. Israel is a longtime provider to the region, but liberalizing U.S. policy toward major exports and a new supplier in Turkey have also contributed to more than doubling the imports from 2001–2010 to 2011–2020. East Asia and the Pacific have been the third-largest importer, with purchases by South Korea from the United States, Indonesia from China, and the Philippines and Singapore from Israel each coming in the past decade. South and Central Asia have been in slight decline, as Indian purchases have fallen off and rising Pakistan imports from China have not closed that gap. Non-regional deliveries to the United Nations and unknown recipients have made up a small portion of UAS transfers in estimated production cost terms, but across the period 10.1% of imports to the United Nations or imports that could not be traced were UAS. The proportionally large share of UAS and loitering munitions among deliveries to unknown importers suggests a note of caution for this analysis, as UAS and loitering munition deliveries may prove harder to track than some traditional weapon systems.

[15] Teal also notes that "the Asia-Pacific region may represent an even larger segment of the market, but several significant players in the region, namely Japan and China are not especially transparent about their plans compared to Europe" (Zaloga et al., 2022, p. 2).

Choice of Systems for Top Importers

Closer examination of UAS transfers to the top 10 importers reveals that just a handful of systems make up the bulk of UAS exports when measured by estimated production cost. Figure 11 shows that the bulk of the proliferation of capabilities has happened in the last 5 years, with the sale of a large number of Wing Loong-2 systems, in conjunction with a smaller number of highly capable U.S. Global Hawk (RQ-4A) systems. The Wing Loong-2 is a Chinese UAS that is similar to the U.S.-made Reaper family. Both have long loiter times, can be armed, and are of similar size (Air Force, n.d.; OE Data Integration Network [TRADOC], n.d.). The Israeli Hermes and Heron are similar in size and capability to the TB2, though only the TB2 is marketed as an armed platform (Elbit Systems, n.d.; Israel Aerospace Industries, n.d.; Baykar, n.d.). The final high-end systems that make up a significant portion of capability proliferation are the Global Hawk, which is the largest system of the group and can remain aloft for up to 30 hours, miles above where even commercial airliners fly, and is often used to conduct strategic reconnaissance tasks, and the MQ-9 Reaper, which is well known for its role as an armed UAV in U.S. counterterrorism and counterinsurgency efforts (Northrop Grumman, n.d.). Considering that the U.S. Reaper and the Wing Loong-2 are similar systems, demand for further armed UAS, including U.S. systems, may now be limited for states that made their first import of armed UAVs in the past decade and do not show signs of sustained demand.



Source: SIPRI Arms Transfers Database," June 12, 2022, https://www.sipri.org/databases/armstransfers; CSIS analysis.

Figure 6. Top 10 Recipients of UAS and Loitering Munitions Deliveries (SIPRI Arms Transfers Database, 2022; CSIS, n.d.)

Characteristics of Top Importing States

Looking deeper to the top 25 importer countries, this group includes nine larger U.S. treaty allies with advance militaries (including NATO itself, along with the complicated case of Turkey and the possibly frontline South Korea), 10 countries spending an average of 2.65% of their GDP on their militaries between 2000 and 2020 (with India the lowest at 2.69%), and two frontline states, the Philippines (a less wealthy U.S. ally) and Ukraine. Outside of those three groupings, Indonesia, Nigeria, and Egypt—in the number 13, 16, and 19 spots, respectively—are pivotal countries in their respective regions but not as large proportional spenders. Large U.S. treaty allies predominantly bought from Israel or the United States. In the other categories, China and Israel are the largest players, often selling midsize systems like the Heron—though there are exceptions like Ukraine, which primarily imported UAS and loitering munitions from Turkey.

Frontline states also have a distinctive set of needs that may guide their future procurement decisions on UAS, even if they share some traits with other importers. For states prioritizing military spending, UAS may be particularly appealing because of their ability to project presence at a lower cost than crewed counterparts. Frontline states, on the other hand, may be more interested in developing a minimum viable capability that can manage an adversary with more robust counter-UAS capabilities than those Armenia deployed in the Nagorno-Karabakh war. This may lead to needing features like autonomy, which allows systems to operate even if remote control is temporarily disabled, but more broadly raises the importance of the attritability of UAS. This will likely drive those states to purchase lower-end systems (like the TB2) in order to meet their immediate needs. By bifurcating the market, it becomes clear where future demand may exist, demand that will surely create new proliferation concerns for the policy community.

Conclusions

The rapid growth of armed UAS imports, especially in the Middle East and Africa, presents two competing paths forward for UAS export goals. One approach would be to continue arguing for further moves to converge the treatment of UAS with forms of aircraft and ordnance and munitions that the United States more freely exports. This approach does not address concern as to the impact of UAS on nations' willingness to use force and related concerns. Given these challenges, this may be easier for states that are party to the Joint Declaration on UAS, members of the Arms Trade Treaty or MTCR, and those that have a history of abiding by end-use agreements.

Another option would be a heightened focus on frontline nations concerned about great powers, with special attention to Asia and the Pacific.[16] The ability of UAS to substantiate battlefield claims to dominate the information environment may prove relevant during the competition phase with great powers that may otherwise control the narrative.[17] More importantly, the command-and-control support role is inherently high-emission in a way that may be less suitable to low-observability high-end UAS and aircraft inhabited by troops. For these systems to be useful for frontline states, they must be produced in sufficient quantities to tolerate the attrition that comes with targeting by modern integrated

[16] Traditional employment cases for UAS systems have focused on counterinsurgency or low-intensity conflicts. However, as they prove increasing useful in higher-end conflict, and as more capable UAS systems enter the market, that traditional mission set that focused on the Middle East and Africa is evolving as perceived threats also shift toward the Indo-Pacific.

[17] Stories of heroism in wartime can be inherently difficult to verify, but in Ukraine, UAS footage lent credibility to accounts. As one story noted, "not all the details of these claims could be independently verified . . . [but] the huge amount of aerial combat footage published by the Ukrainians underlines the importance of drones to their resistance" (Borger, 2022).

air defenses. This demand could be met by evolving established systems or new technology, but in either case, the export control approach would likely remain similar to legacy systems.

Striking the right balance between unnecessarily proliferating capabilities and ensuring that allies and partners have the systems they need will be the key balancing act going forward. U.S. companies are largely at the whim of how the government decides to navigate these questions of proliferation. While domestic demand may continue to grow alongside new concepts for UAS employment, the future of global demand is likely to be robust as front line states seek to access new capabilities. Navigating these competing interests will certainly prove to be a complex challenge for both industry and government.

References

Air Force. (n.d.). *MQ-9 Reaper*. https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104470/mq-9-reaper/https%3A%2F%2Fwww.af.mil%2FAbout-Us%2FFact-Sheets%2FDisplay%2FArticle%2F104470%2Fmq-9-reaper%2F

Alberque, W. (2021, November 2). *Revitalising arms control: The MTCR and the HCoC*. International Institute for Strategic Studies. https://www.iiss.org/blogs/research-paper/2021/11/revitalising-arms-control-the-mtcr-and-the-hcoc

The ATT | Arms trade treaty. (n.d.). http://www.armstrade.info/the-att/

Baykar. (n.d.). *Bayraktar TB2*. http://www.baykartech.com/en/uav/bayraktar-tb2/

Blom, J. D. (2010). *Unmanned aerial systems: A historical perspective*. Combat Studies Institute Press.

Borger, J. (2022, March 28). The drone operators who halted Russian convoy headed for Kyiv. *The Guardian*. https://www.theguardian.com/world/2022/mar/28/the-drone-operators-who-halted-the-russian-armoured-vehicles-heading-for-kyiv

Bureau of International Security and Nonproliferation. (n.d.). *Missile technology control regime (MTCR) frequently asked questions.* https://www.state.gov/remarks-and-releases-bureau-of-international-security-and-nonproliferation/missile-technology-control-regime-mtcr-frequently-asked-questions/

Bureau of Political-Military Affairs. (2017, October 16). *Joint declaration for the export and subsequent use of armed or strike-enabled unmanned aerial vehicles (UAVs).* U.S. Department of State. https://2017-2021.state.gov/joint-declaration-for-the-export-and-subsequent-use-of-armed-or-strike-enabled-unmanned-aerial-vehicles-uavs/

Code of Federal Regulations. (1993, July 22). *Part 121 - The United States munitions lists*. National Archives. https://www.ecfr.gov/current/title-22/chapter-I/subchapter-M/part-121

Commerce Control List. (n.d.). *Category 9 - Aerospace and propulsion*. Bureau of Industry and Security, U.S. Department of Commerce. https://www.bis.doc.gov/index.php/documents/regulations-docs/2340-ccl9-4/file

Definitions of Terms as Used in the Export Administration Regulations (EAR), 15 C.F.R. 772.1 (2022, July 22). https://www.ecfr.gov/current/title-15/subtitle-B/chapter-VII/subchapter-C/part-772/section-772.1

DoD. (2013). *Unmanned systems integrated roadmap: Fiscal years 2013-2038*. https://digital.library.unt.edu/ark:/67531/metadc949794/

The drone databook. (n.d.). https://dronecenter.bard.edu/projects/drone-proliferation/databook/

The drone databook. (2019, September 25). https://dronecenter.bard.edu/projects/drone-proliferation/databook/

Elbit Systems. (n.d.). *Hermes™ 450*. https://elbitsystems.com/products/uas/hermes-450/

Fabian, E. (2022, July 27). *Israel says IDF's armed drones can now be talked about, unless it's to sell them*. https://www.timesofisrael.com/israel-says-idfs-armed-drones-can-now-be-talked-about-unless-its-to-sell-them/

Federal Register. (2021, January 12). *Change to the license review policy for unmanned aerial systems (UAS) to reflect revised United States UAS export policy*. https://www.federalregister.gov/documents/2021/01/12/2020-27983/change-to-the-license-review-policy-for-unmanned-aerial-systems-uas-to-reflect-revised-united-states

Fuhrmann, M., & Horowitz, M. C. (2017). Droning on: Explaining the proliferation of unmanned aerial vehicles. *International Organization, 71*(2), 397–418. https://doi.org/10.1017/S0020818317000121

General Policies and Provisions, 22 C.F.R. 126 (n.d.). https://www.ecfr.gov/current/title-22/chapter-I/subchapter-M/part-126

Gertler, J., & Zoretich, T. (2022). *World civil unmanned aerial systems: Market profile & forecast 2022/2023*. Teal Group. https://shop.tealgroup.com/products/wcuav

Gettinger, D., Michel, A., & Keenan, T. (n.d.). *The drone databook*. Bard University. https://dronecenter.bard.edu/projects/drone-proliferation/databook/

Hall, A. R., & Coyne, C. J. (2014, September 3). The political economy of drones. *Defense and Peace Economics, 25*(5), 445–60. https://doi.org/10.1080/10242694.2013.833369
Israel Aerospace Industries. (n.d.). *MALE UAV: The Heron TP is a multi role, advanced, long range UAS*. https://www.iai.co.il/p/heron-tp
Keating, E. G., Kerman, J., & Arthur, D. (2021, June 1). *Usage patterns and costs of unmanned aerial systems*.
Kimball, D. G. (2020, September). *U.S. reinterprets MTCR rules*. Arms Control Association. https://www.armscontrol.org/act/2020-09/news/us-reinterprets-mtcr-rules
Maritime security dialogue: A discussion with the assistant commandant of the Marine Corps. (2022). https://www.youtube.com/watch?v=-XZwtMBwrYo
Miller, J. (2013, August 19). Strategic significance of drone operations for warfare. *International Relations*, *13*.
Missile Techonology Control Regime. (n.d.). *Equipment, software and technology annex – MTCR*. https://mtcr.info/mtcr-annex/
Northrop Grumman. (n.d.). *Global Hawk*. https://www.northropgrumman.com/what-we-do/air/global-hawk
NTI. (n.d.). *Arms trade treaty (ATT)*. The Nuclear Threat Initiative. https://live-nuclear-threat-initiative.pantheonsite.io/education-center/treaties-and-regimes/arms-trade-treaty-att/
OE Data Integration Network (TRADOC). (n.d.). *Wing Loong II Chinese medium-altitude long endurance (MALE) unmanned aerial vehicle (UAV) - WEG MediaWiki*. https://odin.tradoc.army.mil/mediawiki/index.php/Wing_Loong_II_Chinese_Medium-Altitude_Long_Endurance_(MALE)_Unmanned_Aerial_Vehicle_(UAV)
Office of the Spokesperson, U.S. Department of State. (2015, February 17). *U.S. export policy for military unmanned aerial systems*. https://2009-2017.state.gov/r/pa/prs/ps/2015/02/237541.htm
Office of the Under Secretary of Defense for Acquisition and Sustainment. (2022, February). *State of competition within the defense industrial base*. Department of Defense. https://media.defense.gov/2022/Feb/15/2002939087/-1/-1/1/STATE-OF-COMPETITION-WITHIN-THE-DEFENSE-INDUSTRIAL-BASE.PDF
O'Rourke, R. (2020, May 29). *Renewed great power competition: Implications for defense—Issues for Congress*.
Performance Assessments and Root Cause Analyses. (2018). *Unmanned systems integrated roadmap 2017-2042*. Office of the Assistant Secretary of Defense for Acquisition. https://news.usni.org/2018/08/30/pentagon-unmanned-systems-integrated-roadmap-2017-2042
Sabbagh, D., & McKernan, B. (2019, November 27). Revealed: How UK technology fuelled Turkey's rise to global drone power. *The Guardian*. https://www.theguardian.com/news/2019/nov/27/revealed-uk-technology-turkey-rise-global-drone-power
Sanders, G., Jang, W. J., & Holderness, A. (2022, March 29). *Defense acquisition trends 2021*. https://www.csis.org/analysis/defense-acquisition-trends-2021
Schneider, W. (2020, August 6). *Modernizing the missile technology control regime*. http://www.hudson.org/research/16293-modernizing-the-missile-technology-control-regime
SIPRI arms transfer database. (2022, June 12). https://www.sipri.org/databases/armstransfers
Stohl, R., & Dick, S. (2018, August). *The arms trade treaty and drones*. Stimson Center. https://www.stimson.org/2018/arms-trade-treaty-and-drones/
Strickland, F. (2013). *The early evolution of the Predator drone*, *57*(1), 6.
Study on armed unmanned aerial vehicles – UNODA. (n.d.). https://www.un.org/disarmament/publications/more/drones-study/
Tirpak, J. (2021, July 22). Secret Global Hawk successor due in 2027-2029. *Air Force Magazine*. https://www.airforcemag.com/secret-global-hawk-successor-due-in-2027-2029/
Trotti, C. (2022, May 16). *Swarming to victory: Drones and the future of great power competition*. The Center for the National Interest. https://nationalinterest.org/blog/techland-when-great-power-competition-meets-digital-world/swarming-victory-drones-and-future
U.S. policy on the export of unmanned aerial systems. (2019, May 21). https://2017-2021.state.gov/u-s-policy-on-the-export-of-unmanned-aerial-systems-2/
Van Ham, P. (2017). *The MTCR at 30: Ideas to strengthen the missile technology control norm*. Clingendael Institute. https://www.jstor.org/stable/resrep17354
Wezeman, P. D., Kuimova, A., & Smith, J. (2021, April 30). *Arms transfers to conflict zones: The case of Nagorno-Karabakh*. SIPRI. https://www.sipri.org/commentary/topical-backgrounder/2021/arms-transfers-conflict-zones-case-nagorno-karabakh
Work, B. (2015, November 7). *The third offset strategy* [Presented at the Reagan Defense Forum, Ronald Reagan Presidential Foundation and Institute]. https://www.defense.gov/News/Speeches/Speech/Article/628246/reagan-defense-forum-the-third-offset-strategy
Zaloga, S. J., Rockwell, D., & Zoretich, T. (2022). *World military unmanned aerial systems: 2022/2023 market profile & forecast*. Teal Group. https://shop.tealgroup.com/products/wmuav

Improving Precommissioning Assignments and Readiness on the U.S. Coast Guard Offshore Patrol Cutter

Jennifer Lamping Lewis—is a Senior Economist at the RAND Corporation and a member of the Pardee RAND Graduate School faculty. She has applied her expertise in game theory, market design, auctions and procurement competitions, and statistical analysis to a variety of issues in defense acquisition and workforce management. Her acquisition work includes the development of a dynamic procurement model that simulates competition among defense contractors over time, an assessment of multiphase competition in the procurement of surface vessels, an analysis of joint approaches to acquiring counter-unmanned aircraft systems (C-UAS), and a study of strategic investment for discovering and developing counter-IED capabilities. Her workforce management work includes an evaluation of a pay-for-performance pilot program for civilian personnel in the acquisition workforce, the development of a forecasting model of civilian deployment, and a study of the effects of a proposed extension to military tour lengths. Lewis formerly served as the Associate Director of RAND's Forces and Resources Policy Center. Prior to joining RAND, she spent 6 years on the faculty of the University of Colorado at Boulder. Lewis received her doctorate in economics from Columbia University and a bachelor's degree in economics from Princeton University. [jlamping@rand.org]

Aaron C. Davenport—is a Senior Researcher at the RAND Corporation and an Associate Director of the Infrastructure, Immigration, and Security Operations (IISO) Program, part of the RAND Homeland Security Research Division (HSRD). Davenport retired as a senior officer in the U.S. Coast Guard. His final assignment was Chief of Cutter Forces for a fleet of 250 ships and 8,500 seagoing personnel. He also served as founding Deputy Chief, USCG Office of Counter-Terrorism and Special Missions, and Executive Officer, Counterdrug Operations, U.S. Southern Command. Davenport's sea duty includes six ships and command of two large cutters, enforcing international treaties, international immigration and trafficking laws, and performing institutional security governance and capacity building assistance, humanitarian assistance, and joint maritime operations throughout the Pacific, Atlantic, Caribbean, and Bering Sea. He was also detailed to the White House Staff as Special Advisor for Homeland Security and Counterterrorism for two administrations (Obama/Bush). Davenport received his master's degree in environmental sciences from the Fielding School of Public Health, University of California, Los Angeles and a bachelor's degree in marine sciences from the U.S. Coast Guard Academy. [aarond@rand.org]

Brynn Tannehill—is a Technical Analyst at the RAND Corporation. She did four deployments to the U.S. Central Command area of responsibility between 2000 and 2006 as a SH-60B Pilot, P-3C Pilot, and Campaign Analyst. In 2008, she began working in private industry on projects such as autonomous collision avoidance systems for BAMS and Global Hawk, modeling future unmanned aerial vehicle control systems, and designing adaptive, dynamic scenario generation for F-16 pilots with the 711th HPW/RHA at Wright–Patterson Air Force Base. While at RAND, Tannehill has contributed to projects involving cybersecurity, Army aviation, Marine Corps aviation, Marine Corps medical capabilities, process modeling, unmanned undersea vehicles, unmanned surface vehicles, agile acquisition, cost validation, and Navy manpower. Tannehill received her master's degree in operations research from the Air Force Institute of Technology and a bachelor's degree in computer science from the U.S. Naval Academy.

Austin Lewis—is a Reliability Engineer at Apple. Prior to joining Apple, he was a Research Assistant at the RAND Corporation, where he worked on a number of projects related to acquisition practices and the implementation of policies across the acquisition process for the U.S. Coast Guard and other services. Lewis received his doctorate in reliability engineering from the University of Maryland and a bachelor's degree in chemical engineering from Stanford University.

James V. Marrone—is an Economist at RAND Corporation. He is primarily a methodologist, using a variety of statistical methods to conduct causal inference for national security research. Major topical focuses are military families and young servicemembers, counter-extremism and disinformation, and cultural heritage in disaster and conflict zones. Recent examples of research projects include quasi-experimental analyses of military attrition, experimental and theoretical analyses of Russian online

disinformation tactics, and the development of scalable methods to assess damage to historic and archaeological sites. Marrone was on temporary detail at the Consumer Financial Protection Bureau's Office of Servicemember Affairs in 2020, and he is also an Adjunct Professor of Economics at Johns Hopkins University School of Advanced International Studies. Marrone received his doctorate in economics from the University of Chicago, a master's degree in economics from Universitat Pompeu Fabra, and bachelor's degrees in mathematics and physics from the University of Chicago.

Victoria M. Smith—was a Research Assistant at the RAND Corporation, where she focused on modeling, cost estimation, and emerging technologies. Prior to joining RAND, Smith was a Research Assistant with the Technology and Policy Research Initiative at the Boston University School of Law, where she researched the effects of technology on society. Smith received her bachelor's degree in economics and international relations from Boston University.

Barbara Bicksler—is a Communications Analyst at the RAND Corporation, working primarily in the National Security Research Division and Project AIR FORCE. She has extensive experience integrating research results into reports and presentations for senior officials in the Department of Defense, Congress, and other government agencies. Her experience covers directing, managing, and participating in multidisciplinary study teams. Bicksler received her master's degree in public policy from the John F. Kennedy School of Government, Harvard University, and a bachelor's degree in economics from James Madison University.

Abstract

As the first of 25 offshore patrol cutters (OPCs) nears delivery, the U.S. Coast Guard (USCG) is focusing greater attention on the staffing needs of these ships, particularly during the precommissioning period. USCG leadership believes that crew satisfaction with these assignments is low and that this has implications for force readiness. In addition, the USCG has limited return on its training investment if crew members leave the service or return to shore duty soon after their precommissioning assignments. Thus, increasing institutional knowledge is also a priority.

Researchers evaluated 11 courses of action (COAs) that the USCG could consider to improve crew satisfaction with precommissioning assignments and overall fleet readiness—the first being the status quo precommissioning process. Of the remaining 10 COAs, five would delay crew reporting; three would develop expertise, facilitate the sharing of best practices across OPC crews, and promote standardization; and two would adjust personnel assignment and compensation policies.

Although some COAs are mutually exclusive, others could be combined to address a broader set of problems or more effectively address a single issue. The most appropriate combination depends on how the USCG prioritizes the various evaluation criteria. One way forward would be for the USCG to adopt an incremental approach: Implement some of the more-feasible COAs in the short term while working toward some of the higher-impact COAs over the long term.

This executive summary presents the key findings of this research. A more detailed account of the research methods and findings can be found in Improving Precommissioning Assignments and Readiness on the U.S. Coast Guard Offshore Patrol Cutter, by Jennifer Lamping Lewis, Aaron C. Davenport, Brynn Tannehill, Austin Lewis, James V. Marrone, Victoria M. Smith, and Barbara Bicksler, RR-A1617-1, 2022 (www.rand.org/pubs/research_reports/RRA1617-1.html).

This research was sponsored by the U.S. Coast Guard and conducted within the Strategy, Policy, and Operations Program of the Homeland Security Operational Analysis Center federally funded research and development center. Comments or questions should be addressed to the project leaders, Jennifer Lamping Lewis, at jlamping@rand.org and Aaron C. Davenport, at aarond@rand.org.

Executive Summary

As the first of 25 offshore patrol cutters (OPCs) nears delivery, the U.S. Coast Guard (USCG) is focusing greater attention on the staffing needs of these ships, particularly during the precommissioning (PRECOM) period. USCG leadership believes that crew satisfaction with these assignments is low and that this has implications for force readiness. In addition, because of the timing of crew training and rotations, the USCG has limited return on its training investment if crew members leave the service or return to shore duty soon after their PRECOM assignments. Thus, increasing institutional knowledge is also a priority.

The USCG is interested in strategies to improve the desirability of assignment to a precommissioned cutter and retain top talent within the major-cutter community. To assist the USCG, researchers from the Homeland Security Operational Analysis Center, in collaboration with the Major Cutter Post-Delivery Modernization Tiger Team, developed and evaluated options that the USCG could consider to improve crew satisfaction with PRECOM assignments and overall fleet readiness. This work was based on a review of relevant documents and literature, interviews with subject-matter experts throughout the USCG and at the prime contractor, and analysis of personnel data.

Courses of Action

The research team and the USCG developed 11 courses of action (COAs)—the first being the status quo PRECOM process. The remaining 10 COAs take varied approaches to improving crew satisfaction, ensuring that crews are adequately prepared for operational patrols, promoting the transfer of knowledge from crew to crew, and achieving standardization across the fleet.

Some COAs would delay crew reporting, thereby shaving 10 to 15 months off the time crews would spend on activities that precede operational readiness of the vessel. In most cases, this would require a reorganization of PRECOM activities and a reassignment of some of these activities to other parties, such as a preliminary crew assembly facility (PCAF), contracted mariners, or the shipbuilder. Delayed reporting would allow the crew to spend fewer days in port performing postdelivery installations and tests and more days underway participating in operational patrols. The COAs that fall into this category are

COA 2: expanded PCAF

COA 3: further expanded PCAF for training and home port transit

COA 4: contracted mariner crew

COA 5: cutter delivery at home port

COA 6: more than two crew reporting phases.

Other COAs would focus more on developing expertise, sharing best practices across crews, and promoting standardization. The requisite transfer of knowledge could occur across multiple hulls or within a single hull. The former could be achieved by establishing a cadre that performs postdelivery installations and other PRECOM activities on multiple hulls. The latter could be achieved by varying tour lengths or staggering crew reporting dates such that veteran crew members overlap with newly assigned personnel on a single hull. The COAs that share this orientation are

COA 7: operational centers of excellence (a hub-and-spoke model)

COA 8: voluntary tour extensions

COA 9: phased crewing across OPC hulls.

The two remaining COAs would preserve the current PRECOM process and schedule but adjust personnel assignment and compensation policies to (1) select those service members who find PRECOM assignments more desirable and (2) use incentive pay to compensate them appropriately for any remaining dissatisfaction. These COAs are

COA 10: targeted incentive pays

COA 11: bidding for assignment incentive pay.

Table 1 maps the full set of COAs to the problems associated with the current PRECOM process, as detailed in an October 2020 issue paper prepared by the Deputy Commandant for Operations, Office of Cutter Forces (CG-751; Office of Cutter Forces, 2020). The column for COA 1 is empty because it represents the status quo. A check mark indicates that the COA would address the problem in that row.

Course-of-Action Evaluation

To evaluate the COAs, we developed a broad set of criteria that reflect the concerns expressed by the study sponsor and members of the Major Cutter Post-Delivery Modernization Tiger Team. We grouped these criteria into five classes:

crew satisfaction

crew preparation and knowledge retention

timeliness

feasibility or ease of implementation

cost.

Because the available quantitative data were sparse, the evaluation was largely qualitative. For each COA, we identified the potential benefits and drawbacks within each of the five criterion classes, but, in many cases, we could not quantify the benefits and drawbacks or their associated probabilities. Nevertheless, the information gleaned from the event and timeline analyses, personnel data analysis, literature review, and case studies was sufficient to identify which COAs are likeliest to achieve the USCG's goals within each of the five criterion classes.

Table 1. Alignment of Courses of Action with Identified Problems

	COA										
	Status Quo	Delayed Crew Reporting					Developing Institutional Knowledge			Incentive Pays	
Problem	1	2	3	4	5	6	7	8	9	10	11
Precommissioning assignments are not desirable.											
No sea pay or sea time										✓	✓
More than 180 days on temporary duty		✓	✓	✓	✓	✓				✓	✓
No basic-allowance-for-housing protection										✓	✓
Postdelivery activities and ready-for-operations workload significant		✓	✓	✓	✓					✓	✓
Phase I crews unable to attend special events		✓	✓	✓	✓	✓		✓		✓	✓
Minimal operations for officers with 2-year tours		✓	✓	✓	✓	✓		✓		✓	✓
The crew is not adequately prepared, and the fleet lacks standardization.											
Investments in factory and familiarization training not realized		✓	✓	✓	✓	✓		✓			
Loss of institutional knowledge and lack of standardization		✓	✓	✓			✓	✓	✓		
First underway periods are high risk			✓						✓		

NOTE: ✓ = the COA would address the problem indicated. The COAs are as follows:
1 = the current PRECOM process
2 = expanded PCAF
3 = further expanded PCAF for training and home port transit
4 = contracted mariner crew
5 = cutter delivery at home port
6 = more than two crew reporting phases
7 = operational centers of excellence (a hub-and-spoke model)
8 = voluntary tour extensions
9 = phased crewing across OPC hulls
10 = targeted incentive pays
11 = bidding for assignment incentive pay.

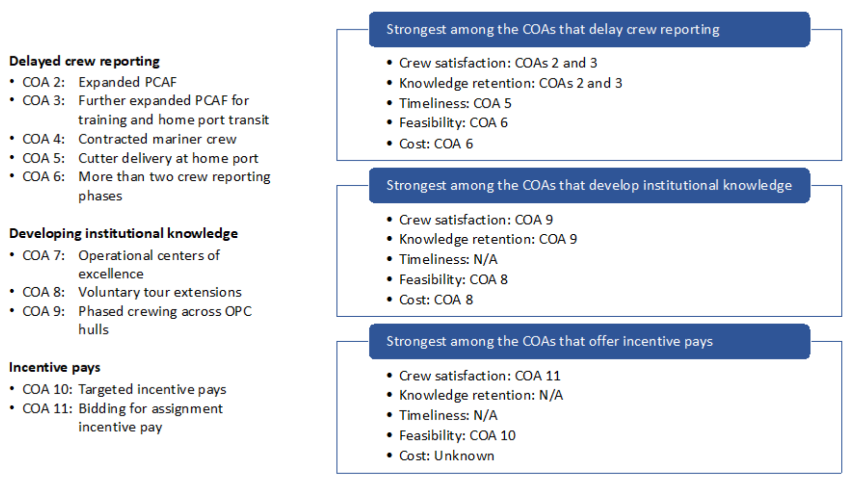
We found that, among the five COAs that would delay crew reporting, COAs 2 and 3 (expanded PCAF and further expanded PCAF) are strongest on crew satisfaction and the transfer of knowledge, COA 5 (cutter delivery at home port) is strongest on timeliness, and COA 6 (more than two crew reporting phases) is strongest on feasibility and cost.

Among the three COAs that center on developing institutional knowledge, COA 9 (phased crewing across OPC hulls) is strongest on crew satisfaction and the transfer of knowledge, and COA 8 (voluntary tour extensions) is strongest on feasibility and cost. None of the COAs would improve timeliness by a meaningful margin.

Between the two remaining COAs, which focus on incentive pay, COA 11 (bidding for assignment incentive pay) is stronger on crew satisfaction, and COA 10 (targeted incentive pays) is stronger on feasibility. Neither COA would affect timeliness or the transfer of knowledge from crew to crew. Both COAs would have cost implications, but it is not clear which one would be more cost-effective. Figure 1 summarizes these findings.

Although some COAs are mutually exclusive, others could be combined to address a broader set of problems or more effectively address a single issue. The most appropriate combination depends on how the USCG prioritizes the various evaluation criteria. Many of the COAs present a trade-off between (1) improvements in crew satisfaction and knowledge transfer and (2) ease of implementation (feasibility) and affordability (cost). One way forward would be for the USCG to adopt an incremental approach: Implement some of the more-feasible COAs in the short term while working toward some of the higher-impact COAs over the long term.

In this report, we do not recommend a specific COA; instead, we provide the USCG with an array of options, the information necessary to identify those options that align best with the service's priorities, and a structure for combining the selected options to address a broader set of problems or more effectively address a single issue. The discussion provided in this report is aimed at informing the USCG's decisions. These include updates to the OPC operating facility change order, vessel acceptance procedures, and deployment plan, as well as assignment policies and practices for the crew of the third OPC hull, the USCG Cutter *Ingham* (WMSM-917), and following vessels.[1]



Note. COA = course of action, N/A = not applicable. "Unknown" indicates that the study team did not have enough information to identify the strongest COA.

Figure 1. Course-of-Action Evaluation, by Criterion Class, Within Course-of-Action Group

References

Office of Cutter Forces, Assistant Commandant for Capability, Deputy Commandant for Operations. (2020, October 30). Issue paper: Major cutter post delivery modernization. U.S. Coast Guard.

[1] A WMSM is a maritime security cutter, medium.

Economic Tradeoff Analysis of a Product Line Architecture Approach Through Model-Based Systems Engineering: A Case Study of Future Mine Countermeasures Unmanned Underwater Vehicles (UUV)

LCDR Joao Franklin Alves (Brazilian Navy)—is NPS Alumni. He was born in Rio de Janeiro, completed his undergraduate studies in Naval Sciences at the Brazilian Navy Academy (2010), and obtained his master's degree in Systems Acquisition Management last summer. His research interests include life cycle management of defense systems, systems tradeoff and affordability analysis, product line architecture and model-based systems engineering approach, defense acquisition process, systems engineering and program management integration, and total life cycle costs. [jfranklinsbpa@gmail.com]

Abstract

The defense sector often develops systems to operate for at least 15 years, which can reach 40 or even 50 years. Those systems tend to be cheaper, more rapidly developed, and reliable when developed on product lines (PL). Product line architecture surges with potential to improve the acquisition process, resulting in a more rapid insertion of cost-effective warfighting capabilities. This research investigates the impact of the PL approach by analyzing the future generation of mine countermeasure (MCM) unmanned underwater vehicle (UUV) architecture alternatives, employing a detailed reuse model based on COPLIMO framework. The research integrates parametric cost modeling with model-based systems engineering (MBSE), feeding the existing baseline knowledge regarding PL architecture. Furthermore, this can improve systems acquisition processes, deliver more agile capability, and reduce total life cycle costs (LCC). The integration of models highlights significant differences among the architectural variations considered early in the acquisition process before substantial financial commitments. Early decisions determine most of the total LCC and establish a baseline for long-term system performance. Hence, the choice of favorable design alternatives is crucial to program success. The results demonstrate that up-front investments in product lines generate a significant return on investment (ROI).

Introduction

In summary, this study evaluates how investing in a product line approach can benefit acquisitions of defense systems, reducing the total life-cycle costs (LCC). The research also highlights the importance of unmanned systems for mine countermeasures (MCM) operations, especially unmanned underwater vehicles (UUV), exploring them as the object of the study.

Deshmukh et al. (2010) state that several costs may be involved in developing product lines. The foremost step is identifying similar characteristics (commonalities) and variabilities. Creating reusable components requires a certain degree of up-front investment, which later can generate savings from a family of a systems perspective. In this context, it is possible to estimate the effort/cost through parametric tools in order to develop components with a certain degree of reuse and adaptability. The first does not require variations among systems, characterized as a black-box, and the second would be subject to adaptation that needs to be reused, being called adapted.

This research assesses the possible benefits of reusing components in a family of systems compared to the investments needed to develop individual stovepipe systems. Although the reuse-driven investments approach was initially more used for software-intensive systems, some authors have demonstrated that it can be used for hardware-intensive systems with the same effectiveness (Deshmukh et al., 2010; Hall, 2018). The systems engineering process enables identifying similarities among products to develop reusable infrastructure and components. In this way, initial projects will likely increase their timelines and costs. On the other hand, the later products of this product line may have their schedules and costs significantly reduced through the reuse of components, in addition to having a simpler integration (Deshmukh et al., 2010).

The product line (PL) approach is evaluated in this research across the integration of parametric cost modeling within the model-based systems engineering (MBSE) approach. A modeling framework based on the Constructive Product Line Investment Model (COPLIMO; Boehm et al., 2004) may enable the systems acquisition community to analyze an economic tradeoff during the earlier systems design phase, exploring the possible return on investment (ROI). Thus, this analysis demonstrates the relevance of a PL architecture approach through an economic tradeoff analysis in terms of commonality and variability of the future MCM UUVs.

Research Questions

The research investigates the potential benefits of enlarging the product line architecture approach through the systems engineering process of future alternatives for MCM UUVs. This study consists of an approach that employs parametric cost modeling, some empirical data collection from recent research, and the demonstration of MBSE approach to assessing economic savings through systems product line architecture. Then, answering the questions below contributes to the achievement of this objective:

- Can the product line architecture approach benefit the development of the next-generation MCM UUVs designs instead of using non-reusable systems/components?
- Can potential technological changes/solutions be used as performance drivers in the analysis of MCM UUVs product line architecture?
- How can the OVM contribute to the product line strategy?
- How can the product line approach be integrated into a parametric cost model in order to conduct a cost analysis and ROI assessment of MCM UUVs?
- What is the potential ROI for applying a product line architecture when developing MCM UUVs?

Background And Literature Review

Throughout recent years, the U.S. Navy conducted studies and found that unmanned maritime systems (UMS) are crucial to face contemporary and expected threats. Through the Unmanned Campaign Framework (U.S. Navy, 2021) issuance, the DoD established priorities in developing and deploying diverse unmanned vehicles designed to complement the current makeup of its naval assets. The document highlights that it is essential to aggregate systems acquisition management and technical capabilities to accelerate the development, testing, and production of effective unmanned systems.

In parallel to this unmanned development effort, the DoD released its Digital Engineering Strategy (DoD, 2018), which established relevant goals to create a paradigm shift for how the DoD has to manage its systems across the transition to a Digital Engineering (DE) environment. The MBSE methodology is a core aspect of digitalizing the systems engineering process (SEP), enabling researchers to conduct systems analysis and cost estimations when architecting and modeling complex systems. The SEP has a crucial role during the system life cycle since requirements, earlier architecture, and the design phase, widely known as the pre-conceptual phase, often compromise more than 80% of the total LCC. The system's development will determine the following production and operation and sustainment (O&S) costs, as illustrated in Figure 1.

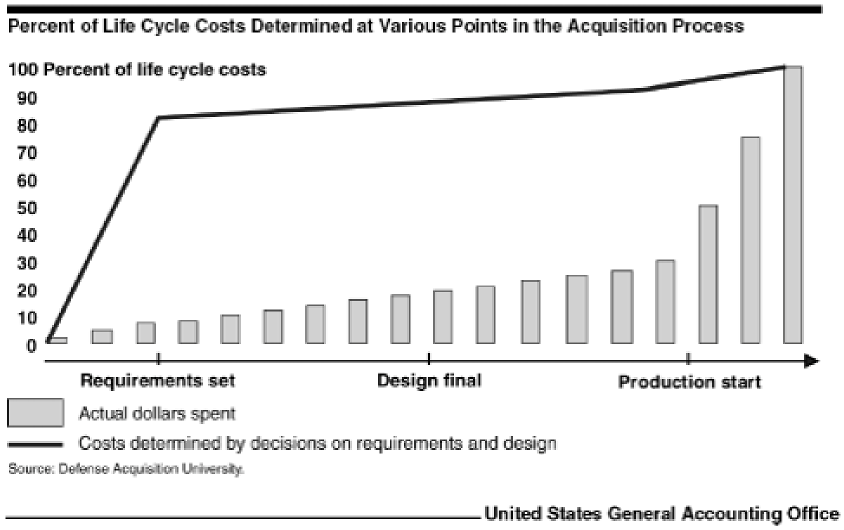


Figure 1. Cost Commitment Throughout the Life Cycle. (Schinasi, 2003).

Recent research (Chance, 2019; Fraine et al., 2019; Hall, 2018) found that developing hardware and software components to be reused in different programs through a portfolio approach results a great potential for savings. That occurs not only across the developmental phase (RDT&E) but also during the following system life cycle phases. Furthermore, commonality also has the potential to impact systems suitability aspects such as system reliability, usability, supportability, maintainability, and training, potentially reducing future O&S costs of naval assets.

From the integration of systems engineering and program management perspectives, this study explores the relevance of a product line engineering (PLE) approach across an economic tradeoff analysis regarding commonality aspects of future MCM UUVs. Previous studies conducted by Hall (2018), Chance (2019), and Fraine et al. (2019) have already demonstrated how the product line architecture has great potential to bring significant economic results in comparison to a one-off approach. Unlike PL architecture, one-off approach does not consider commonalities and variabilities through the pre-conceptual phase of complex systems, thus promoting an isolated development process, resulting in redundant development efforts, adding extra costs. From this perspective, Madachy and Green (2022) state the importance of applying PL approach during the earlier design phase when architecting and developing systems.

Product Line Approach—Product Line Engineering (PLE)

Pohl et al. (2005) remember that the earlier concept of the production line came from the automotive industry, specifically by Henry Ford, enabling mass production for a great demand cheaper than unique system production. In spite of that, it lowered the chances of diversity across the products, meaning that all consumers used to purchase rigidly the same item.

As people developed different car demands after the Model T (Ford Co.) boom, the automobile industry faced high demand for personalized products. From that period, the "mass customi[z]ation" concept surged. According to Pohl et al. (2005, p. 4), the term means "taking into account the customers' requirements and giving them what they wanted."

Further, the industry developed the platform concept, seen as a technology baseline for other advances or processes that have been built. Through this process, the automotive industry developed common platforms for different car models, decreasing the production cost for a specific model.

Pohl et al. (2005) also highlight many motivations for the PLE approach. They suggest the existence of a break-even point in terms of ROI, which in software engineering can be reached around the third system developed under a PLE approach (Figure 2). An individualized cost drop is achieved when software or hardware components are reused across different systems. Up-front investment is necessary to generate a common platform (Pohl et al., 2005) that will further cause cost reduction through the successively produced systems.

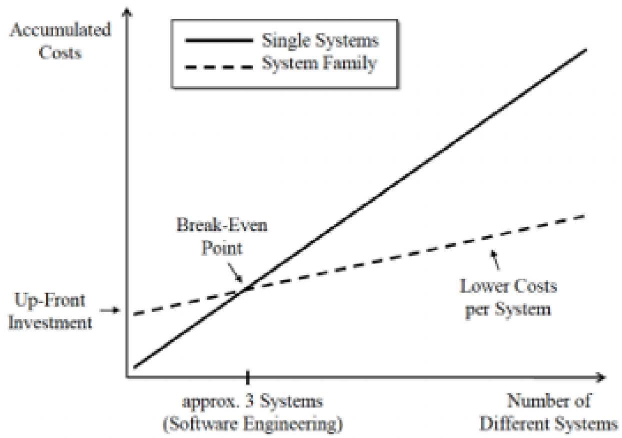


Figure 2. Costs For Developing Kinds of Systems as Single Systems Compared to Product Line Engineering.
(Pohl et al., 2005).

The core objective is to generate customized systems at reasonable costs under a portfolio approach, by which relative cost savings are even higher (Haller et al., 2022). Applying PLE to the architecture and design of the next-generation MCM UUV systems can form a system baseline. Further, it can reduce the individualized costs by reuse and consequently enhance the decision-making through a portfolio approach. From that perspective, the government and contractors should invest in developing a certain amount of components for reuse when dealing with defense systems acquisition; in opposite to developing systems independently in silos, which would also mean more cost in future maintenance efforts (Pohl et al., 2005) and consequently through the O&S phase.

Pohl et al. (2005) contrast the idea of the PL approach with the single system engineering approach, in which the components are developed individually and isolated. According to them, the core strategy to develop a product line is thinking about commonality first and variabilities further. It is possible creating a common platform by developing reusable components followed by identification of the elements that have to be unique.

Methodology

Using the systems engineering approach and the Orthogonal Variability Model (OVM; Pohl et al., 2005), this study capture variability and commonality obtained from six alternative functional architectures previously detailed by Camacho et al. (2017) through MBSE. This way, the baseline of this research's methodology is considering those alternatives as system architecture for the analysis since the authors focused on their performance assessment and did not explore economic tradeoff analysis. Then, regarding the functional architecture decomposed by Camacho et al. (2017) is possible to identify components and/or set of components using the OVM described by Pohl et al. (2005). After that, this study estimates the expected reuse category (reused, adapted, and mission unique) percentages of the MCM UUVs' components/set of components across the identification of variations and variation points from the product line OVM.

Further, those expected reuse category percentages represent parametric inputs to the cost model based on COPLIMO to support the approach's ROI analysis and consequently enhance the decision-making process during the earlier architecture and design phases, when adopting a portfolio approach to manage the next-generation MCM UUVs programs. This economic analysis of the product line architecture approach through the integration of MBSE approach and a parametric cost modeling enables the assessment of potential cost savings across the system life cycle, even investing about 70% (basic COPLIMO standard) more during the development of the system baseline. This way, the life cycle cost of the portfolio (family of systems) can be reduced by integrating different systems that, although they demand distinct capabilities, share similar operations objectives and capabilities. Figure 3 summarizes the main steps of this study's methodology.

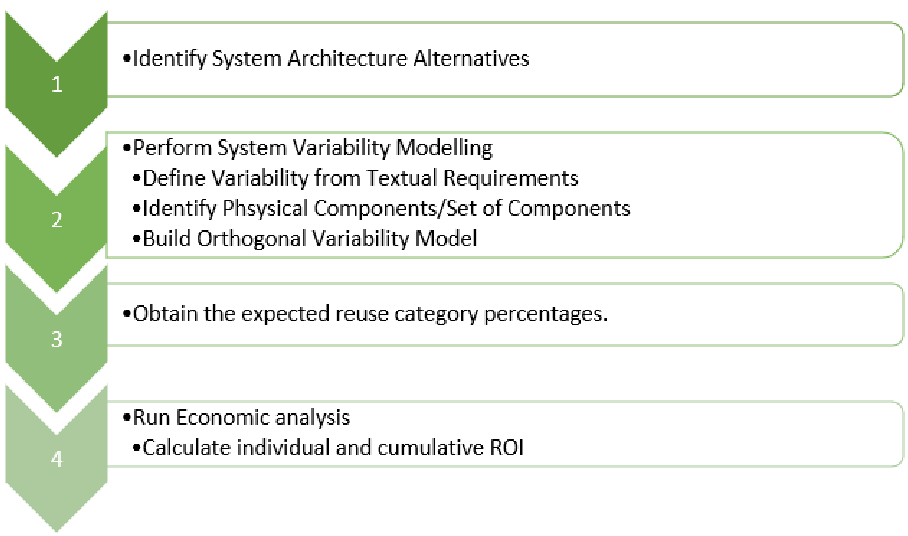


Figure 3. Process to Determining ROI Through a Product Line Approach

Identifying System Architecture Alternatives

The NWP 3-15 Mine Warfare Doctrine (DoN, 1996) primarily classifies MCM into two broad groups: offensive (proactive) and defensive (enabling). The offensive MCM has a preventive characteristic as opposed to the defensive MCM, which has the characteristic of cleaning an already mined site.

Figure 4 depicts the MIW functional decomposition from the DoN mine warfare doctrine. This diagram demonstrates a progressive perspective of the MCM (1.2) process as a subdivision of the MIW (1.0). Then, the MCM is divided into offensive and defensive, decomposed into passive and active. The active MCM currently employs UUVs predominantly in mine hunting operations.

Camacho et al. (2017) demonstrates that the first step of a common mine hunting CONOPS is the decision to perform that. The sequence of events considered begins with the MCM mission planning. After the planning is ready, the mission effectively starts with the unmanned vehicle launch from a host vessel, which navigates to the MDA. Then, it runs sorties until it is picked up by the launch/recovery platform. Finally, the post mission analysis (PMA) is conducted. The detailed mine hunting functional decomposition can be observed in Figure 5.

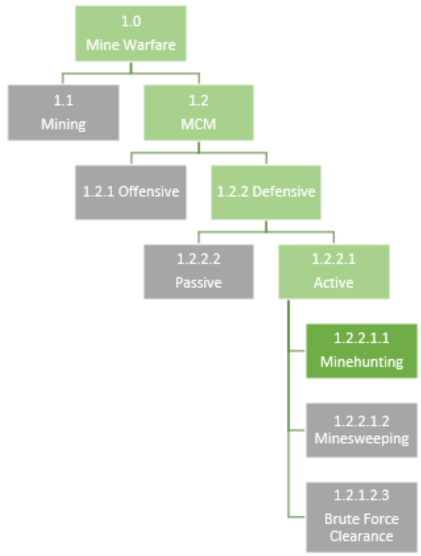


Figure 4. MIW Functional Decomposition Diagram. (DoN, 1996).

Figure 5. Mine Hunting Functional Decomposition Diagram. (DoN, 1996).

The PLE approach and open architecture guide this study to achieve a common system design (baseline) for the next-generation MCM UUVs to obtain potential savings in their total life cycle costs. Two potential technological changes/solutions identified by Camacho et al. (2017) are used as core performance drivers to the MCM UUVs' concept of operations, "data processing location" and "communications cadence," which were combined by the authors using MBSE tools, generating six potential architecture alternatives described in Table 1.

Table 1. Alternative Functional Architectures.
(Camacho et al., 2017).

		Communications Cadence		
		No Communication (NC)	**Intermittent Communication** (IC)	**Constant Communication** (CC)
Data Processing Location	Off-board UUV	Alternative 1. Post-Mission Analysis [Status Quo]	Alternative 2. IC with Off-board Data Analysis	Alternative 3. CC with Off-board Data Analysis
	On-board UUV	Alternative 4. RTA with Physical Transfer of MILECs	Alternative 5. RTA with IC of MILECs	Alternative 6. RTA with CC of MILECs

Alternative 1 (NC and Off-board data processing) was chosen as the baseline architecture for the next-generation MCM UUV. It is characterized by the absence of remote communication capability and the absence of on-board data processing capacity. This architecture was the status quo technology when Camacho et al. (2017) conducted their performance-focused research. The other alternatives comprise the proposed product line combining two main subsystems' capabilities, communications cadence and data processing location. Each alternative will guide the identification and assessment of components in the OVM from the requirements analysis.

Further, the authors developed a functional hierarchy using the Innoslate (SPEC Innovations, n.d.), a MBSE tool that catches the core aspects and behavior needed for the systems. The functional decomposition starts at the highest level (Figure 6). It then goes to the most detailed level that captures the variations among the proposed communication alternatives and the different data processing methods. The processes required throughout the system life cycle are represented in Figure 7.

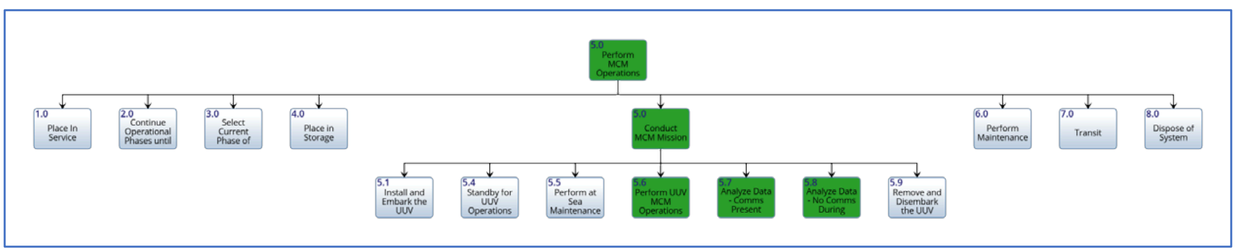


Figure 6. Functional Hierarchy.
(Camacho et al., 2017)

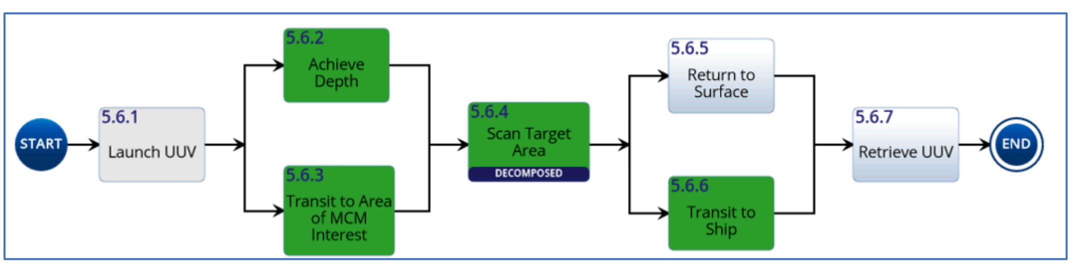


Figure 7. 5.6 Perform UUV MCM Operations.
(Camacho et al, 2017).

The execution steps of the UUV MCM operations considered for this research development were those previously determined by Camacho et al. (2017). The UUV hypothetically operates far from a host ship when performing them. In this way, UUV launch and retrieve would occur from this. For the efficient execution of the function, it is also essential to consider the transit to and from the minefield and the reach of the desired depth for hunting the mines and their return. As well as Camacho et al. (2017), this study focuses on the functions performed in the minefield. Thus, five central subsystems directly related to the 5.6 functions are considered: communication cadence, data processing location, locomotion, navigation, and sensors–data collection. Along this, it is possible to evaluate internal and external data processing architectures and three communication cadences, as previously described in Table 2. The key factor in classifying these communication functions is related to the data. When processed on board, they are considered mine echo (MILEC), being called raw data when this processing does not occur onboard

Figures 8 and 9 depict the functional progress considering the availability or not of the technologies proposed as the game changer for the shape of alternatives proposed by the authors. They suggest that the IC is performed when the UUV reaches the surface to communicate. On the other hand, CC is constantly performed underwater through acoustic communication methods.

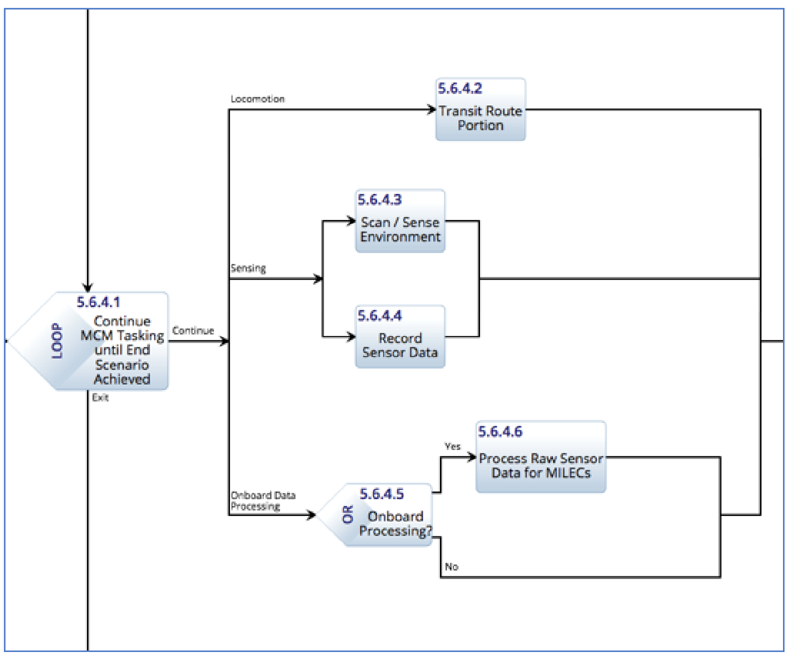


Figure 8. 5.6.4 Scan Target Area–Sensor Data Collection Portion. (Camacho et al., 2017).

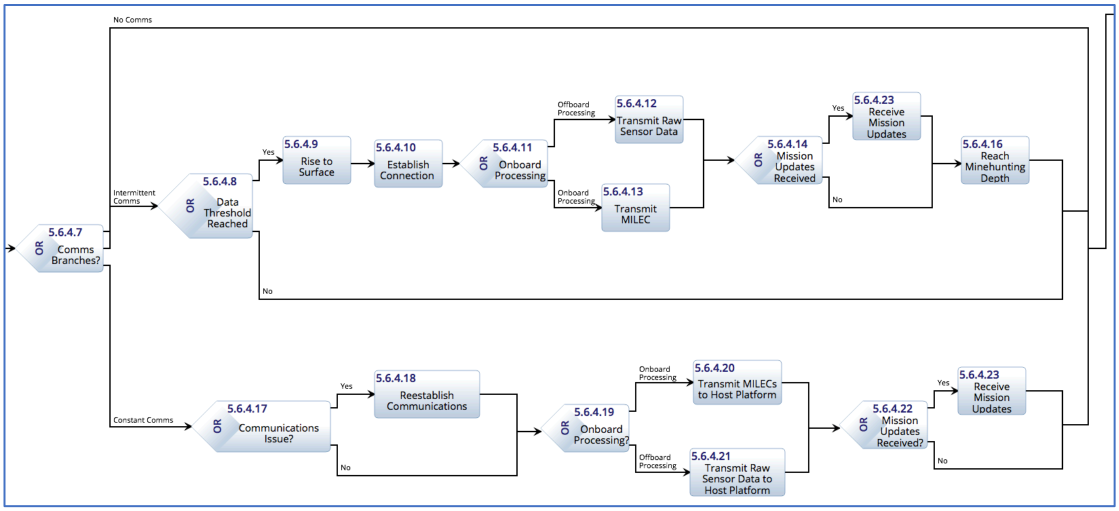


Figure 9. Scan Target Area–Communication of Data. (Camacho et al., 2017).

System Variability Modeling

The next step of this research methodology is the system variability modeling, which comes from software PLE.

Defining Variability in Textual Requirements

Through the analysis of the six next-generation MCM UVVs architectures studied by Camacho et al. (2017), this study identified five variation points for further decomposition and component allocation.

In this section, the textual requirements that enable greater accuracy in developing OVMs were defined. These requirements were based on those developed by Camacho et al. (2017) and Haller et al. (2022) for MCM UUVs. The criterion used to identify the requirements was based on the works mentioned. Two of them, the communications and the data processing subsystems, play a key role, as they work as drivers to variations among the alternatives in this research. The remaining subsystems (navigation, locomotion, localization) were selected because they are crucial for the operation of the UUVs for the execution of the studied mission.

Variation Points Decomposition and Components Identification

After obtaining a set of data from incorporating the textual variability requirements allocated to each variation point, components or a set of potential components were identified.

Subsequently, the components/set of components were associated with the six potential architectures, the baseline, and five alternatives developed under the product line approach. The objective is to identify the demand for those components across the alternatives and provide the baseline knowledge for the next step of the analysis.

Orthogonal Variability Model (OVM)

The concept of orthogonal variability model comes from the software engineering. Pohl et al. (2005, p. 75) as "a model that defines the variability of a software/system product line." Through a graphical notation, the OVM exposes the variability in the product line. This notation makes it possible to define the dependencies in terms of variability, an important feature of the relationship between VP and variants. Pohl et al. (2005) argue that this relationship obeys some conditions. This way, a VP can be associated with a single variant or offer several. Similarly, a variant can be associated with only one VP or different ones. It is also important to note that all VPs must always be associated with at least one variant. In the same way, all variants must be related to at least one VP.

OVMs for variation points highlight alternative variant choices as well as variability dependencies. In this step, each of the five points of variation and the proposed alternatives were combined to produce the OVM product line. This OVM product line makes it possible to drill down into constraint dependencies for variants and VPs. In this way, it provides a common model to determine which variation points and variants would be needed for each alternative that constitutes the MCM UUV product line.

Then the six possible architectures for next-generation MCM UUVs were exposed in OVM diagrams, presenting optional variants associated with five subsystems UUVs, described as variation points.

The proposed baseline architecture chosen in this study to the next-generation MCM UUVs (alternative 1), is characterized by the absence of remote communication capability and the absence of on-board data processing capacity. This architecture was the *status quo* technology when Camacho et al. (2017) conducted their research. This alternative includes constraint dependencies associated with those two main system capabilities in terms of communication and data processing subsystems.

Expected Reuse Category Percentages

After identifying the components, this research performed an individual analysis in order to obtain their classification regarding their reusability throughout the six MCM UUV architecture alternatives. Concomitantly, rationales were defined to clarify their categorization as reused, adapted, or mission unique.

After that, it was possible to identify which components were present in each alternative. In this route, this study determined how many components were present through alternatives, and finally, the number of components reused, adapted, and mission unique. These numbers were then transformed into percentages that later served as input parameters to calculate the system equivalent sizes in the economic analysis.

Economic TRADEOFF Analysis

System Constructive Product Line Investment Model

Using a detailed reuse model based on COPLIMO focusing on hardware components, this study overlaps that limitation since it assessed the variations among each of the six alternatives via COPLIMO reused parameters. This study accounted for their differences providing much more information for systems acquisition decision-making.

The COPLIMO manual (n.d.) exposes the core input parameters (percentages) considered for the system ROI analysis: Uniq%, Adap% and Ruse%. The percentages obtained in the previous step were used to feed the model.

Detailed Reuse Model Based on COPLIMO

To calculate the economic benefit of using a product line approach, the basic COPLIMO uses the product equivalent size measure to compare the effort/cost of the components developed for reuse vs. components developed as a stovepipe approach. While that model uses the average size (μ) in equation below to find the product equivalent size (PES), this detailed model employs the number of components estimated through five subsystems (communication, data processing, locomotion, navigation, sensors, and data collection) explored across six architecture alternatives proposed for the future MCM UUVs.

$$PES = \mu * Uniq\,\% + \mu * Adap\% * RCR(Adap) + \mu * Ruse\% * RCR(Reuse)$$

where μ = Average Size.

In this way, it was possible to determine the net savings in effort/cost and the accumulated savings in effort/cost. Then, the ROI index was determined as well as the accumulated ROI through these six alternatives.

Sensitivity Analysis

As the reuse model initially used the COPLIMO standard up-front investment value, 1.7 (70%), this research also explores a sensitive analysis comparing the effects of the RCDR variation in order to expand the analysis regarding the differences in ROI results. This analysis was conducted by entering different RCDR, 1.5 (50%), 1.6 (60%), and 1.8 (80%).

Results

The association of the variants related to each VP with their respective requirements and the components or set of components related to it were carefully demonstrated. When more than one component (set) was associated with a variation, it was only considered a new identification/classification if at least one new component was added. On the other hand, when a requirement/variant was met by a component/set that was previously indicated (it meets more than one variation), there was no insertion of a new one. Table 2 shows the demand for components for each of the alternatives.

Table 2. Components vs. Architecture Alternatives

Components or set of components	Requirements to Conduct MCM UUV Mission	Alternative 1/Baseline (NC + Off-board)	Alternative 2 (IC + Off-board)	Alternative 3 (CC + Off-board)	Alternative 4 (NC + On-board)	Alternative 5 (IC + On-board)	Alternative 6 (CC + On-board)
	Communication (1.0)						
C1	1.0.1 upload mission requirements	X	X	X	X	X	X
C2	1.0.2 allow remote communications on surface		X	X		X	X
C3	1.0.3 allow remote communications underwater			X			X
C4	1.0.4 start the mission when commanded	X	X	X	X	X	X
C5	1.0.5 allow manual download (All versions can have this capability)	X	X	X	X	X	X
C2	1.0.6 allow surface data transfer (IC)	N/A	N/A	N/A	N/A	N/A	N/A
C3	1.0.7 or allow sub-surface data transfer (CC)	N/A	N/A	N/A	N/A	N/A	N/A
	Data Processing Location (1.1)						
C6	1.1.1 process the data on-board (RTA)				X	X	X
C7	1.1.2 process the data off-board	X	X	X	X	X	X
	Locomotion (1.2)						
C8	1.2.1 complete a mission of *xx* duration	X	X	X	X	X	X
C9	1.2.2 develop a top speed of *xx* knots	X	X	X	X	X	X
C10	1.2.3 rise to surface from mine hunting depth in a *xx* time	X	X	X	X	X	X
	1.2.4 dive to mine hunting depth from surface in a *xx* time		X	X	X	X	X
	Navigation (1.3)						
C11	1.3.1 know its geographic location when navigating on surface	X	X	X	X	X	X
C12	1.3.2 know its geographic location when navigating underwater	X	X	X	X	X	X
C13	1.3.3 open ocean navigation	X	X	X	X	X	X
C14	1.3.4 store waypoints	X	X	X	X	X	X
C15	1.3.5 contain obstacle avoidance software capable of avoiding obstacles of *xx* size within *yy* distance	X	X	X	X	X	X
	1.3.6 perform returning to its point of deployment at mission conclusion	N/A	N/A	N/A	N/A	N/A	N/A
	1.3.7 conduct to a specific location when commanded	N/A	N/A	N/A	N/A	N/A	N/A
	Sensors and Data collection (1.4)						
C16	1.4.1 discern between an emission and background noise	X	X	X	X	X	X
C17	1.4.2 track contacts	X	X	X	X	X	X
C18	1.4.3 detecting mines of *xx* size from *yy* distance (on board)				X	X	X
C19	1.4.4 detecting mines of *xx* size from *yy* distance (off board)	X	X	X			
C20	1.4.5 cover a search area of *xx* dimension	X	X	X	X	X	X
	1.4.6 collect data while searching	N/A	N/A	N/A	N/A	N/A	N/A
	1.4.7 search for targets at a UUV's top speed xx	N/A	N/A	N/A	N/A	N/A	N/A

Figure 10 exposes the entire next-generation MCM UUV Product Line OVM and the constraint dependencies across variants and variation points. The information previously depicted in Table 2 is so organized under the OVM structure, demonstrating the constraint dependencies among them through the interconnection among the components and driven by the alternatives, defined here as VPs.

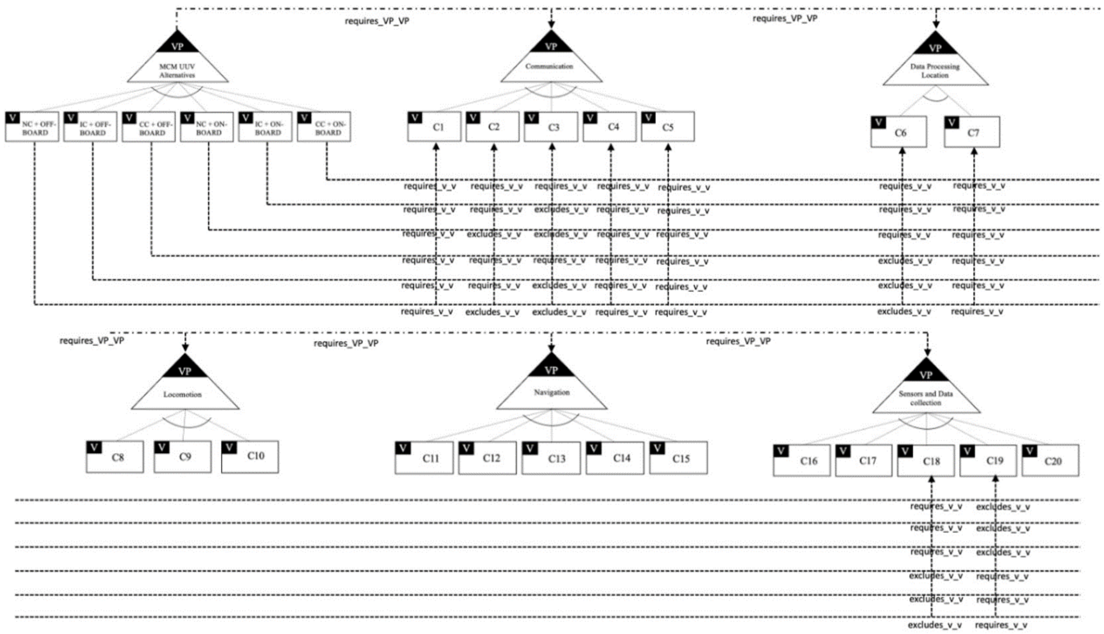


Figure 10. Next-Ceneration Mine Countermeasure UUV Product Line Orthogonal Variability Model

The PL investment in the baseline product reflects subsequent PL effort/costs across the five subsequent alternatives of approximately 14 in each product., representing an individual ROI of around 130% (Table 3). The break-even-point falls at the alternative 2, the second product in the proposed family of systems, culminating in a ROI of 551% across those six products through a PL approach. It demonstrates how relevant, from an effort/cost point of view, this approach can be impactful and reach savings during the life cycle of a family of systems, considering that it can generate future savings throughout the entire system's life cycle.

From the result of equation used to calculate the product equivalent size (PES), it was found for the six architecture alternatives proposed for the future MCM UUVs. The result of this calculation is shown in column 1 of Table 3. The second column represents the difference between the equivalent size vs. the non-reuse size, resulting in net effort/cost savings depicted in the third column. From that, it was possible to calculate the cumulative effort/cost savings (column 4). Then, the ROI index was obtained by dividing the net effort/cost saving by the PL reuse investment (column 5), and the sixth column depicts the cumulative ROI through those six alternatives.

Table 3. ROI Analysis for RCDR 1.7 Through Six Architecture Alternatives

	Eq. Size - Reuse Model	Non-Reuse Size	PL Effort Savings	Cumulative Savings	ROI	Cumulative ROI
Alternative 1 (Baseline)	26.5	16	-10.5	-10.5	-1.00	-1.00
Alternative 2	3.2	17	13.8	3.3	1.31	0.31
Alternative 3	4.2	18	13.8	17.1	1.31	1.63
Alternative 4	3.8	17	13.2	30.3	1.26	2.89
Alternative 5	4.2	18	13.8	44.1	1.31	4.20
Alternative 6	5.2	19	13.8	57.9	1.31	5.51
PL Reuse Investment	10.5					

Figure 11 presents the reuse effort savings through the alternatives and Figure 12 focuses on the cumulative ROI.

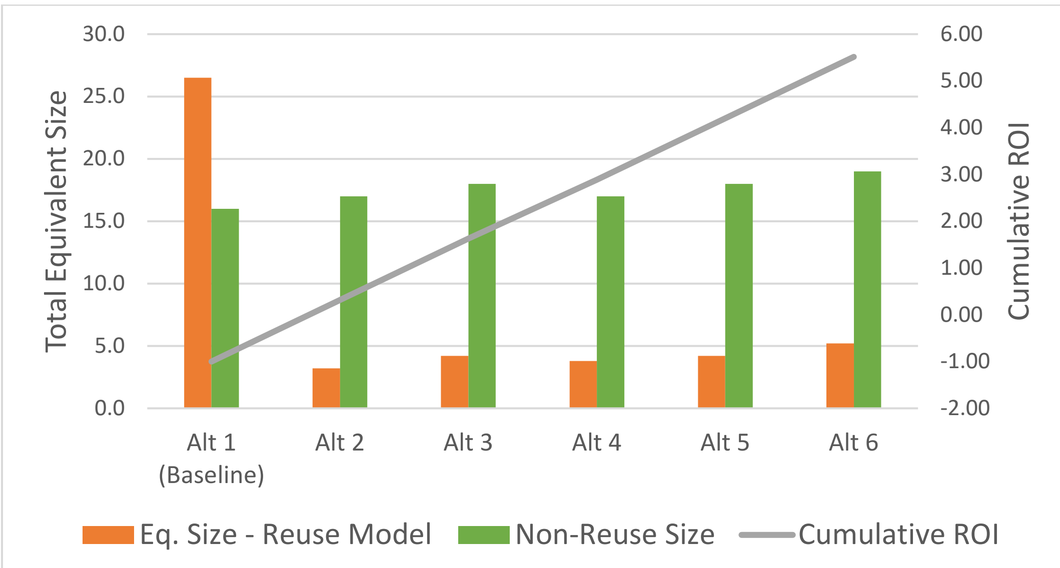


Figure 11. MCM UUV Reuse Effort Savings Through the Alternatives

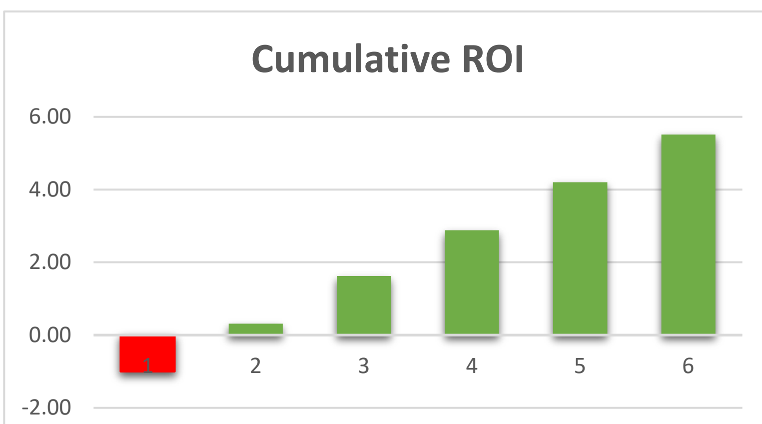


Figure 12. Cumulative ROI for RCDR 1.7

Then, performing a sensitivity analysis which proposes the variation of the RCDR and verifies how the outcomes of the detailed reuse model behaviors throughout the alternatives, it is possible to notice that the ROI index achieves nearly 800% when the

RCDR is 1.5 (50% PL investment). Applying RCDR of 1.6 (60% PL investment) and 1.8 (80% PL investment) results in ROIs of 600% and 470%, respectively.

Discussion

All alternatives presented positive and considerable ROI, most with equal values (alternatives 2, 3, 5, and 6), culminating in a break-even point in the second alternative developed in a proposed product line, regardless of the order chosen between the architectures. A slight exception appeared in alternative 4, which resulted in 5% lower than the others, in charge of the magnitude of 130%, making it a difference that can be considered negligible. Hence, the results support the idea that the cumulative ROI keeps a nearly linear behavior among the six alternatives, both in the primary and sensitive analyses. All alternatives proved to be viable to be part of a PL considering the different architectures of MCM UUVs studied.

Through the conduction of a sensitivity analyses, which tested an up-front investment variation between 1.5 (50%) and 1.8 (80%), the cumulative ROI result varies between 470% and 800%, proving valuable in this entire range of initial investment in the reusability approach. Even investing almost twice, what would be a hundred percent mission unique system's components, there is a relevant ROI in a family of products.

Although the concept of PL originally appeared in the private industry, the defense sector can benefit a lot during the process of engineering its systems, forming a mentality of commonality and reusability in order to promote, jointly with the contractors, the development of systems that meet that. Given the results obtained, the PL approach can provide the acquisition and development of defense systems, as the MCM UUV considered in this work, with great financial returns. Hence, there is great potential for savings over the system's life cycle, which in the defense environment can reach 50 years, since common components generate logistical and maintenance savings, in addition to being a team training facilitator. Particularly regarding the UUVs studied, such systems can be developed with a range of flexibility for use in different mission types, generating greater flexibility for the naval force that operate them. From the earlier definition of the system requirements as well as the system architecture, the systems engineering team and the program manager can jointly enable the availability of more than one product, which can meet different kinds of concepts of operations with more than one configuration. However, what initially may seem like just a high investment to develop systems with a high level of commonality proves to be advantageous when the demand for different configurations rises, bringing even better results in cumulative ROI.

Although this study only explored the architectural alternatives of MCM UUV, that approach is not limited to those systems. Instead, it can be applied in distinct engineered systems such as aircraft, ships, submarines, etc. The defense sector often demands different configurations for a given system developed in order to meet needs in different concepts of operations. In this way, attributing this mentality to the formulation of the requirements and especially in the architecture phase of the defense systems can generate great savings in the total life cycle cost, in addition to great flexibility for the service.

Integrating systems engineering and program management can provide several benefits to defense programs. The strategic association among PL approach, systems engineering, and program management approaches can benefit future defense programs, which demand a long development, then production and operation. A vision of flexibility still in the system's design phase will bring several future benefits, both in the economic sphere and in the effectiveness of operations since the defense sector may have available systems with similar and adaptable characteristics seeking to fulfill different missions. A reuse model falls between developing a fully standardized system without any flexibility and a system with a whole individualized shape. The approach allows planning the percentage of reuse and adaptability of components from the beginning.

Conclusion

This research investigated the potential benefits of enlarging the product line architecture approach through the systems engineering process of the next-generation MCM UUVs. To achieve that, the study employed parametric cost modeling, some empirical data collected from recent research, and the demonstration of MBSE approach to verify potential economic savings through systems product line architecture. At the end, it is possible to answer the following questions proposed in the Introduction:

Can the product line architecture approach benefit the development of the next generation MCM UUVs designs instead of using non-reusable systems/components?

From the analysis of hypothetical data about the next generation of MCM UUV, it was possible to conclude that yes, the product line architecture approach can benefit the development of the next generation MCM UUVs.

Can potential technological changes/solutions be used as performance drivers in the analysis of MCM UUVs product line architecture?

Focusing on the two main subsystems previously proposed by Camacho et al., the data processing (on-board or off-board) and communication capabilities, it is possible to conclude that the technological variants did not have a relevant impact on the product line approach analysis. In this way, it suggests that the decisions of which order of alternatives must be prioritized should fall on the performance data achieved by the authors.

How can the OVM contribute to the product line strategy?

The tool allows an essential analysis of the relationships between the available/analyzed variants. Indeed, the OVM tool is even more relevant given the complexity of current systems since they have a very large number of possible variants. Thus, testing them through software that model in OVM is very useful for decision-making.

How can the product line approach be integrated into a parametric cost model in order to conduct a cost analysis and ROI assessment of MCM UUVs?

It was shown that integrating the two approaches can generate important benefits in cost analyses, especially in life cycle cost analyses. The ROI analysis can be expanded to the O&S phase, extending the study to logistics, maintenance, and training data.

What is the potential ROI for applying a product line architecture when developing MCM UUVs?

It was possible to obtain a wide range of ROI through the variation of the parameter of up-front investment in product line/reusability. The lowest individual ROI obtained was that of alternative 4, with an RCDR of 1.8, resulting in 110%. The highest ROI was achieved by alternatives 2, 3, 5, and 6 with an RCDR of 1.5, resulting in 185%.

References

Alves, J. F. S. (2022). *Economic tradeoff analysis of a product line architecture approach through model-based systems engineering: a case study of future mine countermeasures unmanned underwater vehicles* [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/handle/10945/71000

Boehm, B., Brown, A. W., Madachy, R., & Yang, Y.. (2004). A software product line life cycle cost estimation model. *Proceedings. 2004 International Symposium on Empirical Software Engineering, 2004*(ISESE ’04), 156–164. https://doi.org/10.1109/ISESE.2004.1334903

Camacho, M., Galindo, D., Herrington, D., Johnson, T., Olinger, A., Sovel, J., Stith, W., Wade, J., & Walker, P. (2017). *Investigation of requirements and capabilities of next-generation mine warfare unmanned underwater vehicles* [Capstone project report, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/handle/10945/56878

Chance, K. A. (2019). *Naval combat systems product line economics: Extending the constructive product line investment model for the aegis combat system* [Master’s thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/handle/10945/62854

COPLIMO Product Line Investment Model. (n.d.). Retrieved August 8, 2022, from http://coplimo.org/

Deshmukh, A., Jacques, D., Housel, T., Wortman, M., Boehm, B., Sullivan, K., & Collopy, P. (2010). *2010 value of flexibility—Phase I* (Technical Report SERC-2010-TR-010-1; p. 165). Stevens Institute of Technology, Systems Engineering Research Center. https://apps.dtic.mil/sti/pdfs/ADA637770.pdf

Fraine, N. D., Jackson-Henderson, T., & Manfredo, V. (2019). *Naval ASW combat system product line architecture economics* [Systems Engineering Capstone Report, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/bitstream/handle/10945/62720/19Jun_Fraine_et%20al.pdf?sequence=1&isAllowed=y

Hall, R. (2018). *Utilizing a model-based systems engineering approach to develop a combat system product line* [Master’s thesis, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/handle/10945/59675

Haller, K., Kolber, D. S., Storms, T. R., Weeks, J. B., & Weers, W. (2022). *Unmanned underwater vehicle mission systems engineering product reuse return on investment* [Systems Engineering Capstone Report, Naval Postgraduate School]. NPS Archive: Calhoun. https://calhoun.nps.edu/handle/10945/69650

Madachy, R., & Green, J. (2022). Systems and cost effectiveness modeling of unmanned systems product lines for acquisition. *Acquisition Research: Creating Synergy for Informed Change*, 9.

Madachy, R., & Green, J. (2019). *Naval combat system product line architecture economics* [Report]. Naval Postgraduate School. https://calhoun.nps.edu/handle/10945/62913

Naval Doctrine Command. (1996). *NWP 3-15 mine warfare*. Department of the Navy. https://ia802709.us.archive.org/4/items/milmanual-mcwp-3-3.1.2-mine-warfare/mcwp_3-3.1.2_mine_warfare.pdf

Pohl, K., Böckle, G., & Linden, F. van der. (2005). *Software product line engineering: Foundations, principles, and techniques* (1st ed). Springer.

SPEC Innovations. (n.d.). *Innoslate—Systems engineering and requirements management software*. Innoslate: The MBSE Solution of the Future. Retrieved August 4, 2022, from https://www.innoslate.com/

United States Navy. (2021). *Department of the Navy unmanned campaign framework* (p. 40).

U.S. Department of Defense. (2018). Digital engineering strategy. https://ac.cto.mil/wp-content/uploads/2019/06/2018-Digital-Engineering-Strategy_Approved_PrintVersion.pdf

PANEL 8. MODEL-BASED SYSTEMS ENGINEERING

Wednesday, May 10, 2023	
2:15 p.m. – 3:30 p.m.	**Chair: Angela S. Beach,** Director, Integrated Warfare Systems Engineering (05H), Naval Sea Systems Command ***An Integration Framework for Digital Transformation of DoD Systems Engineering and Acquisition*** Kelly Alexander, Stevens Institute of Technology Tom McDermott, Stevens Institute of Technology ***An Agile Model-based Systems Engineering Method to Accelerate Value Delivery*** Ronald Giachetti, Naval Postgraduate School ***Development of Digital Engineering Artifacts in Support of MBSE Driven Test Planning and Execution and Acquisition Decision Making*** Craig Arndt, Georgia Tech Research Institute Jeremy Werner, Georgia Tech Research Institute

Angela S. Beach—was selected as a Department of Navy (DON) Senior Executive in July 2019 and serves as the Director for Development and Integration in Program Executive Office, Integrated Warfare Systems (PEO IWS). In this role she is responsible for integrated system requirements and resources for combat systems and associated elements. Ms. Beach facilitates the execution of effective systems engineering processes for development, integration, and test of surface combat system capabilities for PEO IWS.

Ms. Beach was previously the Deputy Technical Director of the Naval Surface Warfare Center, Dahlgren Division (NSWCDD). In this role, she led the planning and execution of Dahlgren's technical mission of research, development, test, and evaluation of Surface Naval warfighting systems. Her responsibilities included directing a workforce of over 4,000 employees and overseeing an annual operations budget of $1.5 billion.

Ms. Beach served as the acting Major Program Manager for Weapon System Directorate (AW) at Aegis Ballistic Missile Defense (BMD), Missile Defense Agency. Prior to her PM assignment, Ms. Beach served as the AW Deputy Program Manager managing a high performance engineering and programmatic workforce consisting of four divisions with over 550 civilian, military, contractor and other government agency employees. She was responsible for the design, development, testing, BMD integration, and fielding of all Aegis BMD Weapon Systems, equaling over $1 billion Total Obligation Authority across the Future Years Defense Plan.

Prior to her DPM assignment, Ms. Beach served as Division Head of the AWS Development Division of the Aegis BMD Program in MDA. In 2008, Ms. Beach managed the Weapon System upgrades used for Operation Burnt Frost, the killing of an inoperative satellite.

Ms. Beach began her career at NSWCDD as the Weapon Systems Engineering Program Manager in the Aegis Program. She led the Aegis BMD Initial Defensive Operations (IDO) certification efforts in 2004 in accordance with the Presidential directive. After leaving NSWCDD, Ms. Beach held key leadership positions at the Missile Defense Agency

Ms. Beach holds a Bachelor's Degree in Mathematics from Old Dominion University. She has been recognized with two Department of the Navy Superior Civilian Service Awards and the Meritorious Civilian Service Award. She is a member of the Acquisition Professional Community and is DAWIA Level 3 certified in both Program Management and SPRDE, and has completed the Program Managers course, PMT 401, from Defense Acquisition University.

An Integration Framework for Digital Transformation of DoD Systems Engineering and Acquisition

Dr. Kelly Alexander—is the Chief Systems Engineer at System Innovation. She has over 35 years of experience in systems engineering and project management.. As a US Department of Defense civilian, she served as the Director of Systems Engineering Policy and Program Support, Director for Common Operating Environment at HQ US Army, and spearheaded the transition of modular software into the US Army's tactical software. She also led the Army's digital transformation and modular open systems using open standards and open architectures. Dr. Alexander earned a PhD in Systems Engineering from George Washington University, master's degrees from George Washington University (Systems Engineering) and National Defense University (National Resource Strategy), and a bachelor's degree in Industrial Engineering from NC State University. [kelly.d.alexander12.ctr@mail.mil]

Tom McDermott—is the Chief Technology Officer of the Systems Engineering Research Center (SERC) and a faculty member in the School of Systems and Enterprises at Stevens Institute of Technology in Hoboken, NJ. With the SERC he develops new research strategies and is leading research on digital transformation, education, security, and artificial intelligence applications. He previously held roles as Faculty and Director of Research at Georgia Tech Research Institute and Director and Integrated Product Team Manager at Lockheed Martin. Mr. McDermott teaches system architecture, systems and critical thinking, and engineering leadership. He provides executive level consulting as a systems engineering and organizational strategy expert. He is a fellow of the International Council on Systems Engineering (INCOSE) and recently completed 3 years as INCOSE Director of Strategic Integration. [tmcdermo@stevens.edu]

Abstract

This paper presents the results of a Systems Engineering Research Center (SERC) research task entitled "Program Managers Guide to Digital and Agile Systems Engineering Process Transformation." This research task supports a larger set of DoD activities being led by OUSD/RE under the term "Systems Engineering Modernization" (SEMOD). The motivation for SEMOD stems from the need to integrate across independent guidance provided down to the DoD SE and acquisition communities related to Digital Engineering, Modular Open Systems Approach, Mission Engineering, and Software Engineering/ Agile/ DevOps across the multiple pathways of the Adaptive Acquisition Framework. The SERC/government research team found there is a lack of an integrated approach to implementation of SE Focus Areas that is creating a delay in full implementation of the Digital Transformation, which is necessary to ensure the relevant guidance, skills, and training, are available to deliver a robust, disciplined approach to weapon systems acquisition.

Introduction

The research conceptualized an integration framework that has at its core "shared and authoritatively managed data" that can be transformed through various models and tools to create Digital Artifacts. These artifacts are used by various decision makers and others needing digital access to the design and descriptions of the system across its life cycle. In early years, these artifacts were usually paper documents or drawings, now they are mostly based on digital technologies but far from "seamlessly integrated and interoperable."

As the research team developed the integration framework, we came to realize first that existing SE mostly linear lifecycle depictions like the "Vee" model and the DoD's "Defense Acquisition Wall Chart" do not promote the future vision of data and models at the core of SE and acquisition. Secondly, since future systems will be "built for change" using concepts of continuous iterative development, do the somewhat linear models of existing SE lifecycle representations still adequately guide us? In response, the team shifted to developing a new conceptual view of the full SE Modernization Lifecycle, which we called the Supra-system

Model. This view depicts all acquisition pathways as continuous processes with data at the core, models as the decision tools, and SE lifecycle processes as the decision points (and artifacts).

First, the research redefines systems engineering as a cyclic approach, rather than a linear one. Although almost all literature attempting to standardize on a lifecycle model will say that activities are ongoing and should continue through the lifecycle, the current Vee model does not reflect the iterative nature of today's systems and capabilities.

Second, the integration framework clearly shows that an acquisition program can enter the lifecycle at any point, and integrates across all six acquisition pathways of the Adaptive Acquisition Framework.

Third, this integration framework makes the digital transformation clear using a layered model with data storage and transformation at the core, models as the data transformation layer, and systems engineering process areas as the outer layers.

SE Modernization Integration Framework

Program managers today are facing a myriad of acquisition process changes centered on the need for more rapid deployment of capabilities, better weapon system portfolio management, and efficiencies created through digital transformation. There is a need for documentation of lessons learned, program best practices, and standard guidance for program Systems Engineering that incorporates a holistic approach inclusive of the four SE Modernization focus areas, the six acquisition pathways, and the digital transformation outlined in the DoD Data Strategy.

In this project, we first attempted to derive a framework to integrate across all aspects of future systems engineering by analyzing the text from current SE-related SE standards and the independent DoD guidance from each of these change areas. We found that existing DoD and SE process guidance did not capture the relationships across these focus areas of SE Modernization. We also recognized that systems engineering guidance still retains its historical alignment with Major Capability Acquisition (formerly Major Defense Acquisition Programs (MDAP))and has not become integral with other system approaches such as innovation and prototyping, agile software development, business and service systems, and data-connected systems. We found that we had to step away from history and visualize a new set of mental models to guide the practice of systems engineering in future DoD uses. This report starts with a historical view of SE in DoD acquisition activities, discusses the imperatives driving a modernized view, places SE in the digital transformation of all engineering and acquisition, then proposes "The Supra-System Model" as a revised mental model that integrates across all engineering and acquisition activities, and possibly beyond acquisition into other activities that benefit from modernized, digitally transformed SE.

SE has long been integral to DoD Acquisition Processes

Systems engineering principles and methods were adopted by the DoD in the late 1960's/early 1970's as a way to manage technical and programmatic development and risk across the engineering and management components of large complex weapon systems. The DoD published Military Standard 499A, Systems Engineering Management, in 1969. When the first iteration of DoD 5000.01 "The Defense Acquisition System" (DAS) was published in 1971, it defined a systems engineering related set of guidance including consideration for problem/operational needs, alternatives, test and evaluation, and support and update. It also introduced related management activities such as contracting, risk, source selection, and documentation. Mil-Std-499B was introduced in 1992 but was never published, as military standards were cancelled in the early 1990's as part of DoD acquisition reform initiatives. The majority of the concepts in Mil-Std-499B were incorporated into the Defense Acquisition University (DAU) Systems Engineering Fundamentals handbook in 2001. This contained a graphical SE lifecycle process description as well as the now familiar milestone driven acquisition process shown in Figure 1.

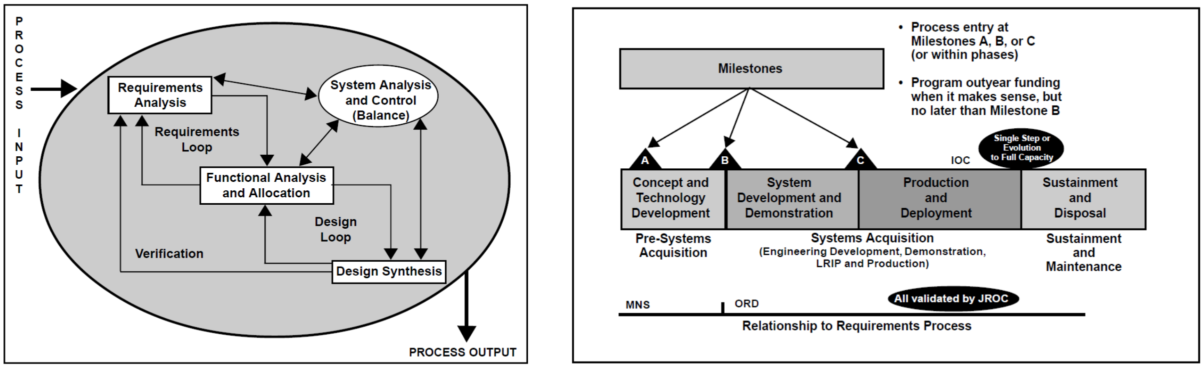


Figure 1. Initial DoD SE Process Model and acquisition process flow (DAU SE Fundamentals 2001)

The concept of the V-model was developed simultaneously, but independently, in Germany and in the United States in the late 1980s. It has been used interchangeably to represent 1) the concept of decomposition/synthesis of a systems development into different levels of functional definition, realization, and test (Figure 2); and 2) an SE technical and management process model (Figure 3).

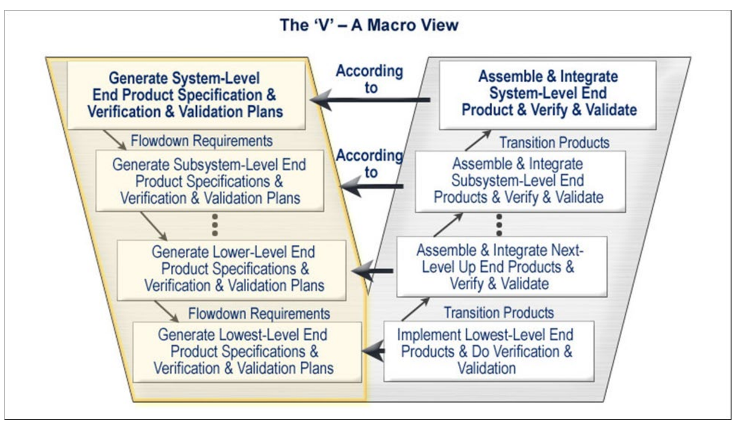


Figure 2. The Vee-model as a functional decomposition/synthesis process (INCOSE SEBOK)

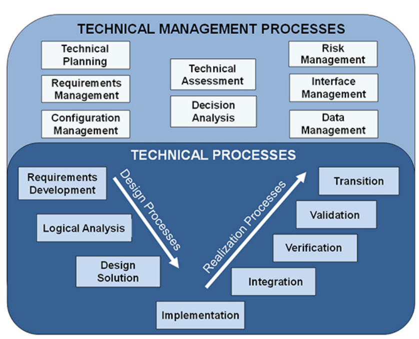


Figure 3. Revised SE Process Models of 2003 in the DAU Acquisition Encyclopedia, using the Vee-model to as a set of technical processes. https://www.dau.edu/acquipedia.

The current DAU documentation of the Vee-model generalizes and combines these two perspectives, as shown in Figure 4. The current acquisition model for MDAPs, now known as Major Capability Acquisitions (MCA) is shown in Figure 5. The current DoD SE Guidebook does not show an equivalent technical review process for the other AAF acquisition pathways. However, each of the pathways does provide some lifecycle guidance and guidance on tailoring reviews and audits (https://aaf.dau.edu/aaf/aaf-pathways/).

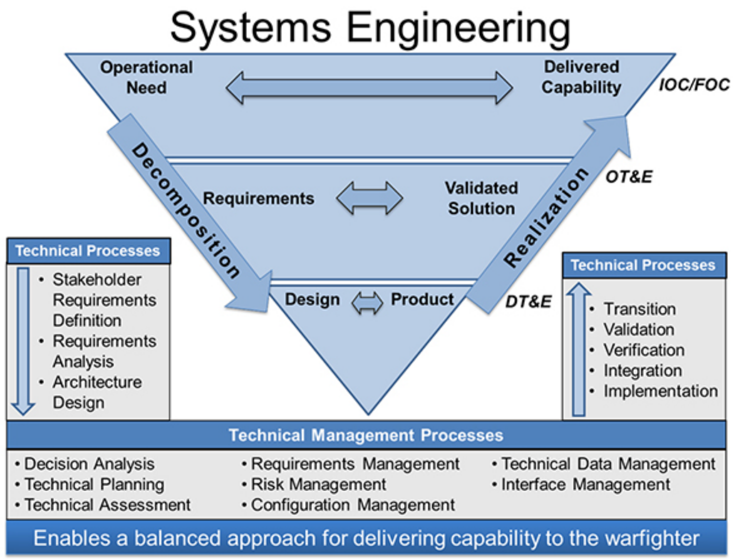


Figure 4. Current DoD SE Processes (DoD SE Guidebook 2022)

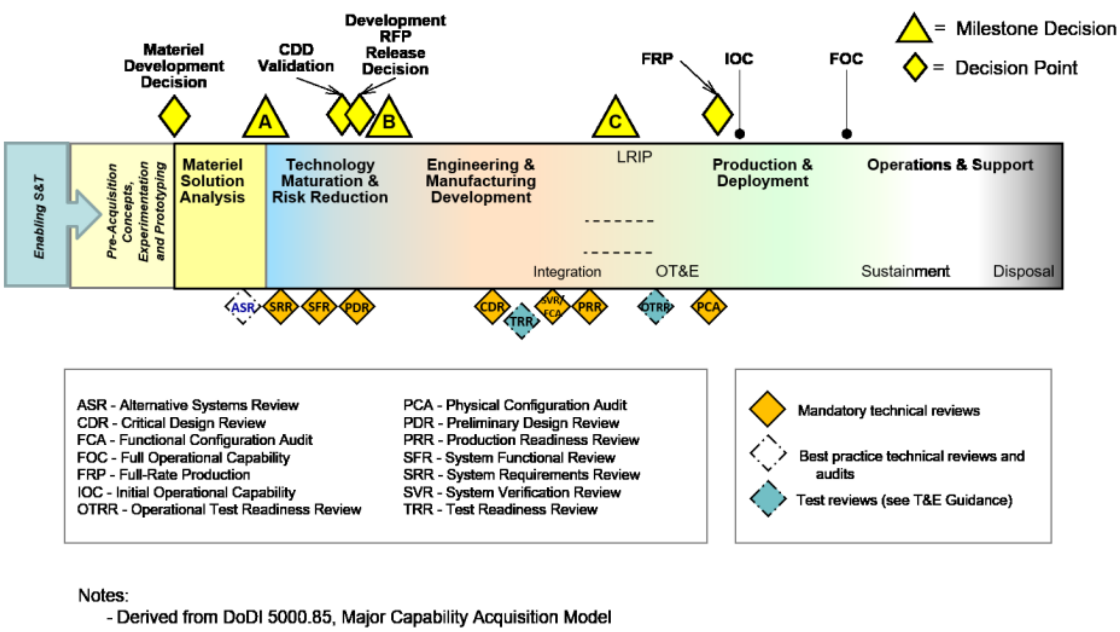


Figure 5. Technical Reviews and Audits for the MCA Life Cycle (DoD SE Guidebook 2022)

The discipline and its use in DoD acquisition has long been associated with realization of physical systems and related equipment, in Major Defense Acquisition Programs (MDAP). These figures are shown to highlight how "mental models" of SE have been codified into DoD acquisition for over 50 years. Meanwhile SE has grown to a much broader discipline, impacting software systems, business systems, manufacturing systems, innovation systems, enterprise systems, and other system types used by the DoD. Many of these applications have developed their own lifecycle process models in response to this traditional SE literature and related use, viewing "traditional SE" as slow and non-responsive to change.

Why SE Modernization?

Today many defense capabilities are not only physical; they are software intensive, highly connected, and have extensive automation and user configuration capabilities. Software engineering became a discipline in 1967, manufacturing automation (the third industrial revolution) began in the 1970's, and the World-Wide-Web was invented in 1989. The DoD's Defense Modeling and Simulation Office was opened in the early 1990's and large-scale networked simulation of defense systems followed. All of these have continued to evolve the SE discipline, not as a whole, but as a set of related sub disciplines (systems engineering, software systems engineering, information technology and enterprise architecture, distributed modeling & simulation, and automated manufacturing systems). **It is notable that each of these sub disciplines views lifecycle process and technical review as something that is much more iterative than what is implied by current SE guidance.**

Following successful evolution of the Unified Modeling Language (UML) in the software discipline, the Systems Modeling Language (SysML) was published in 2007 and started the growth in Model-Based Systems Engineering (MBSE) as an improved approach to manage technical and programmatic risk. "Industry 4.0" originated in 2011 and introduced the concept of a "digital twin" as a non-physical product realization. The DoD's Digital Engineering (DE) Strategy was published in 2018, ushering in the vision of a digital era of systems engineering. As the International Council on Systems Engineering noted in their Vision 2035 document: "The future of Systems Engineering is Model Based, leveraging next generation modeling, simulation and visualization environments powered by the global digital transformation, to specify, analyze, design, and verify systems."

Throughout all of this change, the primary use of systems engineering in the DoD, and associated DoD acquisition guidance, has continued to center on physical realization of large-scale monolithic systems and other critical capabilities intended to persist for many years. The need for rigorous definition, analysis and test of these critical systems will always exist; and the time has come to integrate the systems engineering sub disciplines into a common framework that responds to the digital age. A further SE vision statement might read: "the future of SE is more iterative and responsive to user needs." Future SE discipline needs to be more model-based and more agile and responsive, which will be accomplished with more efficient lifecycle processes.

SE Modernization Focus Areas

In FY2021, the SERC was tasked by the DoD to conceptualize and build an integration framework for SE Modernization as applied to all DoD acquisition life cycles. Between 2019 and 2021, the DoD published its latest 5000 series guidance, "The Adaptive Acquisition Framework" in 2021 to show the various development and acquisition pathways for software (2020), IT and business systems (2020), services (2020), and a streamlined "middle tier" acquisition (2019) for more mature rapidly fielded systems. This followed a series of legislative directions to the DoD four focus areas for SE Modernization as defined below:

1. **Digital Engineering (DE)** – Defined in the DoD DE Strategy as "an integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal." As directed in DoD policy, "DE will provide for the development, validation, use, curation, and maintenance of technically accurate digital systems, models of systems, subsystems, and their components, at the appropriate level of fidelity to ensure that test activities adequately simulate the environment in which a system will be deployed."
2. **Modular Open Systems Approach (MOSA)** – Defined in DoD policy as "an acquisition and design strategy consisting of a technical architecture that adopts open standards and supports a modular, loosely coupled and highly cohesive system structure." This modular open systems approach includes publishing of key interfaces within the system and relevant design disclosure. MOSA introduces the 'build for change, not to last' philosophy from software architecture across all aspects of DoD systems.
3. **Mission Engineering (ME)** – Defined in DoD guidance as "the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired mission effects. Mission Engineering is intended to provide engineered mission-based outputs to the requirements process, guide prototypes, provide design options, and inform investment decisions."
4. **Agile Development** – Defined in DoD guidance as "approaches based on iterative development, frequent inspection and adaptation, and incremental deliveries, in which requirements and solutions evolve through collaboration in cross-functional teams and through continuous stakeholder feedback. Agile approaches begin not with detailed requirements, but with a high-level capture of business and technical needs that provides enough information to define the software solution space, while also considering associated quality needs (such as security)." Note that agile does not have to be software specific, and the principles can apply to any process.

In addition, the **DoD Data Strategy** (2020) emphasizes data as a strategic asset, collective data stewardship, data collection, enterprise-wide data access and availability, data fit for purpose, and design for compliance. At this point the SE community may be overly focused on "System Models" and underly focused on "System Data" in the Digital Engineering Strategy. As outlined in the SERC the Digital Engineering Competency Framework (DECF) project, data architecture, data standards, data governance, and talent and culture are all essential components of SE Modernization and may be new concepts to systems engineers (DECF 2020, DECF 2021).

The four focus areas can be viewed as a layered model with a data strategy at the core, as shown in Figure 6. At the center, as envisioned by the DoD Digital Engineering strategy, is shared and authoritatively managed data. Modernization of systems engineering strives for seamless interoperability and integration of all engineering and management disciplines using authoritative sources of system data and models as the continuum that links the disciplines.

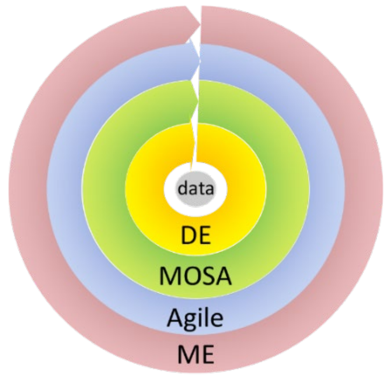


Figure 6. Four focus areas as a layered model
(Cleared for public release DOPSR Case # 23-S-0026)

It should be noted across these focus areas that DE and ME aligns to "the future of SE is model-based" while MOSA and Agile align to "the future of SE is more iterative and responsive to user needs." These are not at odds, as appropriate use of models provides the foundation for iterative learning. **Fundamentally, modernization of SE lifecycle processes must define how data and models are used to be more iterative and responsive to user needs.** In this project we found that is not the mental model or vision of current policy and guidance related to these focus areas. our SE Modernization vision is stated below:

The vision of SE Modernization is to use data and models to create a more agile and responsive acquisition system that can quickly and effectively meet the needs of the warfighter.

Digital Transformation of Systems Engineering

At the core of SE Modernization is "shared and authoritatively managed data" that can be transformed through various models and tools to create Digital Artifacts. These artifacts are used by various decision makers (in development) and others needing digital access to the design and descriptions of the system across its life cycle. In early years these artifacts were almost always paper documents or drawings, now they based on digital technologies but far from "seamlessly integrated and interoperable." The cartoon in Figure 7 might best describe the current state of digital artifact development.

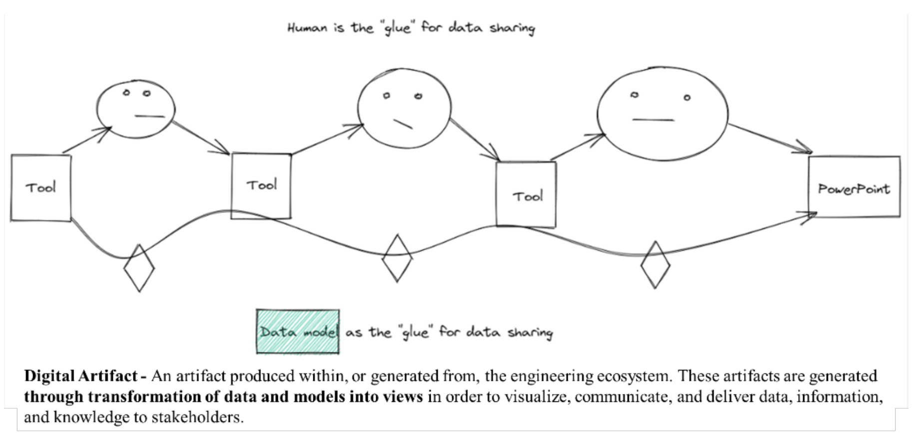


Figure 7. Data Transformation Mental Model
(Cleared for public release DOPSR Case # 23-S-0026)

Systems engineers have long used digital data and various modeling and analysis tools to produce digital artifacts for decision-making. However, the underlying data model has not been "seamlessly shared", and likely not shared at all, and authority for that data has been held by independent activities, generally organized by discipline. Much of the "transformation" is still manual interpretation of disparate data and analyses. This manual interpretation limits our ability to be iterative and responsive across disciplines and disciplinary tools. One might describe the current state of systems engineering as seeing the whole while looking through a set of soda straws. We desire a fully integrated, iterative workflow where the system is the focus, not the owner of the data, or the particular element of a design. Today's primary challenge in digital engineering is not so much being "model-based," it is understanding and creating the underlying data model that integrates across requirements, design, and test, and across disciplines and disciplinary processes, and is shareable and shared.

This leads us to the **value statement** for SE Modernization, depicted in Figure 8 and the box below:

The value of SE Modernization will be realized in more seamless and efficient transfer of data and models from underlying performance drivers through models to decisions, as well as ease of drilling back down from decisions to data.

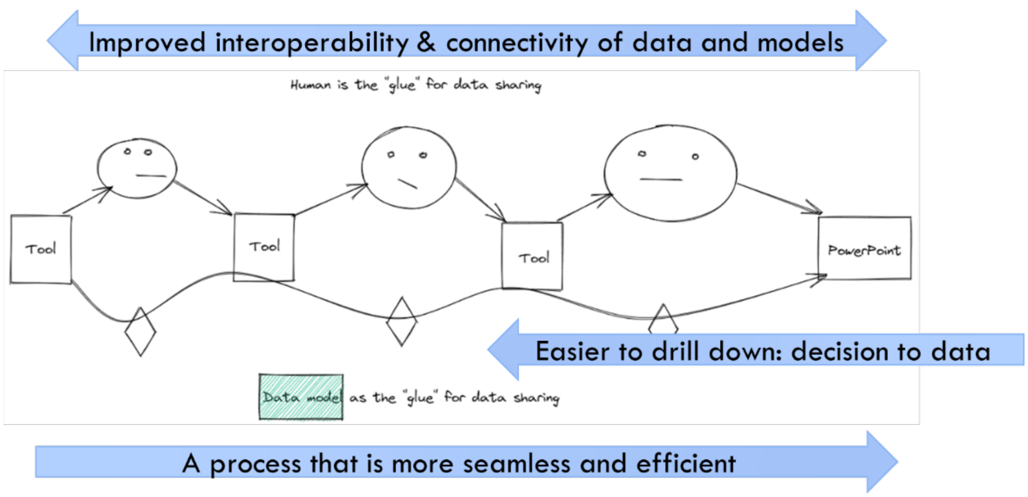


Figure 8. SE Modernization Value Depiction
(Cleared for public release DOPSR Case # 23-S-0026)

Systems engineering and related acquisition processes can be visualized as a set of iterative data transformations from sources of truth that produce artifacts for human consumption – across all stages of a system life cycle.

Figure 9 redraws the widely depicted Define->Realize->Deploy&Use stages of the SE Vee-model in a circular process to represent it as a:

1) set of data transformations at the core;
2) layered across disciplines & tasks;
3) in continuous iterative processes that could be entered from any point.

In the figure we generalize define, realize, and deploy as a "Learn->Build->Measure" to be more consistent with current design literature.

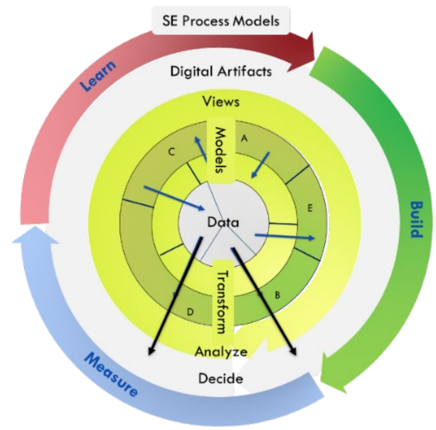


Figure 9. Circular Processes with Data at the Core
(Cleared for public release DOPSR Case # 23-S-0026)

In SE technical and management processes, data is transformed through models into views, which support analyses leading to decisions. These transformations have traditionally produced decision artifacts that were severed from the underlying data and models and captured in independent static document or presentation forms. Digital artifacts may still be documents or presentable views but should remain digitally connected to the underlying data and models from which they draw context and "explainability". This process flow reflects "Data Transformed into Models then Analyzed through Views to make Decisions documented in Digital Artifacts." This process flow has been the core of SE technical and management processes within each lifecycle phase since the inception of SE. It has largely been a manual, inefficient process flow that focused on "presentability" rather than context.

SE lifecycle processes as defined by ISO/IEC/IEEE 15288 do not define a specific ordering of process areas, but much of the literature and existing mental models imply a process ordering that is started in the learn (define) stages. SE lifecycle processes have been used not just in critical systems where up-front system definition and learning are essential, but also in process and system innovation, prototyping, and incremental definition activities where build-first is the pathway to learning; and in sustainment life cycles where deployed system measurement and learning should be applicable to both the system sustainment, but also to define the next build. This SEMOD circular mental model better recognizes that SE technical and management processes can be applied to any life cycle in any type of system. Figure 10 visualizes the domains of SE in association with the ordering of learn, build, and measure cycles.

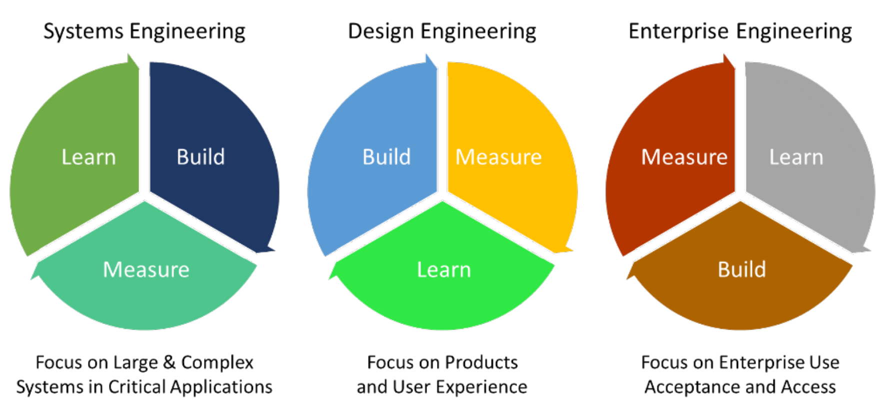


Figure 10. Different lifecycle ordering in different applications of SE

The DoD published the Adaptive Acquisition Framework (AAF) in 2019 (Figure 11). Between 2019 and 2021, the AAF recognized new development and acquisition pathways for software, IT and business systems, services, and a streamlined "middle tier" acquisition for more mature rapidly fielded systems. In the AAF, the Major Capability Acquisition pathway continues the traditional use of upfront SE rigor and its rigorous Learn->Build->Measure cycle and remains as the most known of the acquisition pathways. However, the Urgent Capability, Middle Tier, and Software Acquisition pathways promote an abbreviated definition phase and rapid learning through builds; following SE processes developed in the engineering design and software development fields. The Defense Business Systems and Acquisition of Services pathways are more aligned with the Enterprise Engineering. The challenge of SE Modernization is to maintain appropriate SE rigor and associated process definition in all pathways. **SE rigor is maintained using the data –>transform–> analyze–>decide flow of Figure 9, not through a specific ordering of SE processes**.

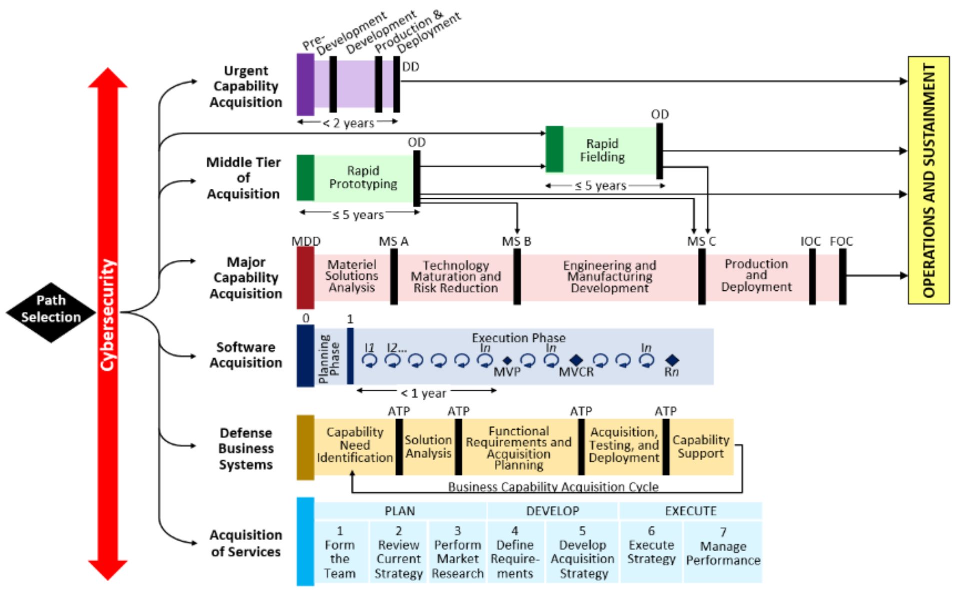


Figure 11. The Adaptive Acquisition Framework (aaf.dau.edu)

The workflow view in Figure 12 shows conceptually how shared and authoritatively managed data is transformed into digital artifacts in different life cycle stages in any pathway. This linear workflow model is familiar and comfortable to system engineers but does not represent the fact that these data transformations into and out of the shared and authoritatively managed federations of data and models actually happen iteratively and continuously across a life cycle. **Increasing responsiveness to the warfighter (or market) does not mean eliminating these critical SE processes, just increasing the number of iterations and shortening the cycle time between them.**

This figure also highlights how the broadly published goal of the DoD Digital Engineering Strategy “Provide an enduring authoritative source of truth” may be misleading to the DoD program management communities. In reality, the “source of truth” will be a distributed federation of data and models. The goal should be revised to “Create govern and use a set of authoritative data and models in order to share knowledge and resources across the system lifecycle.” These data and models might originate in any phase of a systems lifecycle and in any function associated with DoD engineering and acquisition. In fact this will always be the case. “Who owns the data and models” remains a pain point in this transformation.

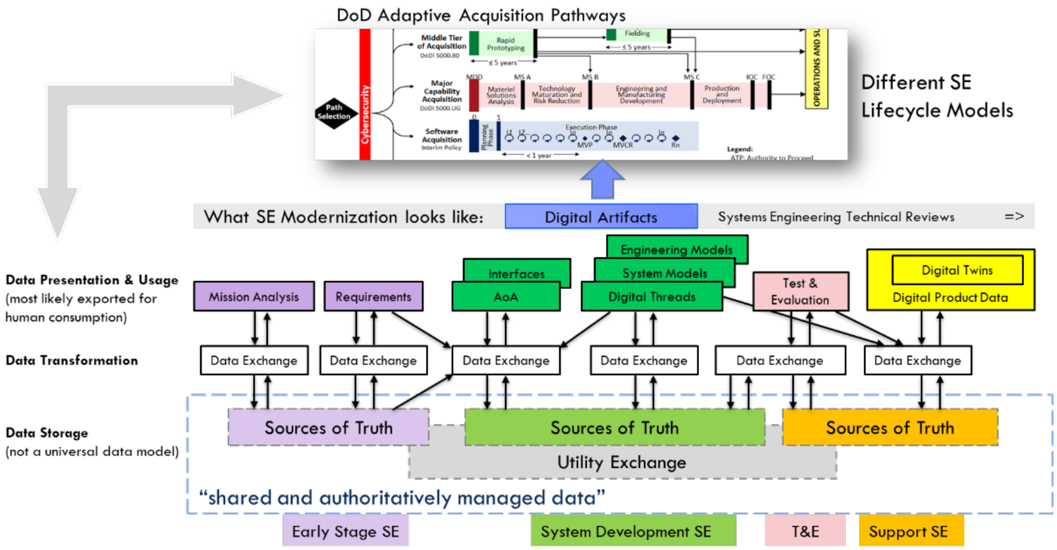


Figure 12. Data Transformation into the Life Cycle

This figure is particularly relevant to SE modernization, as "Data Management" is not currently defined as a disciplinary process in SE standards or DoD engineering policy. Data models and data storage systems are separate systems that must also be developed and deployed in support of the fielded system. These must be defined and built along with other aspects of a systems development. Data engineering and data modeling do follow SE processes but require different disciplinary skills than physical systems.

This leads us to the "roots" of the **integration framework** for SE Modernization, which must address how shared and authoritatively managed data and models are defined, built, deployed, and used in DoD systems:

New SE lifecycle processes must address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not single acquisition program lifecycle.

We found in our interviews and workshops on this project, the terms data, digital models, digital artifacts, digital threads, and virtual systems or "digital twins", all have different definitions, uses, and driving forces behind their lifecycles. They are not being viewed in an integrated set of lifecycle and process models. In this research, we developed a more integrative view of an SE lifecycle model that we call "The Supra-System Model." This mental model was created to be a discussion tool to distinguish historical SE lifecycle and process models from a modernized approach needed to support today's activities and systems.

The Supra-System Model: Evolving the SE Modernization Framework

This discussion begins with background from an abbreviated literature review. Thullier and Wippler in their chapter "Finding the Right Problem" from the book Complex Systems and Systems of Systems Engineering caution us to always consider three lifecycles associated with any system, each with interdependencies and relative positions in the evolution of a system (Thullier and Wippler 2013):

- "*the system lifecycle*: the "experiences" of the system itself;
- *the program lifecycle* of the system: the rhythm of the project during study, development, production, etc. of the system;

- *the engineering cycle*: the processes and activities involved in engineering the system."

Historical SE literature tends to portray these different lifecycles as simultaneous, and combined into a disciplinary framework known as the SE Lifecycle. This may have been appropriate when most SE activities were focused on large-scale physical systems, but with wider application of SE they have become more distinct and separated in their purpose.

It is important to note that there are two established definitions of the term "Lifecycle" (Merriam-Webster):

1. "the series of stages in form and functional activity through which an organism passes between successive recurrences of a specified primary stage" (multi-generational)
2. "a series of stages through which something (such as an individual, culture, or manufactured product) passes during its lifetime." (single generational)

Systems Engineering and the "Systems Lifecycle" as defined by ISO/IEC/IEEE 15288:2015 and the Project Management Institute's (PMI) project lifecycle tend to follow the second definition. Design Engineering, Software Engineering, and Enterprise Engineering models tend to match the first definition better.

ISO/IEC/IEEE 15288:2105 defines a set of process descriptions for describing the lifecycle of systems as both an engineering cycle and a project lifecycle viewpoint. In other words, the Vee-Model representation of SE standards and DoD Acquisition guidance reflects a single pass through engineering and program lifecycle activities but the actual system lifecycle, the "experiences of the system itself," will progress through a number of such engineering and program lifecycles.

Thullier and Wippler note that in the lifecycle of the system itself the "experience of the system" must be evaluated in periods and across levels of temporal or time invariance. In their description the lifecycle a system progresses (experiences its life) from idea; to a virtual existence in models, documents, software, and today many digital artifacts; then to a physical existence. SE technical and management process divides these into stages. SE processes recognize "within each level [of abstraction], we may distinguish periods of time which we may observe the integrity of the structure and behavior of the system [as invariant]." We may use these periods to enable interdisciplinary and collaborative activities, referred to as phase gates or decision points. Virtual artifacts by their nature can cycle through more rapid periods of change than physical artifacts (Thullier and Wippler 2013).

Thullier and Wippler also note that program lifecycle phases "are aligned (or mixed in) with key steps (or stages) of the system lifecycle. This allows us to fix program phases on integrated, coherent, and stable states of the system in question, and thus to make important decisions at precise moments in the life of the system." They further note that the engineering lifecycle is: "the process that consists of moving from need…to an optimized solution – i.e. the best compromise integrating all constraints (cost/ time/performance) for the entirety of the phases and situations involved in the system lifecycle...This should not, however, be taken to mean that these processes must be carried out in a sequential manner" (Thullier and Wippler 2013). In other words, the idea that the system lifecycle, the program lifecycle, and engineering lifecycles can be combined together is a fallacy. There are "periods of temporal invariance" where we can view these lifecycles together in order to make important decisions, otherwise they should be considered as independent. **Trying to force them to remain in lockstep limits our ability to be iterative and responsive.**

It is important to note that systems engineering lifecycles and processes are not new, they have just evolved in different ways since first envisioned in the 1960's. Stanley Shinners in the 1967 book "Techniques of Systems Engineering" first introduced the concept of SE as the methodological approach to define, realize, and deploy a system inherent in today's SE lifecycle processes. Shinners defined the general techniques of SE that exist today: understand the problem, consider alternative solutions, choose the most optimum design, synthesize the system, test the system, compare test results with requirements and objectives, and update the system characteristics and data. This early process flow represents the basis for SE as the "technical and management driven systems oriented problem-solving process" that permeates much of the SE literature and DoD practice today (Shinners 1967). It also is the basis of software DevOps practice. This "systems engineering rigor" should not be changed but must be applied to all systems, both virtual and physical, in any program management lifecycle. What is changing today with the advance of digital computing is how we maintain SE rigor using the modernized data –>transform–>analyze–>decide flow referred to in Figure 9.

Finally, Arthur David Hall in A Methodology for Systems Engineering (1962) stated that SE must consider the environment the system enters into: "the environment is the set of all objects outside the system: (1) a change in whose attributes affect the system and (2) whose attributes are changed by the behavior of the system." Thus, we cannot bound the system away from its external environment but must consider the experience of the system to be affected both by the technical and management processes that evolve the system and the external situations that seek to adapt the system. Ludwig von Bertalanffy in General Systems Theory (1968) noted that systems can be divided according to levels of complexity into systems, supra-systems, and subsystems. The different levels interact and are not independent of each other. While engineering lifecycle should be interested in decomposition of system into subsystems, the system itself should not be managed independently from its supra-system. The program lifecycle should ideally consider both subsystem and supra-system interdependencies.

The Supra-System Model: the SE Modernization Mental Model

Thus, four individual lifecycles may affect the "experience of the system." These must be distinguished if we want an SE process model that reflects any acquisition pathway with the SE rigor we have been accustomed to in historical SE and acquisition lifecycle process models. One is the lifecycle of the system itself and potentially of the offspring; it produces (both aspects of the lifecycle definition). Two others are the engineering and program or project lifecycles, which conduct processes internal to the life of the system. Finally, is what we call the "supra-system" lifecycle, which reflects the direct experiences of the system itself in its operational context as related to the closest other systems it interacts with; A supra-system is defined is a larger system that integrates or contains other systems.

In addition to recognizing that each of the four lifecycle/process models may be individually relevant; the roots of our integration framework of Figure 9 require that each of these lifecycle processes must evolve to address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle. Much of this data is contextual data in the supra-system. The established DoD views that combine management processes/lifecycle and technical processes/lifecycle do not fit well into the circular data-oriented mental model: technical (engineering) iterations and management (program) iterations have very different decision processes and respond to different types of data, with some content overlap. Furthermore, SE is a holistic or systems-oriented problem solving approach that reflects both the system and the supra-system. These are visualized together in Figure 13.

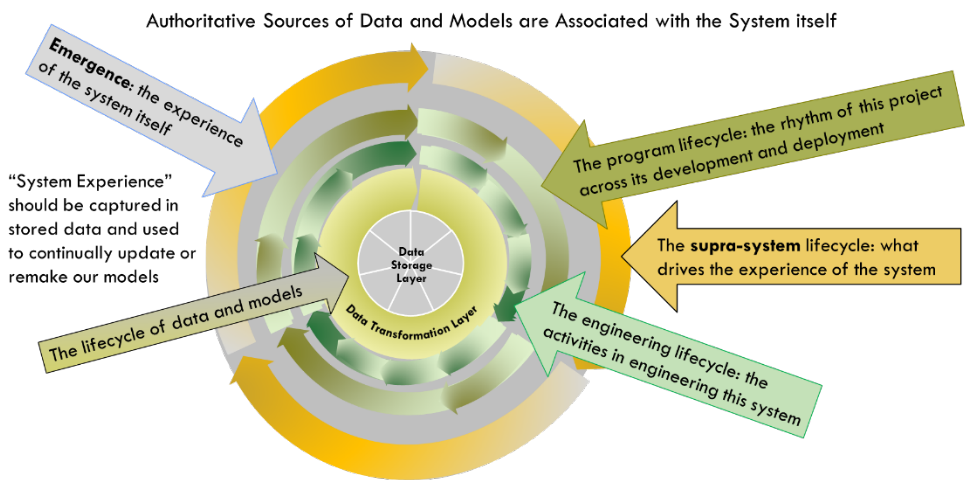


Figure 13. Multiple lifecycles of interest centered on data and models

To reflect fully the model of Figure 13, the team shifted to developing a new conceptual view of the full SE Modernization Lifecycle, shown in Figure 14. This is the Supra-system model. This view is an attempt to capture everything associated with DoD engineering and acquisition activities in one mental model. It must be tailored and redrawn based on differing types of development, delivery, and support processes. This view is complex, but with study, it becomes insightful in several ways. First, it illustrates systems engineering as a cyclic approach, rather than a linear one. Although almost all literature attempting to standardize on a lifecycle model will say that activities are ongoing and should continue through the lifecycle, the circular illustration drives this point home more visually and directly.

Second, it captures the view that the "experience of the system itself" is a continuous journey that could be affected by multiple external supra-system evolutions, multiple program cycles, and multiple engineering cycles.

Third, this integration framework makes the digital transformation clear using a layered model with data storage and transformation at the core, models as the data transformation layer, and systems engineering process areas as the outer layers. Data and models can be associated with any activity in the system lifecycle, and must live their lives with the full experienced life of the system, not just a single program lifecycle.

Fourth, it organizes the colors of the outer ring and related SE process in the "Build/Measure/Learn" context, capturing the underlying goal of continuous iterative development.

Finally, it recognizes that data and models may come from any experience of a system, including pre-Material Development Decision (MDD), post Operational Test and deployment and support. In particular, mission engineering and operational test and evaluation activities explicitly learn and measure relationships between the system and supra-system and produce data that should be retained to inform other activities across the full SE Modernization lifecycle.

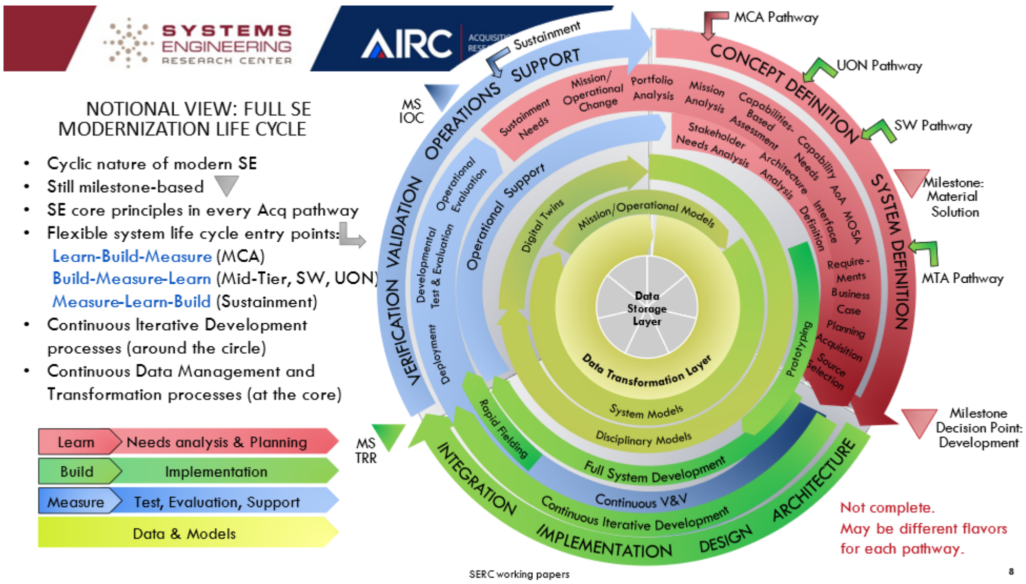


Figure 14. The Supra-system Model
(Cleared for public release DOPSR Case # 23-S-0026)

The integration framework depicted here incorporates traditional DoD acquisition milestones (triangles). However, it highlights them in the context of the multi-faceted work going on and where they fall within the broader context. It highlights the different DoD acquisition pathways and associate SE process instantiations. These fundamentally begin at different points in the system life cycle but should still follow a rigorous SE process model.

Summary and Use

This research found:

“**The value of SE Modernization will be realized in more seamless and efficient transfer of data and models from underlying performance drivers through models to decisions, as well as ease of drilling back down from decisions to data**.”

And:

“**New SE lifecycle processes must evolve that address shared and authoritatively managed sets of digital data and models associated with the full lifecycle of the system itself, not just a single acquisition program lifecycle**.”

In addition, newer systems engineering sub disciplines like software systems engineering, information technology and enterprise architecture, distributed modeling & simulation, and automated manufacturing systems “view lifecycle process and technical review as something that is much more iterative than what is implied by current SE guidance.” This research found that the mission of SE Modernization, contrary to much of the published “future of SE” literature, should focus less on models and more on “increasing responsiveness,” by promoting lifecycle processes that “increase the number of iterations and shorten the cycle time between them.” This led to our vision statement:

“**The vision of SE Modernization is to use data and models to create a more agile and responsive acquisition system that can quickly and effectively meet the needs of the warfighter**.”

Additionally, this research found that data management has become a necessary systems engineering process area for today's systems and enterprises, and this needs to be added to SE lifecycle process standards and associated education and training.

Finally, the research found that current literature does not distinguish between system, program, engineering, and supra-system lifecycle processes and current acquisition guidance often "forces them to remain in lockstep which limits our ability to be iterative and responsive." Acquisition processes should provide more flexibility to the systems engineering community in how they use SE lifecycle processes, and acquisition pathways in the AAF should provide more guidance on the use of SE in each pathway.

This discussion is not a call to change the whole Defense Acquisition System to a new model. It defines a framework that hopefully better integrates across all defense acquisition activities including those that exist outside of an approved material development program. It also tries to place systems engineering in the context of any acquisition pathway. Its main purpose is to refocus the discussion on the system instead of the acquisition of the system or the development of the system, because data and models will have lifecycles that extend beyond a single program or development cycle.

References

L. von Bertalanffy, General System Theory; Foundations, Development, Applications. New York: G. Braziller, 1969.

DAU Acquisition Encyclopedia, https://www.dau.edu/acquipedia

DAU Systems Engineering Fundamentals, DAU Press, January 2001.

Office of the Deputy Director for Engineering, Office of the Under Secretary of Defense for Research and Engineering, Systems Engineering Guidebook, February 2011, https://ac.cto.mil/wp-content/uploads/2022/02/Systems-Eng-Guidebook_Feb2022-Cleared-slp.pdf

N. Geier and K. Alexander, "Systems Engineering Modernization Initiative," NDIA Systems and Mission Engineering Conference, November 2021.

A. D. Hall, A Methodology for Systems Engineering. Van Nostrand, 1962.

ISO/IEC/IEEE 15288:2015, Systems and software engineering — System life cycle processes.

T. McDermott and W. Benjamin, SERC Final Technical Report SERC-2022-TR-009, Program Managers Guide to Digital and Agile Systems Engineering Process Transformation, September 2022.

Mil-Std-499 (USAF), 17 July 1969.

Mil-Std-499A (USAF), 1 May 1974.

P. Thullier and J. Wippler, "Finding the Right Problem," in D. Luzeaux and J. Rualt, eds., Large Scale Complex Systems and Systems of Systems, ISTE, 2011.

Systems Engineering Body of Knowledge, www.sebokwiki.org.

An Agile Model-Based Systems Engineering Method to Accelerate Value Delivery

Ronald Giachetti—is a Professor of Systems Engineering at the Naval Postgraduate School (NPS) in Monterey, CA. He has over 30 years' experience teaching and conducting research in model-based systems engineering, system architecting, and system of systems engineering. He has published extensively with over 50 technical papers, including a textbook on the design of enterprise systems. He has lectured internationally in Europe, Latin America, and Asia. He has held multiple leadership positions including Chair of the Systems Engineering Department and Dean of the Graduate School of Engineering at NPS. He is currently Chair of the Corporate Advisory Board for the International Council on Systems Engineering (INCOSE). He holds engineering degrees from Rensselaer Polytechnic Institute, New York University—Polytechnic, and North Carolina State University. [regiache@nps.edu]

Abstract

Agile methods have shown their value in the software domain and are now the dominant approach to software development. All programs would like to experience similar benefits of customer satisfaction while being on time and within budget. Yet, adopting agile methods to larger scale programs as well as programs involving both hardware and software remains fraught with difficulty, and programs lack guidance on how to tailor these methods. Moreover, defense programs need to adopt model-based systems engineering and digital engineering, which is often seen as counter to agile methods. To overcome this challenge, we cast agility as a mindset to be adopted rather than a set of practices. This paper presents a method that is plan-based at the macro level but implements agility at the micro level. The paper demonstrates the approach for the development of a microgrid for a military base. We discuss the merits of combining the approach and why it is suitable for many defense acquisition programs.

Introduction

We all want to be faster and more agile so as to more quickly respond to changes in what has become a very dynamic strategic and operational environment. Unfortunately, this is not the experience of many Department of Defense (DoD) program managers, some of which spend 2 years or more just gathering needed information to meet acquisition requirements (GAO, 2015). These programs—developing large-scale, complex systems—are under a lot of pressure to more quickly design, develop, and deploy systems (GAO, 2022). The military wants capability delivered now. However, many systems experience long and costly development times. For instance, see the latest news about the Air Force's vision system for aiding mid-air refueling of planes (Losey, 2023). What these organizations want is to be more agile. They want to be able to get capability into the hands of their customers more quickly. These organizations, as well as their customers, see that many software companies in Silicon Valley are able to quickly release and constantly update apps using agile software engineering methods. There is a tremendous push to adopt these agile methods to acquisition programs.

The defense acquisition community is also in the midst of a major transformation with the adoption of digital engineering and its subset of model-based systems engineering (Zimmermann, 2019). Digital engineering promises greater efficiency and effectiveness of the system development process through an integrated tool set connecting all the system designers and other stakeholders who can seamlessly share information.

Engineering is a goal-oriented activity, and traditional engineering is bottom-up, in which an engineer identifies a problem and designs a product to address the problem (Pahl

& Beitz, 2013). However, as systems became large in the 1940s and 1950s, the prevailing engineering approaches feel short. The systems being envisioned were too complex, too large, involved many disciplines, and had many requirements, which overwhelmed traditional approaches. Systems engineering grew out of this environment as a top-down approach to organize and control the technical development of the system. Now, there is growing evidence that the plan-driven systems engineering processes, such as the systems engineering vee model adhered to by most defense acquisition programs, are inadequate for some of the challenges facing programs today. Programs face what is termed a volatile, uncertain, complex, and ambiguous (VUCA) environment. It is near impossible to adequately plan long-term projects in this highly dynamic environment. Moreover, the sequential engineering vee process is too cumbersome and slow for incorporating changes due to emerging technology and requirements changes.

The DoD seeks the speed, agility, and innovation seen in many of the technology companies found in places such as Silicon Valley. Towards this end, the DoD has open Defense Innovation Units (DIU) in multiple cities. One of the practices that enable the observed speed to market and innovation is agile development. Agile practices have been very successful in the development of software products and services, often on smaller scales, such as websites and apps. The agile practices are now being scaled and extended to systems development involving both hardware and software and for much larger, more complex systems.

This paper contributes to the literature thoughts on how to adopt and adapt agile methods to the large-scale, complex projects involving both hardware and software typical of defense acquisition programs. Straight-forward taking of agile practices from software engineering is not possible for these types of systems. Instead, we propose a hybrid approach preserving plan-driven aspects that remain appropriate for large-scale, complex programs with hardware and mingle in principles of agile practices.

Agile Development

Agile development is a software development approach that emphasizes iterative and incremental development, continuous delivery, and customer collaboration. Agile methods value individuals and interactions over processes and tools, working software over comprehensive documentation, and responding to change over following a plan. Agile is beneficial in dynamic environments when the requirements may change or new requirements discovered during development; in the face of complexity of the problem, system, or organization and resulting in learning as you go with the inevitable course corrections.

Agile development executes iterative and incremental development through the use of sprints, which are short periods, usually 2-weeks in length, during which small teams scope, analyze, design, build, and test small increments of working code. This form of time-boxing flips the triple constraint of project management on its head (see Figure 1). Plan-driven methods usually hold the scope or requirements invariant, and then budget and schedules adjust (usually slip) to accommodate the scope. Agile methods hold schedule invariant as well as budget through a constant team size. As a result, the scope must change to accommodate both schedule and budget. Other differences with traditional plan-driven approaches are summarized in Table 1.

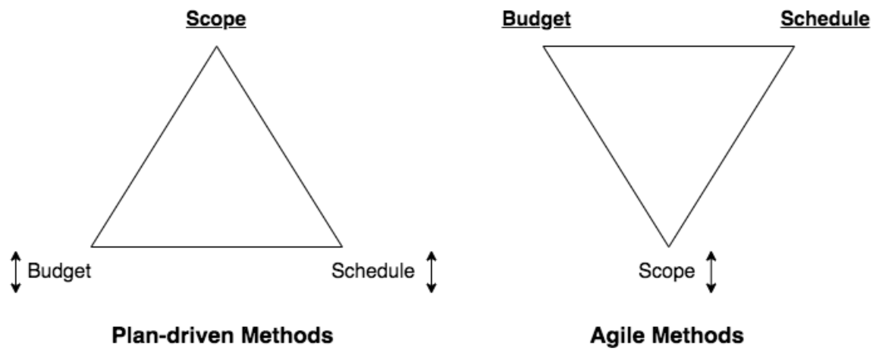


Figure 1. The Triple Constraint in Plan-Driven Vice Agile Methods

The Global Hawk program used iterative and incremental development (Henning & Walter, 2005). Consequently, the iterative and incremental approach is not completely foreign to the DoD. The Global Hawk program had increments of 1-year duration and allowed the operational users to change requirements based on evolving operational needs and what they learned from the previous increments. The increments were as follows:

1. Operationalized the existing system to provide a worldwide operating capability and established sustainable support system.
2. Expanded imagery intelligence (IMINT) and introduced initial signal intelligence (SIGINT).
3. Added full-spectrum SIGINT and defensive threat awareness.
4. Improved the radar to track moving ground targets. Added airborne surveillance and enhanced airspace operations and survivability.
5. Completed full-spectrum operations, expanded communications, and hardened for extreme environments including nuclear, biological, and chemical.

Table 1. Comparison of Plan-Driven and Agile Programs

Plan-Driven Program	Agile Program
Align budget, schedule, and resources (e.g., test range)	Iterative and incremental development of work products
Top-down design	Close and frequent engagement with stakeholders
Long lead-time items	Continuous verification
Interconnections with other systems	Self-managed teams
Identify and design for needed quality attributes (-ilities such as reliability, maintainability, cybersecurity, etc.)	Continuous integration
Comply with regulations and policies; ensure traceability	Rapid learning and risk reduction
Safety critical issues	

Digital Engineering

Digital engineering describes the use of models as the primary means of reasoning, analyzing, designing, documenting, and communicating about the system-of-interest (SoI).

Specifically, the DoD, a major proponent of digital engineering, defines *digital engineering* as “an integrated digital approach that uses authoritative sources of systems’ data and models as a continuum across disciplines to support life-cycle activities from concept through disposal” (Office of the Deputy Assistant Secretary of Defense for Systems Engineering, 2018). A system development project uses a myriad of models of the system, including descriptive models of the systems requirements and architecture, geometric models of all the system’s parts using computer-aided design (CAD), physics-based models of the system for analysis (e.g., finite element analysis, computational fluid dynamics, circuit design), operational models such as captured in discrete-event simulation, reliability models, and many other models of various aspects of the system. All these models would be part of the digital thread, in which changes to data in one model are propagated to all the other interrelated models.

Organizations need to create a digital engineering infrastructure in order to implement the digital engineering vision. Given no single tool exists, organizations must pursue a best of breed approach in which they select and integrate software tools for each of the domains and tasks in the system life cycle. Figure 2 shows the digital thread that emerges when you integrate together the entire tool set for a program. The models in the digital thread become the Authoritative Source of Truth (ASoT) for the program, meaning they are used in design, contracts, and so on.

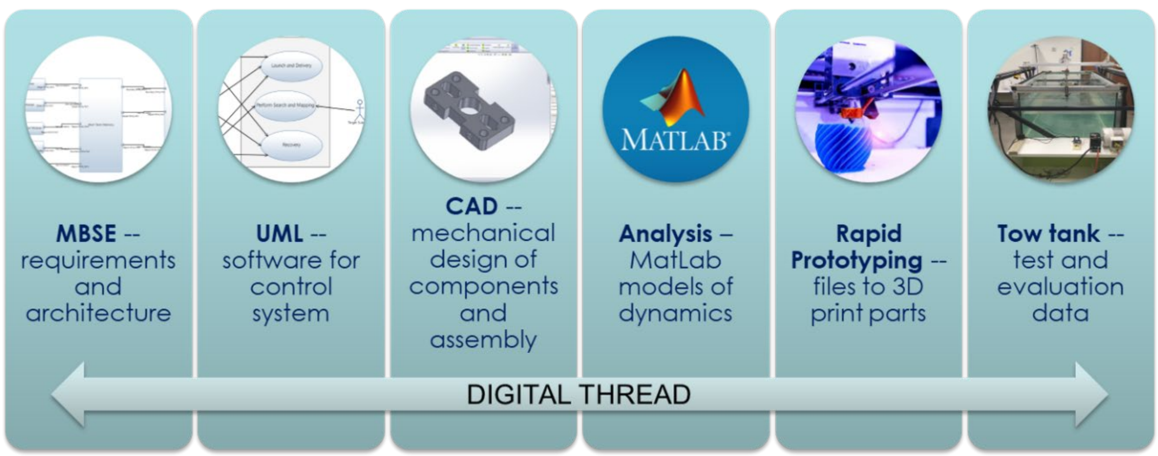


Figure 2. Digital Thread for a Program

Digital engineering can be an important enabler of agile practices on defense acquisition programs because it allows for short iterations of scoping, designing, building models, and testing models in the early phases of system development. This would be a deviation from agile method’s emphasis on working code as output of each sprint. Instead, we would have verified models as the output of a sprint.

Related Work

Agile methods have been widely adopted in software development projects to improve team collaboration, communication, and flexibility in responding to changes in customer requirements. However, the application of agile principles to systems engineering processes, particularly in the development of complex systems with hardware components, is still an area of active research and discussion. The International Council on Systems Engineering (INCOSE) has a team that has been looking at how agility can be infused or adopted by systems engineering organizations (Willett et al., 2021). Their work is part of the Future of Systems Engineering (FuSE) initiative of INCOSE.

Several studies have shown the benefits of applying agile principles to systems engineering processes. For example, Berczuk et al. (2012) showed that the use of agile methods in the development of a safety-critical system led to improved communication, increased customer satisfaction, and better project management. Similarly, Dove (2023) suggested eight principles for agile systems engineering. While the authors do not group the principles, we view four of them as emerging from self-organizing teams (Dove's common-mission teaming, attentive decision-making, shared knowledge management, and being agile), iterative and incremental development, attentive situational awareness, continual integration and test, and feature-based product line architectures.

Scaling agile to larger systems is another area of active research (Dingsøyr et al., 2019). Several frameworks have been proposed to scale agile methods to larger systems, such as the Scaled Agile Framework (SAFe) and the Large Scale Scrum (LeSS) framework (Knaster & Leffingwell, 2017). These frameworks provide guidance on how to coordinate multiple agile teams working on different parts of a larger system. Several studies have explored the effectiveness of scaling agile methods to larger systems. For example, McCaffery et al. (2017) showed that the use of SAFe in the development of a complex software-intensive system led to improved project planning, better coordination between teams, and increased stakeholder satisfaction. Similarly, Elssamadisy et al. (2018) showed that the use of LeSS in the development of a large-scale hardware and software system led to improved team collaboration, reduced project risk, and increased customer satisfaction.

Agile methods have been primarily applied to software development projects, but their application to hardware development is also an area of active research. Hardware development involves longer lead times, more complex dependencies, and greater risk than software development, making it more challenging to apply agile principles. Several studies have explored the application of agile principles to hardware development. For example, Yang et al. (2019) showed that the use of agile principles in the development of a hardware product led to improved communication, reduced project risk, and increased customer satisfaction. Similarly, Thakurta et al. (2020) showed that the use of agile principles in the development of an embedded system led to improved team collaboration, faster development cycles, and reduced project risk. Paasivaara and Lassenius (2019) described Ericsson's long journey of adopting agile to the design and development of their products.

Tailoring a Hybrid Plan-Driven and Agile Development Method

Viewing whether to adopt agile as an all-or-none proposition is the wrong way to be viewing the issue. Defining agile through the methods and practices in software engineering is probably not the best way to think about it either. Rather, a systems engineering organization needs to consider how agile they need to be. Stelzmann (2012) surveyed companies and came up with the suggestion that companies ask themselves two questions. First, to what degree is agility demanded by the market, technology, and other environmental factors? Second, to what degree can the organization be agile? The title of Barry Boehm and Rich Turner's book captures what we are saying in that they see it as balancing disciplined methods—that is, plan-driven methods with agile methods (Boehm & Turner, 2004).

Organization science has long recognized the most effective management style is often contingent upon various internal and external factors (Galbraith, 1973). This is called contingency theory, and it emphasizes the importance of situational analysis, flexibility, and decision-making based on the specific circumstances of each situation. Consequently, we view the best system development model as the fit between the organization, its people, and its culture; the system, how complex it is, how connected to other systems, new technologies; and the business environment, how dynamic it is, and the degree of uncertainty. Figure 3 shows multiple factors as continuums, with those on the left suggesting plan-driven methods are more appropriate, and those factors on the right suggesting agile methods are more appropriate. The first four factors fit the acronym VUCA—an apt description of the business environment facing many organizations. How large the system is comes into play because agile methods have been most successfully applied to smaller projects (although there are counter examples of large project successes). Organizations working in regulated environments and/or dealing with safety critical systems will need more planning, documentation, and traceability of requirements. When systems are part of systems of systems and must interoperate with other systems, then identifying those interfaces and ensuring interoperability is critical, which requires greater levels of planning. Large teams, multiple organizations, and geographically dispersed teams all suggest a need for more planning—certainly a lot more coordination.

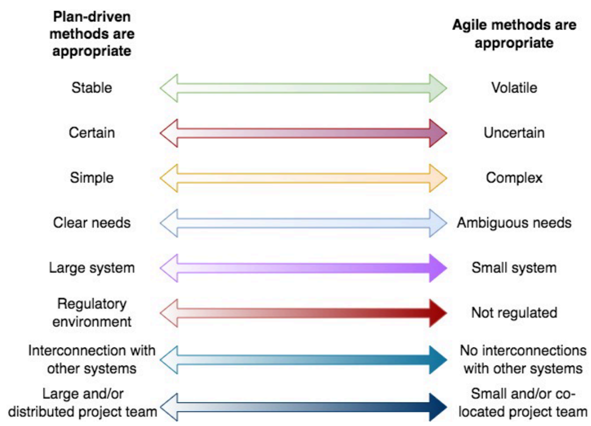


Figure 3. Factors for Deciding on Balance Between Plan-Driven and Agile Methods

Most companies doing large, complex systems development characteristic of the aerospace, defense, and even automotive sectors will likely find they fall to the right on some factors and to the left on others. Such an organization could benefit from greater agility for performing quick iterations to understand the requirements, early discovery of risk, and frequent customer feedback—all in order to deal with the market volatility, uncertainty, and ambiguous customer needs. However, those same organizations still need traditional planning and discipline because they operate in a regulated environment, the system has to interoperate with other systems, and the team is spread out between multiple organizations and time zones.

Planned and Agile System Development

Having established with contingency theory that many defense acquisition programs require both planning and agility, we embark upon how such a hybrid approach can be executed. The method adopts and adapts important agile concepts at multiple levels of development. The method iteratively and incrementally evolves the system models from which the necessary systems engineering artifacts can be generated. The method uses self-organizing teams who determine the best way to handle their work. The teams follow agile practices to learn fast and early through iterations of digital modeling, prototyping, and testing. Lastly, and importantly, is the adoption of an agile mindset by all the people on the program—meaning they trust the highly self-directed teams to do quality work, are committed to continuous delivery of work products and capabilities, measure progress based on work completed, and maintain close interaction and engagement of stakeholders.

Plan-Driven at Macro Level

Systems with hardware require some planning, because hardware often requires parts with long lead times, hardware cannot be refactored, and customers want to know when the system will be first deployed. Additionally, larger systems often have many interfaces and interactions with other systems that must be planned for and controlled. These issues are addressed by macro-planning of the overall system development process and by using a top-down approach starting with a system architecture. Figure 4 shows a high-level view of the system development activities, and Figure 5 shows the more detailed planning prior to the next milestone. The figures show there is extensive parallelism of the activities, but what is missing is the intensity of effort changes. Figure 4 shows verification and validation (i.e., testing) occurs continuously throughout the process. The frequent testing enables continuous design maturation and risk reduction. Within each phase are iterations in the spirit of design thinking of understanding, designing, building, and testing ideas through the use of models. Additionally, there are feedback loops and iterations between phases. For instance, as capabilities are analyzed and defined, the team might rethink how they framed the problem and revise their problem analysis. As a result, the design method progressively analyzes, designs, and evaluates the stakeholder needs, requirements, and mission to build the architectural products.

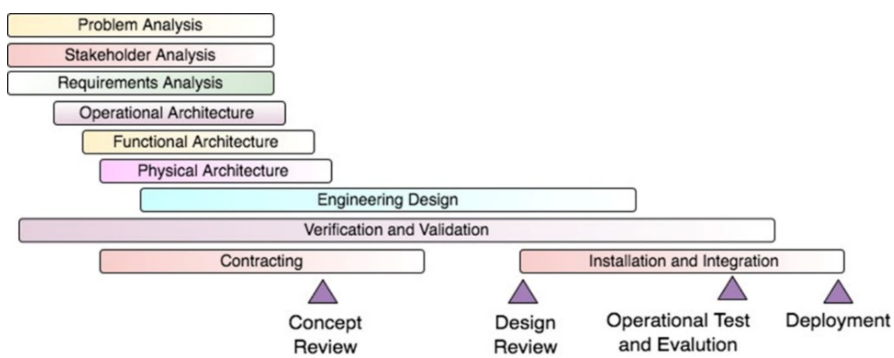


Figure 4. Macro-Plan for a Program Fitted to Acquisition Milestones

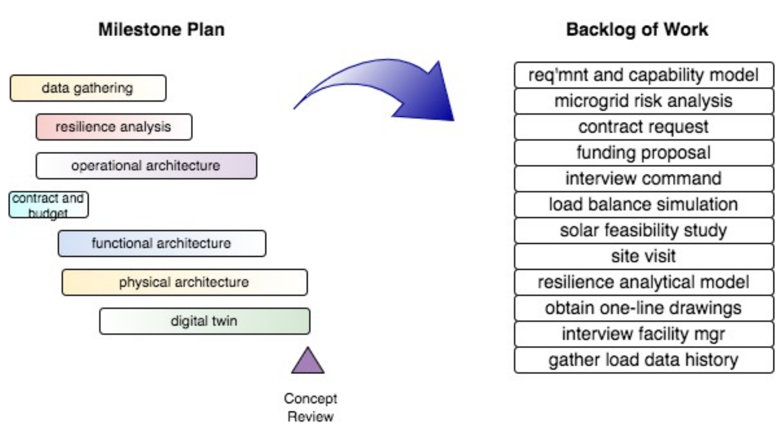


Figure 5. Milestone Planning and Generation of Work Backlog

An important planning document for defense programs would be a roadmap showing the incremental delivery of capability to the forces. Figure 6 shows an example roadmap for a microgrid project to achieve energy security at a military base.

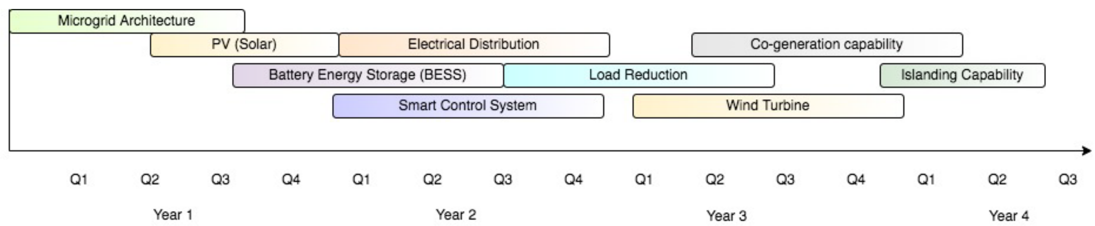


Figure 6. Capability Roadmap

Top-Down Development

The method is top-down, meaning we start with the high-level, holistic design of the entire system and then move on to the subsystems, assemblies, and lower levels. Top-down design is a hallmark of the systems engineering process. Top-down development in systems engineering is important because it provides a structured and organized approach to designing and building complex systems, ensures that the resulting system meets the required functionality and quality standards, helps to manage complexity, and facilitates the integration of subsystems and components. Top-down design allows for a systematic and organized process of designing and building a system that meets the needs of the users and stakeholders. Traditionally, by breaking down the system requirements into smaller subsystems and components, top-down development also makes it easier to manage the complexity of the system. It allows for the identification of potential problems early in the development process, which can then be addressed before they become major issues. Additionally, top-down development facilitates the integration of the subsystems and components, which is critical to ensuring that the system operates as a cohesive whole.

Agile at Micro Level and In Mindset

Agility is foremost a mindset of how to organize projects and conduct work. The agile mindset is shaped by the core values and principles underlining agile system development. These principles are put into practice through various agile methods for how to organize the project team, how to plan the project, and how to execute the work activities in the project. We now proceed to discuss the aspects of the method that are agile. Essential to the development method is working in an iterative and incremental fashion.

Iterative and Incremental Development of Work Products

Iterative development involves building a product through a series of cycles or iterations, with each iteration building on the previous one (see Figure 7). Each iteration includes planning, design, implementation, and testing activities. The goal of each iteration is to add new features, improve existing ones, and fix any issues or bugs that were discovered in the previous iteration. This approach allows developers to receive feedback from users and stakeholders early on, and to adjust the product accordingly.

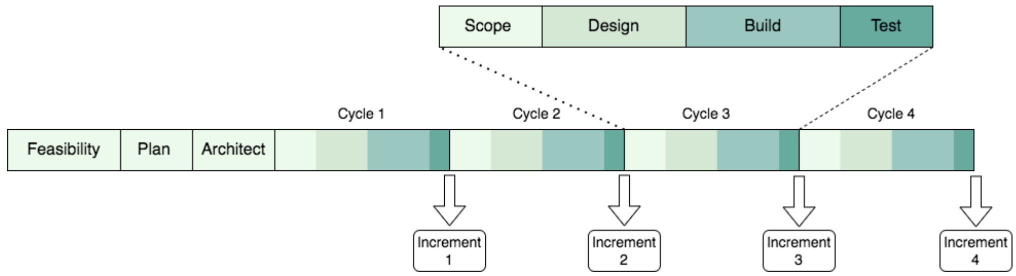


Figure 7. Iterative and Incremental Development Sprints

Empowered Teams

Empowered teams in agile development are teams that have been given the autonomy and authority to make decisions and take ownership of their work. This means that team members are trusted to self-organize and collaborate to deliver high-quality products (Ibarra & Scoular, 2019). In an empowered team, each member is responsible for their role and is accountable for the outcome of their work. They are encouraged to share their ideas and opinions and to challenge the status quo when necessary. They have a sense of ownership over their work and are motivated to deliver value to their customers.

Figure 8 shows the program organization for a microgrid consisting of self-organizing teams. Agile development emphasizes the importance of communication, collaboration, and feedback. Empowered teams are able to communicate freely, share information, and collaborate effectively to solve problems and achieve their goals. They are also able to receive feedback from stakeholders and customers, and use it to improve their work and deliver better results.

Empowered teams in agile development are an essential component of the agile methodology. They help to create a culture of continuous improvement and innovation, and enable organizations to respond quickly and effectively to changing customer needs and market demands.

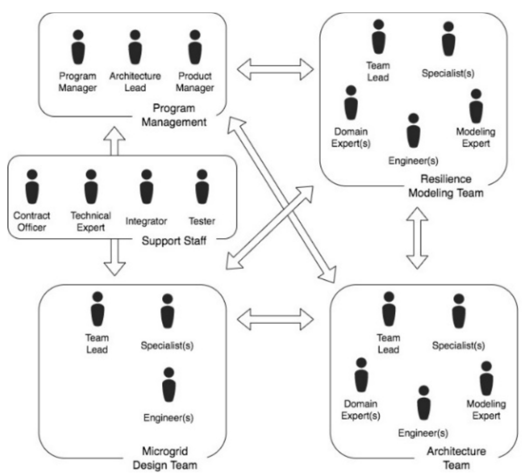


Figure 8. Agile Teams for a Microgrid Project

The agile teams will have a backlog of work identified during the planning phase that needs to be completed. The backlog is a prioritized list of capabilities, system features, intermediate artifacts (e.g., a model), or any task the team needs to work on. In large systems, the tasks sometimes might be just for risk reduction such as a feasibility study. The product owner, who is responsible for representing the stakeholders and defining the product vision, leads this effort.

The backlog is continuously refined and updated as new information becomes available or the team gains a better understanding of user needs. Items in the backlog are prioritized based on their business value, user impact, and technical feasibility, among other factors.

During sprint planning, which is a time-boxed meeting held at the beginning of each sprint, the team selects a subset of items from the backlog that they can commit to completing within the sprint (see Figure 9). The team also discusses the technical details of how they will implement each item and identifies any dependencies or risks that need to be addressed. The team then estimates the effort required to complete each item using a relative sizing technique, such as story points, and creates a sprint backlog, which is a plan of the work that they will undertake during the sprint. The sprint backlog serves as a guide for the team's work during the sprint, and progress is tracked daily during the daily standup meeting. At the end of the sprint, the team reviews the work completed and identifies areas for improvement in the next sprint.

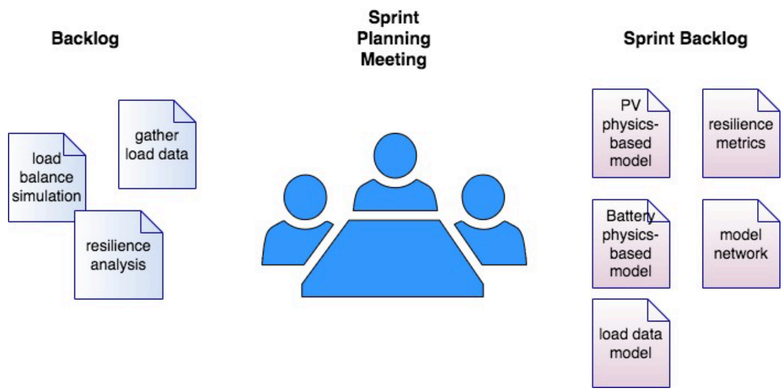


Figure 9. Sprint Planning Meeting Reviews Backlog and Determines Work Tasks to Complete

Continuous Integration

Continuous integration means the project teams are determining in each sprint how the multiple components of the system come together and function as a system. Early on in a program, the integration is of the various models and artifacts being developed by the teams. The digital engineer tools facilitate continuous integration because they can enforce consistency between the models. The benefit of continuous integration is it will reduce risk by identifying issues that occur only when components are integrated into subsystems, and subsystems are integrated into systems.

A program must do some planning in order for continuous integration to be feasible. Figure 10 shows the synchronization of a hardware component with its embedded software. Because hardware takes longer to develop, the sprint length is 4 weeks vice the 2 weeks common to software development. Different teams work on developing each component, and they conduct continuous integration by identifying and managing the dependencies between their components. This ends with an integration test of the functional prototype.

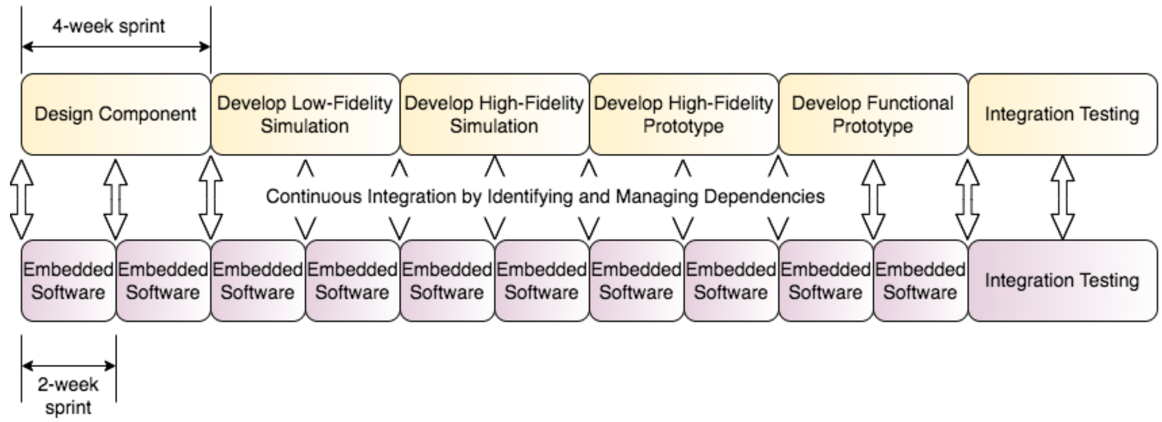


Figure 10. Synchronization and Continuous Integration of Software With Hardware

Continuous Verification and Validation

An important concept in agile development, enabled by iterative development and digital engineering tools, is the continuous verification and validation (V&V) of all work products. The earlier a problem or issue is identified, then the lower the cost to fix the problem. The continuous verification of products—including models, code, prototypes, and so forth—ensures the project teams are always working with quality, functional products. Digital engineering tools enable teams to do the verification on models very early in the system development method. For instance, a team can verify a concept of operations (CONOPs) using simulation, thus lending greater confidence in the overall system design concept. Validation ensures what is being developed is useful and valued by the end users. For this reason, agile methods call for close and continuous interaction with users. Multiple means support the close interaction, including having such stakeholders involved with the program directly, having product owners to represent end user needs, and also through DevOps, which creates a feedback loop from operations to the development team (Miller et al., 2021).

Summary

The research examined the characteristics and principles of agile methods through the lens of how they could be adopted within the defense acquisition community. A comparison with plan-driven approaches was also conducted. Together, through the lens of contingency theory, the paper proposed a hybrid approach combining the plan-based perspective at the macro level and adopting agile practices at the micro level. The method is enabled by digital engineering, which allows for iterations of model development and test during the early phases. The paper also shows how important aspects of systems engineering such as top-down refinement can be preserved in the hybrid development environment.

If agile is a mindset, then adopting agile involves a transformation of the DoD organizational culture, and such transformations take a lot of time and dedicated leadership. However, adopting agile principles into defense acquisition promises to increase the ability of the DoD to better respond to quickly changing requirements and other environmental uncertainties. The result can be getting some capability into the hands of the warfighter sooner.

References

Berczuk, S., Appleton, B., & Konieczka, S. (2012). Agile in a safety-critical project: An experience report. *IEEE Software*, *29*(1), 77–85.

Boehm, B., & Turner, R. (2004). *Balancing agility and discipline: A guide for the perplexed*. Addison–Wesley Professional.

Dingsøyr, T., Falessi, D., & Power, K. (2019). Agile development at scale: The next frontier. *IEEE Software*, *36*(2), 30–38.

Elssamadisy, A., Abu-Tayeh, G., & Brown, T. (2018). *Scaling agile and lean development in the enterprise*. Pearson Education.

Galbraith, J. R. (1973). *Designing complex organizations*. Addison–Wesley.

GAO. (2015, February). *DOD should streamline its decision-making process for weapon systems to reduce inefficiencies* (GAO-15-192).

GAO. (2022, June). *Weapon systems annual assessment: Challenges to fielding capabilities faster persist* (GAO-22-105230).

Hawker, N., & McBride, T. (2016). The use of agile development methods in a large-scale software-intensive system. *Journal of Systems and Software*, *122*, 1–16.

Henning, W. A., & Walter, D. T., (2005). *Spiral development in action: A case study of spiral development in the Global Hawk Unmanned Aerial Vehicle program* [Master's thesis, Naval Postgraduate School].

Ibarra H., & Scoular, A. (2019, November–December). The leader as coach. *Harvard Business Review*.

Knaster, R., & Leffingwell, D. (2017). *SAFe 4.0 distilled: Applying the Scaled Agile Framework for lean software and systems engineering*. Addison–Wesley Professional.

Losey, S. (2023, February 22). After long, costly road, Air Force happy with new KC-46 vision system. *Defense News*.

McCaffery, F., Phalp, K., & Jeary, S. (2017). Scaling agile: An empirical study of large complex software systems. *Journal of Systems and Software*, *131*, 218–230.

Miller, A. W., Giachetti, R. E., & Van Bossuyt, D. L. (2022). Challenges of adopting DevOps for the combat systems development environment. *Defense Acquisition Research Journal*, *29*(1).

Office of the Deputy Assistant Secretary of Defense for Systems Engineering. (2018, June). *Digital engineering strategy* [Technical report]. DoD.

Paasivaara, M., & Lassenius, C. (2019). Empower your agile organization: Community-based decision making in large-scale agile development at Ericsson. *IEEE Software*, *36*(2), 64–69.

Pahl, G., & Beitz, W. (2013). *Pahl/Beitz Konstruktionslehre: Methoden und Anwendung erfolgreicher Produktentwicklung*. Springer–Verlag.

Stelzmann, E. (2012). Contextualizing agile systems engineering. *IEEE Aerospace and Electronic Systems Magazine*, *27*(5), 17–22.

Thakurta, R., Mukhopadhyay, D., & Das, D. (2020). Applying agile practices in embedded system development: An industrial case study. *Journal of Systems and Software*, *168*, 110660.

Willett, K. D., Dove, R., Chudnow, A., Eckman, R., Rosser, L., Stevens, J. S., Yeman, R., & Yokell, M. (2021, July). Agility in the future of systems engineering (FuSE): A roadmap of foundational concepts. *INCOSE International Symposium*, *31*(1), 158–174.

Yang, J., Lappas, T., Egan, M., & Bagaria, N. (2019). Applying Agile methods to hardware product development. *Journal of Systems and Software*, *154*, 1–14.

Zimmerman, P., Gilbert, T., & Salvatore, F. (2019). Digital engineering transformation across the Department of Defense. The Journal of Defense Modeling and Simulation, 16(4), 325–338.

.

Development of Digital Engineering Artifacts in Support of MBSE-Based Test Planning, Execution, and Acquisition Decision Making

Jeremy Werner—PhD, ST was appointed DOT&E's Chief Scientist in December 2021 after initially starting at DOT&E as an Action Officer for Naval Warfare in August 2021. Before then, Werner was at Johns Hopkins University Applied Physics Laboratory (JHU/APL), where he founded a data science–oriented military operations research team that transformed the analytics of an ongoing military mission. Werner previously served as a Research Staff Member at the Institute for Defense Analyses where he supported DOT&E in the rigorous assessment of a variety of systems/platforms. Werner received a PhD in physics from Princeton University where he was an integral contributor to the Compact Muon Solenoid collaboration in the experimental discovery of the Higgs boson at the Large Hadron Collider at CERN, the European Organization for Nuclear Research in Geneva, Switzerland. Werner is a native Californian and received a bachelor's degree in physics from the University of California, Los Angeles where he was the recipient of the E. Lee Kinsey Prize (most outstanding graduating senior in physics). [jeremy.s.werner.civ@mail.mil]

Craig Arndt—currently serves as a principal research engineer on the research faculty of the George Tech Research Institute (GTRI) in the System Engineering Research division of the Electronic Systems Lab. Arndt is a licensed Professional Engineer (PE), and has over 40 years of professional engineering and leadership experience. Arndt holds engineering degrees in electrical engineering, systems engineering and human factors engineering and a Masters of Arts in strategic studies form the U.S. Naval War college. He served as Professor and Chair of the engineering department at the Defense Acquisition University, and as technical director of the Homeland security FFRDC at the MITRE Corporation. In industry he has been an engineering manager, director, vice president, and CTO of several major defense companies. He is also a retired naval officer. [Craig.Arndt@gtri.gatech.edu]

Abstract

In order to effectively implement MBSE in all aspects of testing and in system engineering for the department of defense we need to create models of the acquisition system (acquisition process, as described by the acquisition pathways), models of the critical acquisition artifacts (CDD, RFP, Acq Strategy, SEP, TEMP, AoA, etc.), and key events (technical reviews, SFR, PDR, CDR, TRR, etc.).

Many related efforts are underway throughout the DoD and DOT&E's Strategic Initiatives, Policy, and Emerging Technologies (SIPET) division has sponsored Model-Based TEMP (MBTEMP) Workshops at Johns Hopkins University Applied Physics Laboratory (JHU/APL) in July 2022 and February 2023 to foster collaboration and knowledge exchange to advance MBSE for T&E.

Most of these efforts are looking at one of three paths for creating MBTEMPs:

1. Digitizing the current acquisition artifacts;
2. Creating a hybrid MBTEMP based on the current format and integrating with different models that are being developed within MBSE environments;
3. The development of a completely new method to do T&E planning in a model-based system.

This report summarizes the presentations of the February 2023 workshop, along with the challenges and actions captured there, so as to provide the reader an overview and community entry-point to the many T&E focused digital engineering (DE) efforts that are ongoing across our Department.

Keywords: Model Based System Engineering, Acquisition artifacts, Model based test planning, Digital TEMP

Introduction

The transformation from the historical, document-based acquisition system to DE is resulting in some of the most significant changes to the way the DoD has engineered and developed weapon systems in decades. The shift to the use of DE will not only impact the DoD but the entire military industrial complex. Coined by President Eisenhower in a 1961 address to the American people, the “military-industrial complex” includes the contractors that develop and manufacture the nation’s combat systems (History.com Editors, 2009).

In some ways, the transition to DE is the DoD’s reaction to the larger endeavor in the engineering community to reduce development time and cost by using digital data management technologies across development and manufacturing enterprises. In the DoD’s “Digital Engineering Strategy,” the DoD states that “current acquisition processes and engineering methods hinder meeting the demands of exponential technology growth, complexity, and access to information” (DoD, 2018). DoD leadership believes that DE will enable the DoD to meet the current and upcoming challenges to delivering new capabilities to the warfighters in support of the DoD’s numerous complex missions. To accomplish this, it is crucial to have a realistic DE strategy in place that can be implemented with new DE technologies while maintaining compliance with current acquisition processes. The development of standardized digital data about systems under development and test has other significant advantages. Specifically, the potential of digital systems to accelerate acquisition programs, and the ability to more effectively manage large numbers and systems (portfolios), and mission sets.

The defense acquisition system is defined and governed by both federal law and DoD regulations. The majority of these rules and processes are contained in the Defense Federal Acquisition Regulations (FAR), DoD Instruction 5000.02, and the Defense Acquisition Guidebook (DAG). The methods used across the DoD to develop requirements, perform systems engineering, select vendors, and manage contracts are embedded in these regulations. Included in these processes is the generation and maintenance of major acquisition artifacts. These artifacts have traditionally been written planning documents and analysis that play a major part in both coordinating the agreed-upon approach to the development, T&E, and fielding of systems among decision makers and oversight organizations. These documents have for decades been static; in many cases they have not been effectively updated and managed throughout the lifetime of a programs. As a result, they have less value to the overall success of programs that they are created to support.

None the less, the creation of artifacts is a critical part of the acquisition process, as these artifacts are used to manage acquisition processes and decisions. As part of the effort to digitize the acquisition and the engineering process, these artifacts also need to be digitized; the need to provide decision makers better data to make decisions is one underlying diver for digitizing these artifacts. One of the key acquisition artifacts that needs to be digitized is the Test and Evaluation Master Plan (TEMP) that captures the key elements of acquisition programs’ T&E strategy and associated resources and schedule.

As part of the ongoing effort to advance the state of practice in the use of digital engineering and model-based systems engineering in DoD test and evaluation Model-Based TEMP (MBTEMP) Workshops have been conducted at Johns Hopkins University Applied Physics Laboratory (JHU/APL) in July 2022 and February 2023 to foster collaboration and knowledge exchange to advance MBSE for T&E.

The next section of this paper is a review of the work that was presented at these workshops.

Summary of February 2023 MBTEMP Workshop Presentations

Note: These summaries are impartial and do not indicate any endorsement on behalf of DOT&E. All complete presentations from the workshop are available for the community here: https://www.trmc.osd.mil/wiki/download/attachments/184156180/mb_temp_workshop_2_2023-02-26.zip?api=v2

Jessica Ma, JHU/APL—Background from Workshop 1

Jessica Ma provided an overview of the first MBTEMP workshop sponsored by DOTE's SIPET division and host at JHU/APL in July 2022. The first workshop kicked off with an introduction to the fundamentals of digital engineering and its application to DoD programs provided by Edward Kraft. From there, Suzanne Beers provided a discussion on the key role of using Integrated Decision Support Keys for developing T&E strategies. DOT&E's Chief Scientist, Jeremy Werner, then provided an overview of his objectives with an emphasis on the development of MBTEMPs. Karl Glaeser then provided an overview on the Navy's iTEMPS effort to develop fully-integrated digital T&E strategies, inclusive of not just TEMPS but actual test data and assessments, across the DoN; although the Navy's strategy involves modern digital technologies such as web-based applications and SQL databases it is unique in that it does not invoke SysML. Craig Arndt and Mike Shearin provided an overview of GTRI's MBTEMP-associated efforts. Praveen Chawla of Edaptive Computing, Inc., demonstrated a model-backed word processing and content management solution that DOT&E is funding the development of for MBTEMPs. The fundamentals of SysML were then introduced, which was followed up with a demonstration of a SysML model for the MBTEMP using a torpedo as an exemplar. Finally, table top exercises were conducted to explore future efforts.

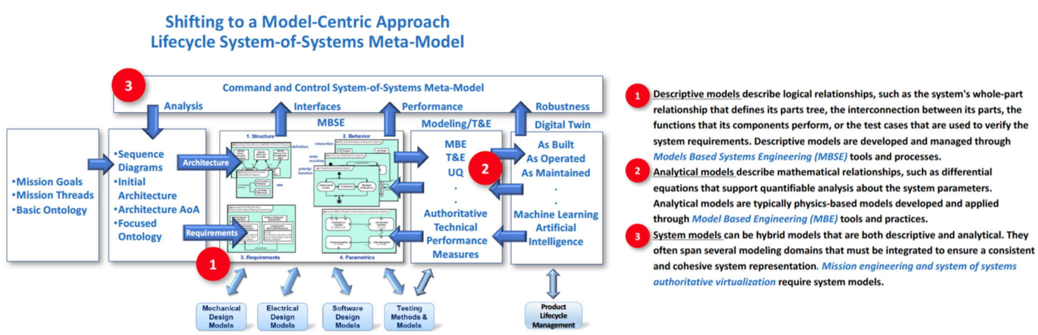


Figure 1. Life Cycle System of Systems Meta-Model

Ed Kraft, JHU/APL—Model-Based TEMP Workflow

Ed Kraft outlined a workflow for developing MBTEMPs (Figure 2) that link mission and systems engineering to the IDSK. He further described an approach for shifting left (and looking right) through the development of early (and late) virtual integrated and operational test. The approach emphasized using graph theory and iterative analysis as the mathematical basis for injecting testing of mission threads via mission model simulations, both early and often.

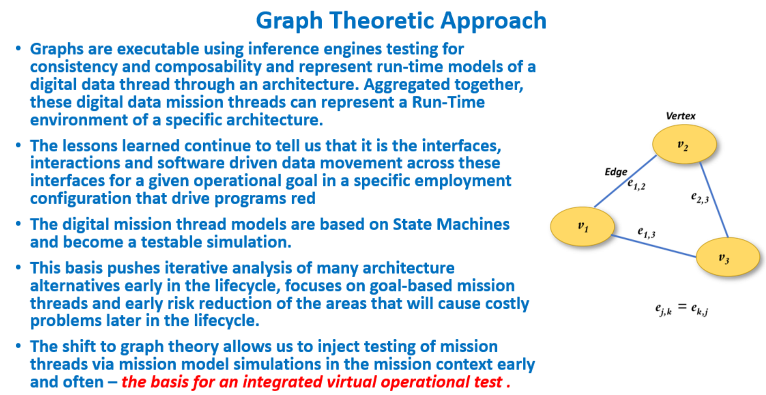


Figure 2. Model-Based TEMP Workflow

Darryl Howell, Contractor Support to DEM&S, R&E, SE&A—Digital/Mission Engineering

Darryl Howell presented R&E SE&A's views on digital and mission engineering with a T&E focus on behalf of Daniel Hettema Director, Digital Engineering, Modeling & Simulation (DEM&S, R&E, SE&A). DEM&S's vision for Digital Engineering was conveyed as:

1. Digital becomes the normal
2. Data and Information flow across disciplines and ecosystems throughout the life cycle
3. Powerful modeling, simulation, and visualization tools are used
4. AI is used to elevate experts and gain insights
5. Decisions are data driven and made with confidence earlier
6. Innovative culture is adaptive and continuously improves practices across the Defense Acquisition life cycle

with the goals of:

- Outpacing rapidly changing threats and technological advancements
- Delivering advanced capabilities more quickly and affordably with improved sustainability to the warfighter

DEM&S's near-term focus is on advancing a community of practice and body of knowledge for digital engineering (Figure 3).

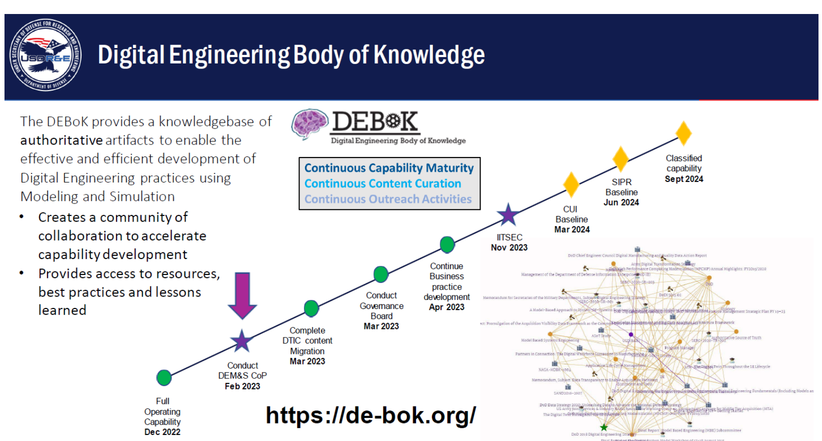


Figure 3. DEBOK

Randy Saunders, JHU/APL—MBTEMP Roadmap and Vision

Randy Saunders presented a roadmap (Figure 4) including a POAM with scheduled roll-out of MBTEMP solutions and outreach to future pilot programs. He described the MBTEMP vision and objectives of:

- Representing the content of current TEMPs to support processes dependent on TEMPs
- Maximizing reuse of model-based artifacts produced already
- Leveraging existing standards for MBSE in the DoD
    - SysML modeling diagrams and tools
    - Integrated Decision Support Key (IDSK, from DoD 5000.89)
- Minimizing effort to express T&E content in an MBTEMP
- Enabling continuous T&E feedback with agile programs
- Encouraging utilization of common infrastructure (at TRMC) for data sharing, analytic tools hosting, and collaboration between programs if they so choose

He detailed a value model for the MBTEMP while conveying that the MBSE will "transform T&E from a source of data to the source of authoritative knowledge for effective decisioning."

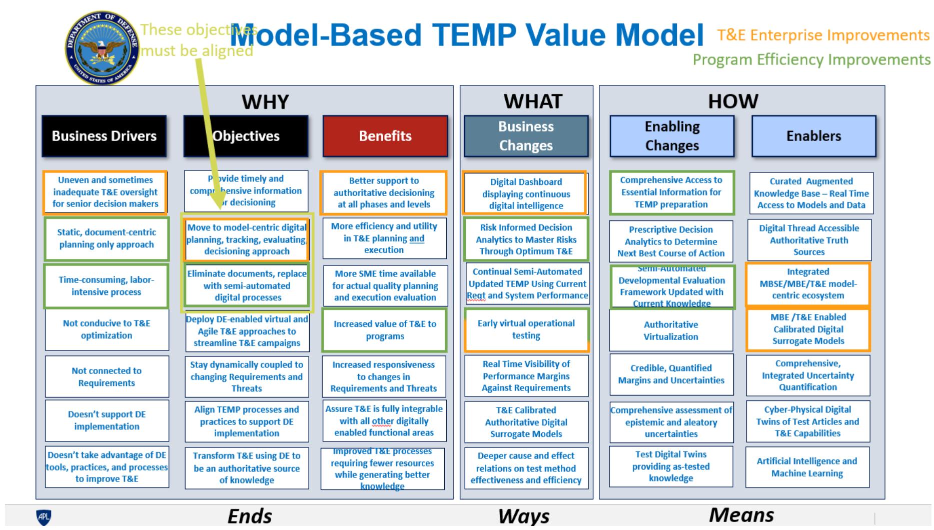


Figure 4. Model-Based TEMP

Jeremy Werner, DOT&E—DOT&E S&T Initiatives

Jeremy Werner provided an update on DOT&E's science and technology plan and associated implementation plan (Figure 5). The implementation plan is aligned to DOT&E's five strategic pillars (Figure5) shown below and it's overarching goal of: Transforming T&E to enable delivery of the world's most advanced warfighting capabilities at the speed of need.

Werner then discussed his FY23 objectives to advance:

- Enterprise data/knowledge management and analysis
- Credible, data-backed all-domain M&S as a service to include Uncertainty Quantification
- Sequential T&E
- Digital transformation and Model-Based Systems Engineering

- T&E of AI, Autonomy, Human Systems Integration (HSI), and Human Machine Teaming (HMT)
- Workforce upskilling, career-long learning, and career pathing.

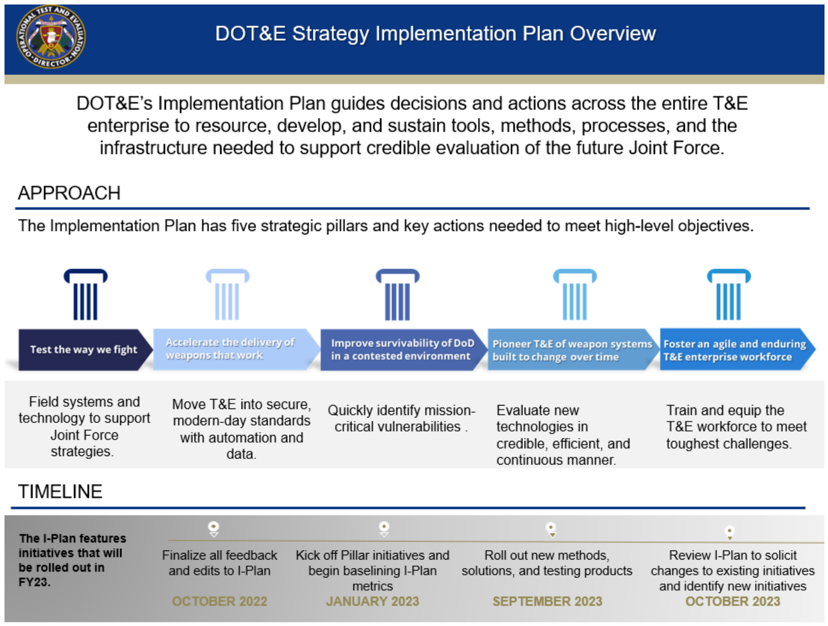


Figure 5. Five Strategic Pillars

Navreeta Singh, DOT&E and Princeton University—Digitally Implementing IDSK as a Relational Database

Navreeta Singh presented a proof of concept implementing an IDSK as a Relational Database Using the Mk 54 Lightweight Torpedo as an exemplar. All related tables from the January 2021 draft of the Mk 54 Lightweight Torpedo TEMP were integrated into this relational database. All steps and code needed to recreate the proof of concept are available here: https://www.trmc.osd.mil/wiki/download/attachments/184156180/mk54_idsk_cui.zip?api=v2

Singh implemented the IDSK database in two languages: R Project, which is popular among the T&E analyst community, and SQLite, which is the world's most popular enterprise SQL database engine and was invented as part of a Navy project that developed software for Arleigh-Burke-class destroyer's damage control.

Praveen Chawla, Edaptive Computing, Inc.—Smart Documentation from Edaptive Computing

Praveen Chawla demonstrated a mature model-backed word processing and document content management system that Edaptive is enhancing for MBTEMP. The solution stores content modules (e.g., system descriptions) in a backend database so that they can be used across multiple documents in a version-controlled way. The solution is integrated into Microsoft Word so that document developers can continue to work in their native environment. The system is currently being enhanced to pull IDSK tables into Microsoft Word–developed TEMPs from a backend SQL database. A future iteration will enable the full generation of IDSK databases directly within the web app from a set of templates without the user needing to have any knowledge of SQL.

Suzanne Beers and William Fisher, MITRE—IDSK Concept & Digital Implementation Vision

Suzanne Beers and William Fisher presented a concept for IDSK and vision for implementing it digitally (Figure 6). The concept described how IDSKs can be used to enable better programmatic decision making. In particular, how the IDSK can articulate a logical evaluation strategy to inform decisions was discussed. IDSKs can convey:

- Decisions to be made and knowledge needed for informed decisions.
- Operational and technical capabilities evaluation to generate knowledge.
- Wargames, experimentation, M&S, test events, analyses and other data sources provide data for evaluation.

Their vision for implementing the IDSK using a variety of tools was then discussed, as seen in Figure 6.

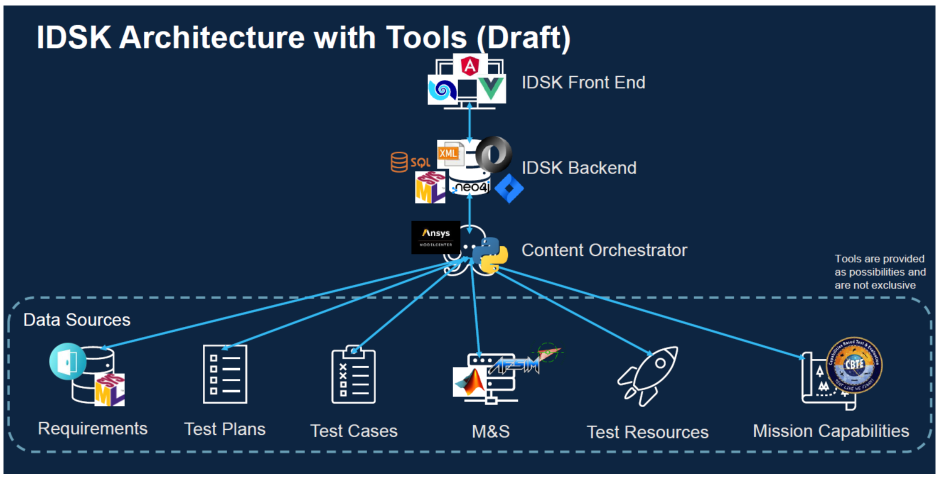


Figure 6. IDSK

Thomas Llanso, JHU/APL—MBTEMP Profile/Data Dashboard

Thomas Llanso discussed creating MBTEMP profiles in SysML and connecting them and their underlying data to dashboards for analytics. The question of "How can we identify and locate test-relevant digital model data for a variety of T&E stakeholders?" was discussed from multiple different viewpoints including MBSE (Figure 7) and the more traditional data engineering approaches used across the modern business enterprise (e.g., SQL).

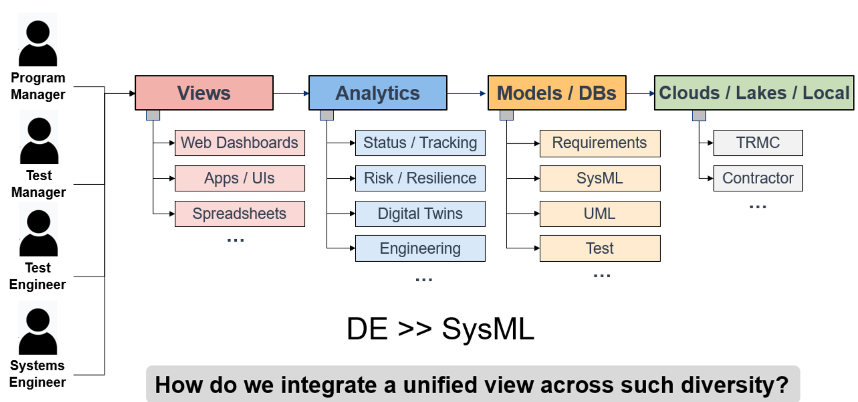


Figure 7. MBTEMP Data Dashboard

Hans Mair, JHU/APL—Torpedo Exemplar

Hans Mair discussed JHU/APL's MBTEMP exemplar of the Mk 54 lightweight torpedo. The analytic augmentation of this MBTEMP to act as an acquisition milestone decision-support planning tool was discussed, in particular. The SysML models of both the TEMP elements (e.g., system description) and the actual system (e.g., guidance and control) were displayed and then put into a unified mission context for T&E to assess the system's operational effectiveness, suitability, reliability, and lethality.

Douglas Kelly, JHU/APL—Enterprise Data Lake

Douglas Kelly provided an overview of the several different data architectures and data solutions, including data lakes, that are commonly used across the business enterprise. One objective was to provide the audience an understanding of these different architectural alternatives. Solutions like data lakes, data warehouses, and data marts were all discussed, as were their advantages and disadvantages, as well as their associated extract, transform, load (ETL) processes, and the types of live end-user applications such as analytics and machine learning they can support. This was all contextualized in terms of DOT&E's vision for building a common, automated data and data analysis environment for the T&E enterprise (Figure 8)—all the way from the tactical edge (e.g., test range) to the C-Suite (e.g., Advana).

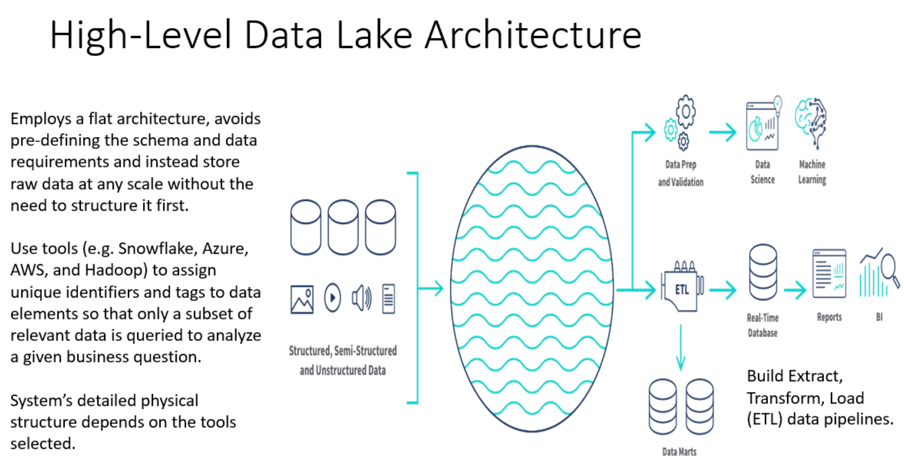


Figure 8. Data Lake

Ryan Norman, Test Resource Management Center (TRMC)—TRMC MBTEMP Supporting Capabilities

Ryan Norman discussed achieving the T&E continuum goal of "shared capability across the continuum life cycle" and result of "shared knowledge informing decisions across systems' life cycles" as well as how "future RDT&E relevance depends on our ability to modernize." He detailed how JMETC is providing an agile infrastructure to enable rapid acquisition with the desired result of providing an "an operationally-realistic environment for rapid experimentation, testing, training, and mission rehearsal across warfighting domains." From there Norman described TRMC's related investment areas as well as the mature capabilities they have available to provide, including TENA, the JMETC 266nramp, CHEETAS—which, among other things, provides a tactical system-to-engineering units data interoperability layer—and many others. Finally, Norman discussed TRMC's upcoming investments in knowledge management, big data analytics (Figure 9), and data science capabilities with a view to conveying CHEETAS central role in this.

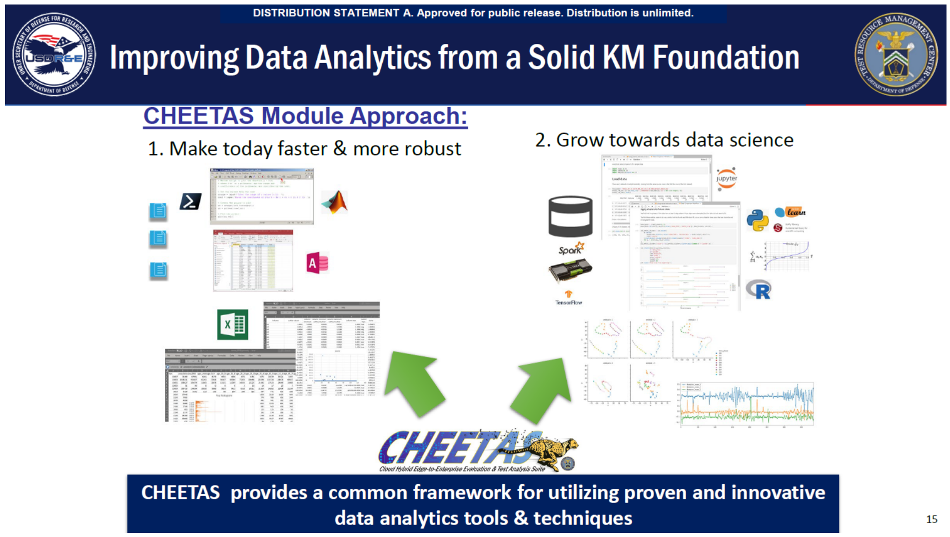


Figure 9. Data Analytics

Martha McNeil, JHU/APL—MBTEMP Analytics

Martha McNeil first presented how an MBTEMP can be used in conjunction with analytics to answer a variety of stakeholder questions (Figure 10) and then facilitated a discussion with the audience about the questions different people would want MBTEMPs to answer. She then provided examples of tools that can be used to generate analytics from SysML models such as Cameo Report Wizard and BluGen.

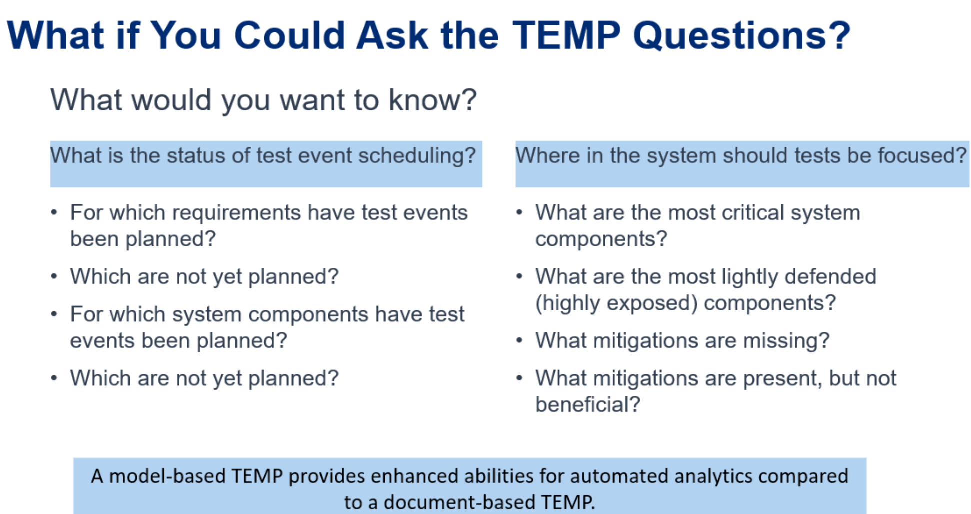


Figure 10. TEMP Questions

Karl Glaeser and Caitlin Szymendera, Department of the Navy (DoN)—Integrated Test & Evaluation Management System (iTEMS) Update from Navy

Karl Glaeser and Caitlin Szymendera provided an updated on the development and rollout of the DoN's iTEMS, which they described as follows:

> The Integrated Test & Evaluation Management System (iTEMS) is a suite of web-based software applications. iTEMS was developed in an effort to streamline the tools currently used across multiple DoN Programs and

platforms. It leverages existing tools, best practices, and lessons learned to reduce development and operation costs. Through the use of iTEMS, data is used, controlled, and expelled in a consistent and measurable manner, providing data consolidation and accurate translation.

iTEMS is the DON's solution (Figure 11) for fully-integrated digital T&E strategies, inclusive of not just TEMPS but actual test data, assessments, and acquisition/test planning; although the Navy's solution involves modern digital technologies such as web-based applications and SQL databases it is unique in that it does not invoke SysML. IOC of iTEM including iTEST (Figure 12) is scheduled for April 2023. The DoN's strategy of "right time" annual updates to TEMPs vice real-time updates was also discussed.

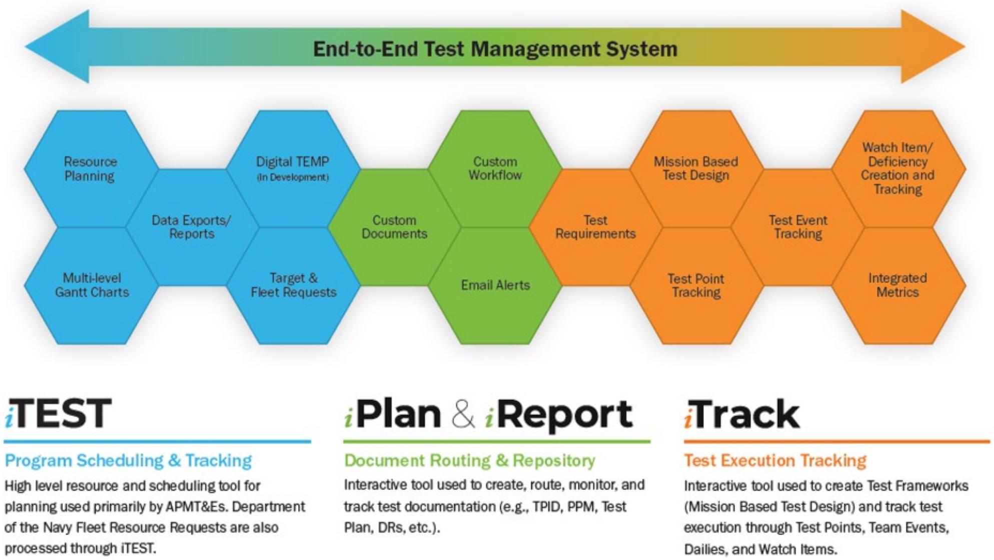


Figure 11. iTEMS

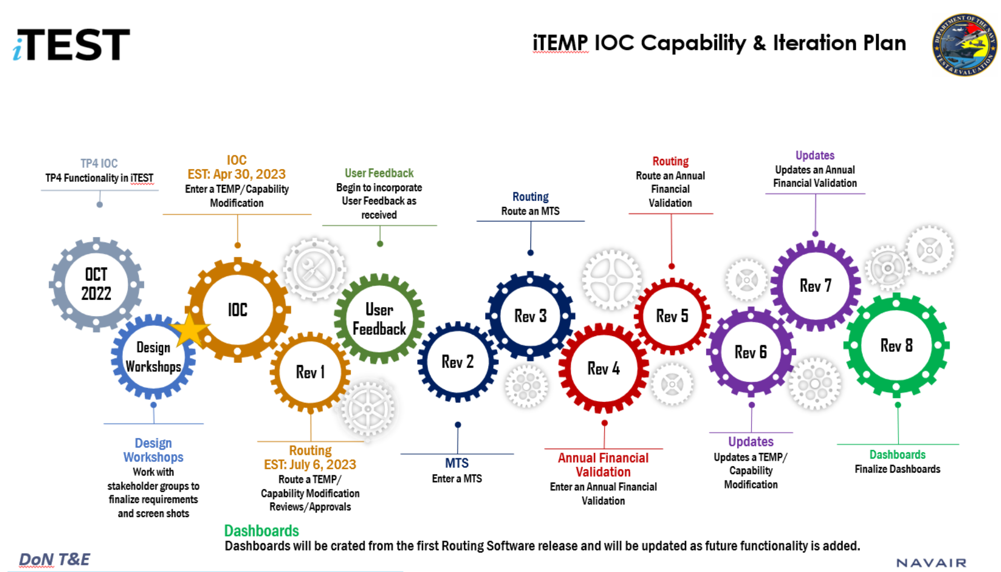


Figure 12. iTEST

Day 3

Ken Senechal, NAVAIR—CBTE / MBSE / IDSK Leading Change

Ken Senechal described NAVAIR's and the DoN's approach to Capabilities-Based Test and Evaluation (CBT&E) and its underlying "Test Like We Fight!" mantra, including a mission-based test design process, as part of capability based acquisition (Figure 13). One goal of CBT&E is to unify CT/DT/IT/OT into a single holistic test and evaluation construct—a holistic "T&E Continuum" using DE and MBSE that includes virtually executing T&E and blending it with systems engineering on the left side of the systems engineering "V." Finally, Senechal reported on the hack-a-thon recently hosted by NAVAIR and the "Raspberry Jammer" developed there.

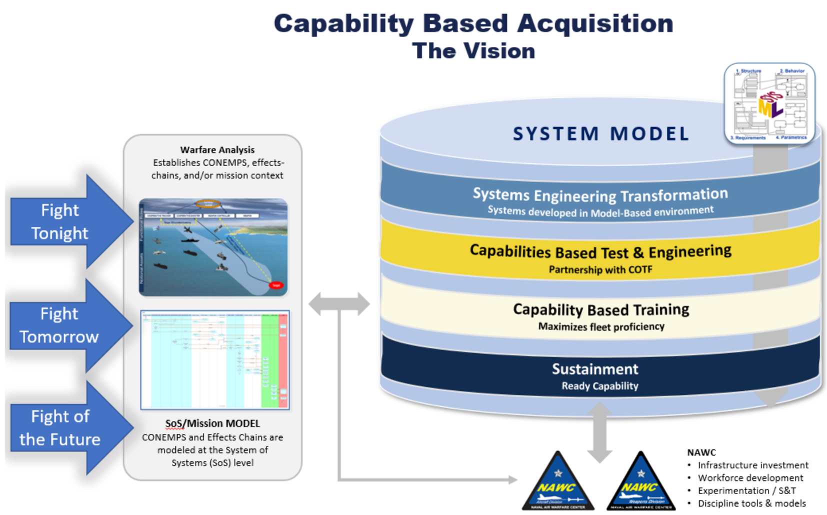


Figure 13. Capability Based Acquisition

Jerome Hugues (CMU, SEI), Dionisio De Niz (CMU, SEI), Zamira Daw (Universitat Stuttgart), and Laura Epifanovskaya (OUSD R&E contractor support)—Transforming MBSE Models into Formally Verifiable Language to Support Test and Evaluation as a Continuum

Jerome Hugues and team introduced the method of formal verification as a rigorous means to test software across vast phase spaces (Figure 14). They described how MBSE reduces the effort of developing complex system by improving:

- Requirements
- Traceability
- Code generation
- Design reuse
- Validation and Verification
- Communication

And how formal verification can reduce fault leakage in the acquisition process that leads to major delays and costs in rework to correct. Future Vertical Lift was provided as an example of how formal verification successfully generated test and development efficiencies. Furthermore, Hugues and team described how reducing fault leakage is a necessity for safety critical systems.

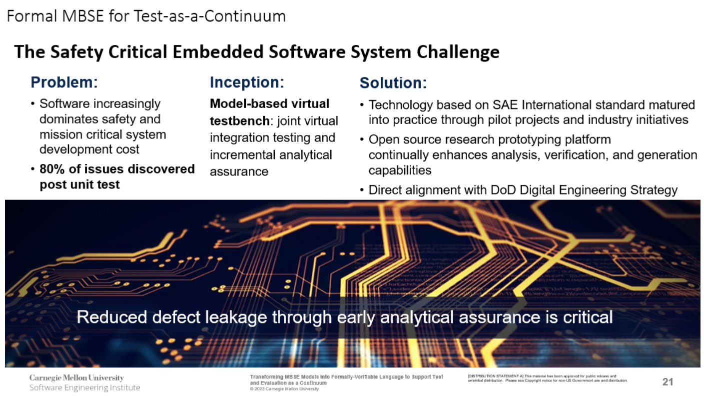


Figure 14. Test as a Continuum

Kent Laursen, General Dynamics Information Technology (GDIT)—GDIT Digital Engineering Environment for USAF Sentinel Ground Based Strategic Deterrent Program

Kent Laursen opened his presentation by conveying the DoD's digital engineering strategy which promotes the use of digital representations of systems and components and the use of digital artifacts to design and sustain national defense systems. He described the department's five strategic goals of digital engineering as:

- Formalize the development, integration, and use of models to inform enterprise and program decision making
- Provide an enduring, authoritative source of truth
- Incorporate technological innovation to improve the engineering practice
- Establish a supporting infrastructure and environment to perform activities, collaborate and communicate across stakeholders
- Transform the culture and workforce to adopt and support digital engineering across the life cycle.

Laursen then described GDIT's enterprise digital engineering stack (Figure 15) and it how it is being used by Sentinel. Finally, Laursen described GDIT's Navigable Relationships (NavRel) framework which can be thought of as a next generation high-dimensional database that incorporates digital threads, schemas, queries with DOORS, Jira, Cameo Systems Modeler, Ansys Model Center integrations along with high level analytics and visualizations.

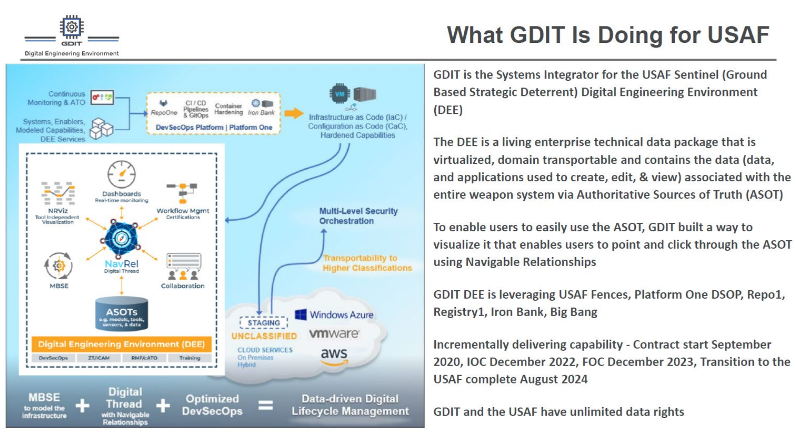


Figure 15. GDIT's USAF MBSE

Tyson Blauw, Space Systems Command—Lead Developmental Test Organization (LDTO): Digital Engineering with Protected Tactical SATCOM (PTS) Developmental Evaluation Framework Demonstration (Space Systems Command)

Tyson Blauw presented the Space Systems Commands' LDTO Developmental Evaluation Framework (DEF) model development progress (Figure 16) and LDTO short-term and long-term goals for digital engineering. Their short-term goals are to:

- Copy critical TEMP inputs into MBSE ecosystem
- Create system under test diagrams in the model for each test event
- Generate use cases/test procedures based on CONOPs and trace to system capabilities
- Trace system under test diagrams to resource allocations
- Generate entry/exit criteria in model for test event.

And their long-term goals are to:

- Conduct daily T&E activities using models
- Utilize model to generate test plans
- Trace known deficiencies to models instead of the Joint Deficiency Reporting System.

Blauw also described the hurtles seen in Figure 16.

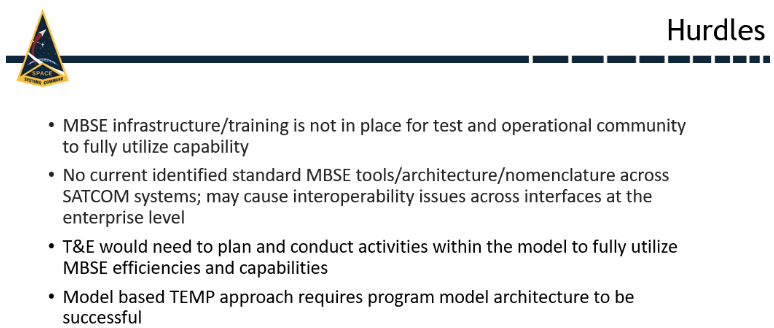


Figure 16. MBSE in Space Systems

Craig Arndt / Michael Shearin, GTRI—MBSE in T&E

Michael Shearin described a GTRI project that uses an exemplar electronic warfare system to:

- Develop a representative set of models linking requirements, design, testing, and risk using MBSE
- Model an example system and demonstrate how test organizations can integrate MBSE models to inform the development of testing documents and plans
- Develop and implement a risk function this will be linked to the integrated model
- Include in the risk model a method for linking to program risks

The project also included modeling and linking test range capabilities. Shearin communicated the impact of the project as follows:

- The model-based test risk function is a new development that gives the program office and the different test organizations better visibility into the different critical aspects of program performance all along the development and testing life cycle of the program.

- By integrating testing and model-based systems development we are extending the current methods of Model Based System Engineering (MBSE) in their application to DoD systems.

Kishor Ramaswamy, Ansys—Digital Engineering Exemplar: Air Force Test Center Targeting Pod

Kishor Ramaswamy described how Ansys is providing simulation capabilities and developing workflows to perform virtual testing of infrared search and track (IRST) systems for the Air Force. These solutions are increasing test coverage and reducing risk by leveraging simulation to gain information on scenarios that would otherwise be unattainable in the real world. From there, Ramaswamy described the M&S architecture, multiphysics models of aircraft sensors, and ability to generate accurate lightweight, fast-running reduced order models (Figure 17) using a combination of statistical and physics-based machine learning techniques.

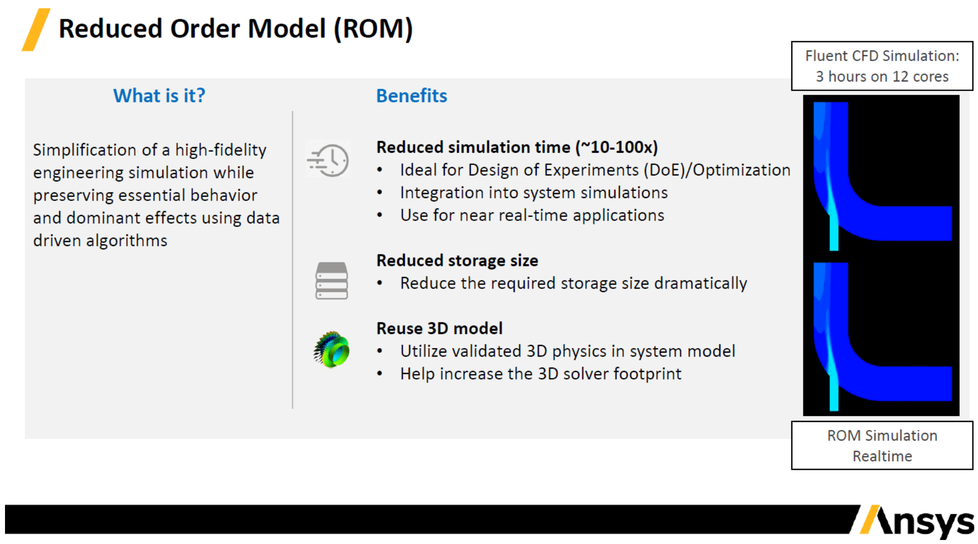


Figure 17. Reduced Order Model

This workshop was a great success in continuing to share project and research progress across the T&E digital engineering community. As the MBSE test community continues to move forward in implementing digital technology into all aspects of the DoD test and evaluation processes, there have been a number of challenges identify that will need to be addressed.

Key Challenges Identified

There are a number of challenges both technically and policy-oriented to finalizing and implementing methods and tools to enable MBTEMPs and other digital acquisition artifacts.

Some of the technical challenges question that need to be answered include:

a. Modeling structures, e.g., MBSE vs. relational database implementations
b. Hosting environments
c. Data standards
d. Enterprise (vice desktop) MBSE solutions.
e. Interoperability requirements of different versions of tools or models.

In addition to the technical challenges there are larger policy issues that will need to be decided and agreed upon across a wide range of stockholders. These issues include but are not limited to:

a. Who will have authority over the format and the content of the digital artifacts?
b. What will be the best practices for developing and maintaining them?
c. What will be the incremental implementation of the new digital formats?
d. How will legacy and in-flight programs be handled?

Impact

The development of MBTEMPs will have a positive impact across DoD acquisition. Specifically, MBTEMPs will lead to better data for better decision making, and better risk management. In addition, the goal of program acceleration will be more achievable if testing and evaluation can provide early insights into what testing is most critical and when that testing can be done early in the program to inform design decisions, before subsequent verification testing. Also, better planning that can be digitally aggregated across the enterprise will lead to better management and planning of test and evaluation resources to support current and future programs, and better integration of capabilities from different parts of the test community.

Actions Identified / Recommended

The MBTEMP workshop at John Hopkins APL earlier this year made significant progress in sharing different approaches and results in developing digital versions of test planning and test execution artifacts. Some of the key actions that were identified by the stakeholders at the workshop include the following:

1. To shift the focus of future workshops more towards usable examples / demonstrations vice Power Point presentations, in an effort to generate product of greater use to the practitioners in the program offices and test centers .
2. Delineate MBTEMP work from fully digitized/integrated T&E strategies (i.e., DoN iTEMS discussed below). While both efforts are needed and valuable there is a need to effectively advance both simultaneously while distinguishing between the two.
3. Establish a working group on DE for T&E that meets monthly to highlight different efforts and cross-coordinate findings and products created by different groups.
4. Identify and convey best practices that can then be used to develop helpful guidance.
5. Work to ensure interoperability across the different technologies being used.

Conclusions and Recommendations

This paper explored the ongoing development of digital versions of acquisition artifacts in an effort to develop methods to realistically develop these artifacts in a manner both consistent with the DoD DE strategy and immediately useful to a wide range of program offices and the test community. This effort was contextualized in terms of the most recent Model-Based TEMP workshop that DOT&E sponsored at JHU/APL in February 2023; this article provided summaries of all of the presentations given at this workshop. Moreover, all of the complete presentations from the workshop are available for the community here: https://www.trmc.osd.mil/wiki/download/attachments/184156180/mb_temp_workshop_2_2023-02-26.zip?api=v2

We are building a growing digital engineering community for T&E and have discovered several key aspects of the development of sustainable digital engineering and digital acquisition practices and systems across the DoD.

1. Because of the current state of DoD acquisition and all of the legacy contracting and engineering processes in use, it is necessary that key acquisition artifacts including the Test and Evaluation Master Plan (TEMP) be digitized in a manner that is consistent and compatible across different organizations, as well as new and legacy programs.
2. The cost and complexity of wide-spread implementation of DE and digital acquisition means that we should consider an incremental approach to implementing these technologies and methods across new and legacy programs. One of the critical advantages of DE and digital acquisition is the ability to accelerate the acquisition process; critical to achieving this acceleration is ensuring that digital transformation does not itself slow programs down.
3. The development of new tools and processes including the MBTEMP should focus on the addressing the needs of acquisition and test practitioners for us to accelerate the delivery of weapons that work vice imposing new cumbersome requirements.
4. We should prioritize integrating our T&E community and processes with the rest of the DE community.
5. Fully realizing DE's potential for T&E's will depended on tight collaboration between the DoD and our industry partners.

We will continue to advance the state of the art of DE for T&E, host and support future events—such as the upcoming DTE&A-sponsored Connect the Dots workshop to be hosted at Institute for Defense Analyses June 27–29, 2023—and collaborate across the DoD and industry to do our part to transform T&E to enable delivery of the world's most advanced warfighting capabilities at the speed of need. We seek your proposals to collaborate with us.

.

PANEL 9. INTERNATIONAL PERSPECTIVES ON ACQUISITION

Wednesday, May 10, 2023	
2:15 p.m. – 3:30 p.m.	**Chair: Lieutenant General David G. Bassett,** USA, Director, Defense Contract Management Agency ***Developing a "Build Allied" Approach to Increasing Industrial Base Capacity*** Jerry McGinn, George Mason University Michael T. Roche, George Mason University ***Competition versus Sole Sourcing in Defence Procurement What are the Factors that Determine Tendering Methods in Government Contracting for Delivering 'Value for Money'?*** Kogila Balakrishnan, University of Warwick Ahmed Tarek El-Said, University of Warwick Zsolt Lazar, University of Warwick

Lieutenant General David G. Bassett, USA— is the director of the Defense Contract Management Agency, headquartered at Fort Lee, Virginia. As the director, he leads a Department of Defense agency consisting of around 11,000 civilians and military personnel who manage more than 225,000 contracts, performed at more than 15,000 locations worldwide, with a total value in excess of $3.5 trillion.

Bassett assumed leadership of DCMA on June 4, 2020. He came to the agency after serving as Program Executive Officer for Command, Control and Communications-Tactical (PEO C3T) since January 2018, where he was responsible for the development, acquisition, fielding and support of the Army's tactical network, a critical modernization priority.

Bassett was commissioned into the Signal Corps in 1988 through ROTC concurrent with a Bachelor of Science in Electrical Engineering from the University of Virginia. As a junior officer, he served in Germany in tactical positions with the 2nd Armored Cavalry Regiment and 123rd Signal Battalion, 3rd Infantry Division.

Following the Signal Officer's Advanced Course and completion of a Master of Science in Computer Science through the University of Virginia, Bassett was assigned to the U.S. European Command Staff, where he served as the Requirements Analysis and Interoperability Action Officer, J6.

He transferred to the Army Acquisition Corps in 1999 and was assigned to Fort Monmouth, New Jersey, as Operations Officer, Communications and Electronics Command Software Engineering Center. Bassett went on to manage software development efforts for the Army's Future Combat Systems program. He then served on the Joint Staff as the Ground Maneuver Analyst, Capabilities and Acquisition Division, J8.

From July 2009 to May 2012, Bassett served as the Army's Project Manager for Tactical Vehicles within the Program Executive Office for Combat Support & Combat Service Support (PEO CS&CSS). He then managed the Joint Program Office, Joint Light Tactical Vehicles (JLTV), through the Engineering and Manufacturing Development award.

In September 2013, Bassett was appointed Program Executive Officer, Ground Combat Systems, where he managed the portfolio of the Army's combat vehicle fleet including major modernization efforts to Abrams, Bradley, Stryker and self-propelled howitzer programs while also initiating the Army's Armored-Multi Purpose Vehicle program. Previous he served as Deputy Program Executive Officer for CS&CSS.

Bassett is a graduate of the Army Command and General Staff College at Fort Leavenworth, Kansas, and a distinguished graduate of the Industrial College of the Armed Forces in Washington, D.C.

Developing a "Build Allied" Approach to Increasing Industrial Base Capacity

John G. (Jerry) McGinn, Ph.D.—is the Executive Director of the Greg and Camille Baroni Center for Government Contracting in the School of Business at George Mason University (GMU). In this role, he has established and is leading the first-of-its-kind university center for research, education and training, and collaboration on issues facing the $500B+ government contracting industry. Prior to joining GMU, McGinn served as the Senior Career Official in the Office of Manufacturing and Industrial Base Policy in the Department of Defense. Previous to the DoD, McGinn spent a decade in senior defense industry roles at Deloitte Consulting LLP, QinetiQ North America, and Northrop Grumman. Before industry, McGinn served in the DoD as Special Assistant to the Principal Deputy Under Secretary (Policy) and as a Political Scientist at RAND. McGinn has published influential George Mason reports, RAND monographs, and articles in The Hill, Business Insider, Defense News, Defense One, and other outlets. McGinn was commissioned into the U.S. Army and served with distinction as an Infantry Officer and is a graduate of Ranger and Airborne Schools. He has received numerous civilian and military awards and has earned a PhD, MS, and MA from Georgetown University as well as a BS from the U.S. Military Academy.

Michael T. Roche—is detailed as a Visiting Fellow of the Greg and Camille Baroni Center for Government Contracting in the School of Business at George Mason University. As a full-time Professor at the Defense Acquisition University, he enables a global learning environment for the Defense Acquisition Workforce, with focus areas of program management, financial management, logistics, and international exportability and acquisition. Roche entered federal civil service in 2010 after a 20-year military career. He served in a variety of acquisition, program management, and support assignments throughout the Air Force and in the Defense Contract Management Agency. Roche is certified to the highest levels of defense acquisition in program management and financial management as well as international affairs. He earned MS degrees in systems management from the Air Force Institute of Technology and military operational art & science from Air Command & Staff College as well as a BS in mathematics from the University of Dayton.

Abstract

The war in Ukraine has clearly demonstrated the need for surge capacity in our defense industrial base. Increasing U.S. production of defense systems is part of the solution to this capacity deficit, but engaging the industrial capacity of American partners and allies is a critical, mutually beneficial, and cost-effective approach as well.

The case studies and analysis in this paper illustrate that we clearly have many of the building blocks in place for a robust "Build Allied" approach. There have been and are in development a number of co-development, co-production, second sourcing, licensed production, and sustainment efforts involving our allies and partners. The case study findings show that these successful efforts have largely been driven by strong leadership, focused cooperative efforts, and effective enablers. Moreover, there is clearly an increased appetite for "Build Allied" efforts to meet National Defense Strategy objectives and address defense industrial capacity shortfalls.

The paper's recommendations focus on strengthening "Build Allied" enablers such as the Australia, United Kingdom, and United States Agreement, the National Technology Industrial Base, and the Defense Exportability Features program, as well as overcoming barriers such as export controls, technology security and foreign disclosure processes, and aspects of the defense acquisition system.

Introduction

Research Issue

The war in Ukraine has clearly demonstrated the need for surge capacity in our defense industrial base. From the skyrocketing demand for and lack of ability to rapidly increase production of Javelins and HIMARS or the shuttered production of Stingers, our defense acquisition system has shown itself to be more brittle than resilient in some critical ways. In response, Under Secretary for Acquisition and Sustainment Dr. Bill LaPlante has strongly emphasized the importance of production, going as far to say that "we as a country did our best to not do production in defense" in our efforts to keep costs down and maintain program schedules (*Bridging the Valley of Death*, 2022). Beyond the current fight in Ukraine, looming security threats in East Asia underscore the importance of producing systems at scale *and* replacing or sustaining them as systems attrit or are destroyed in combat.

Increasing U.S. production of defense systems is part of the solution to this capacity deficit, but a Buy America *only* approach does not fit how we currently produce defense systems nor how we wage wars. Instead, engaging the industrial capacity of American partners and allies could be a mutually beneficial and more cost-effective approach. NATO and other allies have provided equipment to Ukraine, most allies buy U.S. defense systems, and many also produce major parts or sub-systems that are incorporated into platforms principally delivered by U.S. primes.

This paper will examine a select number of international industrial collaboration efforts to address this research question: How can the DoD develop an effective Build Allied approach that creates surge capacity and industrial resilience in support of the National Defense Strategy (NDS) objectives?

The National Defense Strategy

The emphasis on the importance of allies starts at the top. The President's National Security Strategy calls for robust collaboration "to remove barriers to deeper collaboration with allies and partners, to include issues related to joint capability development and production to safeguard our shared military-technological edge" (*2022 National Security Strategy*, 2022). The National Defense Strategy (NDS) further underscores the imperative of increasing this cooperation to build "enduring advantages" in the joint force (*2022 National Defense Strategy*, 2022). The NDS specifically references the need for the Department to work or collaborate with allies and partners 32 times, so this is clearly a DoD priority. This major allied emphasis is also coupled with a sense of urgency given what the NDS calls the "pacing challenge" of China.

There are numerous ways that U.S. forces currently collaborate with partners and allies. Two decades of combat in Afghanistan and Iraq clearly demonstrated that we fight with our allies and partners. These operational activities are central to U.S. strategy, and we conduct regular operations, exercises, and other engagements with countries across the globe under the broad rubric of security cooperation.

Industrial collaboration to "support modernization and future capability development" and "collaborative development and production" is also part of security cooperation, as the NDS notes (*2022 National Defense Strategy*, 2022, p. 10). Co-production, licensed production, cooperative programs, foreign military sales, direct commercial sales, and other efforts are examples of this international industrial collaboration. DoD leaders such as LaPlante have called for an increase in these efforts.

Developing a Build Allied approach

Objective

The objective of a "Build Allied" approach is to create a larger industrial base through international industrial partnerships to build the systems needed for current and future contingencies. This would create more industrial capacity that supports both American and allied capabilities to scale and strengthen the production of existing and future systems. This will also help to increase the rate of production and reduce supply chain bottlenecks that have created challenges in replenishing stockpiles during periods of high operational demand.

Components

The principal components of a "Build Allied" approach include:

- **U.S. subsidiaries.** The creation or expansion of the U.S. footprint by foreign-headquartered companies as a result of investment, program win, or corporate merger.
- **Co-development.** Systems or subsystems cooperatively designed and developed in two or more countries. Shared responsibilities include design, engineering, and applied research.
- **Co-production.** Production of a defense system in two or more countries. Involves the transfer of production technology and complex or sensitive subsystem components from the country of origin to countries producing the system. Recipient may expand production to include subsystems and components.
- **Second-sourcing or licensed production.** Execution of established acquisition strategy to qualify two producers for the part or system. Sometimes called dual sourcing (*Definitions for Co-Development*, n.d.).
- **Sustainment of existing systems.** Maintenance, repair, or overhaul of defense systems.

The good news is that these principal components of a "Build Allied" approach already exist. International cooperative programs such as the F-35 Lightning II and the NATO Sea Sparrow Consortium, for example, include many of these components. Foreign Military Sales (FMS) programs often include co-production and sustainment elements as part of government-to-government agreements. Direct commercial sales (DCS), on the other hand, generally do not build allied industrial capabilities but do strengthen the U.S. industrial base by extending production lines often well beyond the delivery to U.S. forces.

The challenge, however, is that these "Build Allied" components are often perceived as exceedingly difficult and sometimes not worth the effort by government officials or industry executives. Moreover, most of these components are by their nature not transparent because they are government-to-government agreements or proprietary contractual relationships, so they do not have a great deal of visibility outside of a specific program. Developing a more explicit "Build Allied" approach would explicitly promote and foster the consideration and use of these components.

Methodology

To develop this "Build Allied" approach, we will start by examining the bilateral and multilateral enablers that can spur increased production. Then we will examine the barriers to a robust "Build Allied" industrial campaign. Next, we will look at case studies of where allied industrial capabilities contribute to the development, fielding, and sustainment of weapons systems. Finally, we will make a series of recommendations to implement this "Build Allied" approach.

Enablers

We will first examine a number of enablers for a robust "Build Allied" approach. Some of these are long-standing (Reciprocal Defense Procurement MOUs, Security of Supply Arrangements, U.S. subsidiaries), some have been around for a few years (DEF and NTIB), and two are just getting started (AUKUS and NATO DIANA).

U.S. Subsidiaries

The most obvious enabler is the fact that many foreign companies have U.S.-based subsidiaries manufacturing products or conducting services for unclassified and classified DoD programs. For those conducting classified work, these subsidiaries operate under Foreign Ownership, Control or Influence (FOCI) regulations governed by the Defense Counterintelligence and Security Agency, which limits communications and sharing of information between the parent company and the U.S. subsidiary (Defense Counterintelligence and Security Agency, n.d.).

Companies such as BAE Systems, Leonardo DRS, Thales, Elbit, and many others have long-standing major U.S. subsidiaries that regularly compete and win DoD programs. Recently, however, companies such as Saab and Fincantieri Maritime Marine have won the Air Force Trainer and Navy Frigate programs, respectively, through foreign designs coupled with significant investments U.S.-based production (McGinn, 2021, p. 4). In the Army's Optionally Manned Fighting Vehicle (OMFV) competition, three of the five industry teams include major contributions by non-U.S. headquartered firms (Dean, 2023).

Reciprocal Defense Procurement and Acquisition Policy Memoranda of Understanding (RDP MOUs)

There are currently 28 countries that have RDP MOUs with the United States (Defense Pricing and Contracting, n.d.).[1] These MOUs establish agreed-upon procurement principles that foster transparency and openness to competition in each country's respective defense marketplace.

The largest tangible benefit for the non-U.S. signatory countries is that companies headquartered in these countries are waived from Buy America provisions when competing for DoD programs (DFARS 225.872-1, n.d.). The existence of this exemption, however, is often not well recognized in some program offices or on Capitol Hill, and others are opposed to these exemptions in the first place.

Nonetheless, RDP MOUs are key enablers of international cooperative efforts and are central in many of the case studies below. Having greater recognition of the power of these agreements would enable more "Build Allied" efforts.

Security of Supply Arrangements (SoSAs)

There are currently 13 bilateral Security of Supply Arrangements between the United States and partner countries (*Security of Supply*, n.d.).[2] Not surprisingly, all SoSAs are with RDP MOU countries. These arrangements implement part of the Declaration of Principles in the RDP MOUs and recognize the "mutual interdependence of supplies needed for national security" as well as calling for the signatories to "explore solutions for achieving assurance of supply" (*Security of Supply*, n.d.). Some of the signatory nations have established

---

[1] The countries are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Egypt, Estonia, Finland, France, Germany, Greece, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, Turkey, and the United Kingdom of Great Britain and Northern Ireland..

[2] The following countries have SoSAs with the United States: Australia, Canada, Denmark, Finland, Israel, Italy, Japan, Latvia, the Netherlands, Norway, Spain, Sweden, the United Kingdom.

industry codes of conduct as a measure of reliance of their respective industry partners to support defense priorities.

The most telling part of these efforts, however, is the fact that they are *arrangements* not agreements. That underscores the relatively informal and voluntary nature of these bilateral initiatives. There arrangements are confidence-building measures, and there is value in that, but they are not formal commitments by the respective government signatories. Thus, it is not surprising that these arrangements have not been invoked directly in any specific case to date.

Defense Exportability Features

The Defense Exportability Features (DEF) program attempts to address one of the biggest challenges in technology sharing, the level of technology that is incorporated in each specific weapons system. One of the major considerations in TSFD processes is determining what level of capability in each weapons system can be shared with which specific partner. If a program producing an advanced radar for U.S. forces, for example, wants to later export that system to an ally or partner, the radar will likely need to be reverse engineered to a lower capability level for export. That reverse engineering is much more expensive than designing various capability functionality at the front end of a program.

DEF was first authorized by the National Defense Authorization Act for Fiscal Year 2011 (n.d.) to pilot developing and incorporating technology protection features in designated defense systems during research and development. The program was promoted through the department's Better Buying Power initiative which recognized that incorporating exportability features in initial designs provided benefits such as reduced costs, improved U.S. competitiveness, stronger ties to friends and allies, and improved interoperability (DoD AT&L, 2012). DEF's primary objectives are to reduce costs, demonstrate quicker availability of domestic platforms for the international market by incorporating exportable features in design work, and identify lessons learned (*Defense Exportability Features*, n.d.).

As noted in the 3DELRR case below, DEF was established with the intent to incorporate exportable features in design work to help enable quicker availability for international cooperative efforts. While DEF has been useful in 3DELRR, it needs significant scaling to become a core "Build Allied" component. It was funded initially as a pilot program and has continued to limp along at low funding levels, receiving little attention in the last several years.[3] The Ukraine conflict, however, may help revive DEF's prospects. A $50 million reprogramming action in April 2022 transferred money into DEF to "design and incorporate exportability features…that enhance interoperability of…systems with those of friendly foreign countries" (*Reprogramming Action*, 2022).

National Technology Industrial Base (NTIB)

The NTIB has deep roots and was first codified in U.S. law in 1992 when the United States and Canada were one national technology industrial base. It garnered greater attention when the 2017 National Defense Authorization Act (NDAA) added the United Kingdom and Australia to NTIB and, recently, New Zealand was added to the NTIB through the 2023 NDAA.[4] The NTIB has become a strong vehicle for government-to-government initiatives such as the sharing of best practices for countering the potential national security impacts of foreign direct investment.

---

[3] DEF, for example, received $12.6 million in base funding in the FY2023 President's Budget submission (Office of the Secretary of Defense, 2022).

[4] For a more detailed treatment of NTIB, see McGinn (2021, pp. 6–7).

With its industrial base focus, the NTIB would seem to be a natural vehicle for a "Build Allied" approach. The NTIB, however, has not had any success in fostering industrial collaboration with one minor exception. The 2019 NDAA did create an exemption for NTIB U.S. subsidiaries operating under a Special Security Agreement to obviate the need for a national interest determination for proscribed information (McGinn, 2021, p. 4). Overall, however, the NTIB has not been utilized to foster industrial collaboration in any meaningful way, and many have begun to question the NTIB's utility as a vehicle for such efforts (Greenwalt, 2022). This is a major missed opportunity, but this can be turned around. The NTIB governments and industries can work together to create better incentives for utilizing the NTIB to truly spur industrial base collaboration through rule changes, contract clauses, and other mechanisms.

Australia, United Kingdom, and United States (AUKUS) Agreement

Announced in September 2021, AUKUS is an enhanced trilateral security partnership between Australia, the UK, and the U.S. for the governments to strengthen the ability of each to support security and defense interests and build on longstanding and ongoing bilateral ties (*Joint Leaders Statement on AUKUS*, 2021). The UK and U.S. sharing of nuclear propulsion technology for nuclear attack submarines with Australia is the first and most publicized initiative of the agreement, Pillar I. Under that agreement, Australia will develop, build, and deploy a conventionally-armed, nuclear-powered submarine of the existing Virginia-class boats (*Fact Sheet: Implementation*, 2022).

Under Pillar II, there are multiple other advanced capabilities initiatives: undersea capabilities, quantum technologies, artificial intelligence and autonomy, advanced Cyber, hypersonic and counter-hypersonic capabilities, electronic warfare, innovation, and information sharing. The potential to collaborate, for example, on operating manned and unmanned aircraft operating in tandem is already being considered as the U.S. Air Force begins its collaborative combat aircraft program and the Royal Australian Air Force deploys its own robotic wingman, the MQ-28 Ghost Bat (Easley, 2023).

The very nature of AUKUS makes it incredibly conducive to a "Build Allied" approach because it is explicitly focused on capability development and industrial capacity. There are significant concerns, however, about implementing the AUKUS agreement in the face of headwinds over export controls and technology sharing and foreign disclosure issues (Center for Strategic and International Studies, 2023).

NATO DIANA

The North Atlantic Treaty Organization (NATO) has conducted numerous acquisition programs in the past several decades, as evidenced by the three NATO case studies in this paper. With 30 members today, gaining consensus in NATO is challenging, but the three cases illustrated the benefits and challenges of conducting procurement in the Alliance. Multilateral development programs like NATO AGS are exceedingly hard to pull off given all the negotiations required to achieve consensus on each step of the program. Collaborative NATO procurement efforts like Tanker and the Sea Sparrow Consortium, on the other hand, have been more successful.

With these experiences, it will be interesting to see how NATO's Defence Innovation Accelerator for the North Atlantic (DIANA) develops. Established in 2021, attention on DIANA increased in the wake of the war in Ukraine and the need to "build greater resilience into how allies get tech to troops at speed" (Murray, 2023). DIANA is launching three pilot programs on energy resilience, secure information sharing, and sensing and surveillance in the summer of 2023, so the progress of those efforts will be telling for the future of DIANA (*Barbara McQuiston*, 2023).

Barriers

The United States and allies have operated together for decades in Afghanistan, Iraq, and elsewhere. We have established close relationships for sharing intelligence, operational data, and UK and Australian personnel can even operate on U.S. classified networks at combatant commands. Despite these intimate connections, industrial collaboration has always been much more difficult. This section looks at four principal barriers—export controls, technology security and foreign disclosure, the defense acquisition system, and Buy America—to better understand the challenges that need to be addressed to create a “Build Allied” culture that drives government and industry behavior in the coming years.

Export Controls

Export controls are a perennial issue in defense trade and security cooperation. Governed by the International Trafficking in Arms Regulations (ITAR) for defense items and services and the Export Administration Regulation for commercial dual use items, export controls are designed to prevent the transfer of military technology to unfriendly nations or hostile organizations. Numerous efforts have been undertaken reform the export controls system since the 1990s, and some progress has been made.

The failure to make significant progress in export controls with our closest allies has been puzzling, however. There is a long-standing exemption to the ITAR for Canada that permits the transfer of some unclassified defense items and services without an export license (U.S. Department of State, Directorate of Defense Trade Controls, n.d.). This exemption is limited, and companies sometimes avoid using the exemption for fear of costly ITAR violations (Christensen & Goldstein, n.d.). Efforts to obtain Congressional approval for similar ITAR exemptions for the UK and Australia failed in the early 2000s, and the governments then took a different approach, signing bilateral defense trade cooperation treaties in 2007. These treaties, ratified by the Senate in 2010, created a “trusted community” of companies that could share technology and compete for opportunities within this trusted community (*United Kingdom and Australia*, n.d.).

Unfortunately, these treaties have never come close to reaching their potential. They are used for government-to-government transactions to a limited degree, and they have almost never been used by industry. The lack of robust dialogue between government and industry as well as restrictive Senate Treaty implementation language were major factors in this failure and must be avoided in any future reform effort.

Officials involved with AUKUS and informed observers have clearly noted the importance of export control reform to facilitate program success (Clark, 2023). Industry groups in AUKUS countries have outlined strategies for operationalizing AUKUS, including the creation of an AUKUS industry forum, the establishment of a trusted body of government and industry officials to develop certification standards, and recommended U.S. statutory support for the UK and Australia (Aerospace Industries Association, 2023). At the same time, Congress is preparing for the consideration of export control reform legislation. The House recently passed a lopsidedly bipartisan bill directing State and the DoD to report on the licensing requirements for AUKUS collaboration under Pillar II on hypersonic weapons, artificial intelligence, and quantum technologies (Harris, 2023).

Technology Security and Foreign Disclosure

A less well-known but equally important area that can impede international collaboration is the technology security and foreign disclosure (TSFD) processes governed by DoD policy. TSFD policies cover sensitive technology areas such as anti-tamper, low observable and counter low observable, electronic warfare, and others. These are generally highly classified technologies that individually reviewed by various DoD offices to determine their suitability for release to foreign partners. As outlined in Figure 1, there are 13 separate TSFD processes or "pipes" (*DoD International Acquisition Guide*, n.d., pp. 25–26).

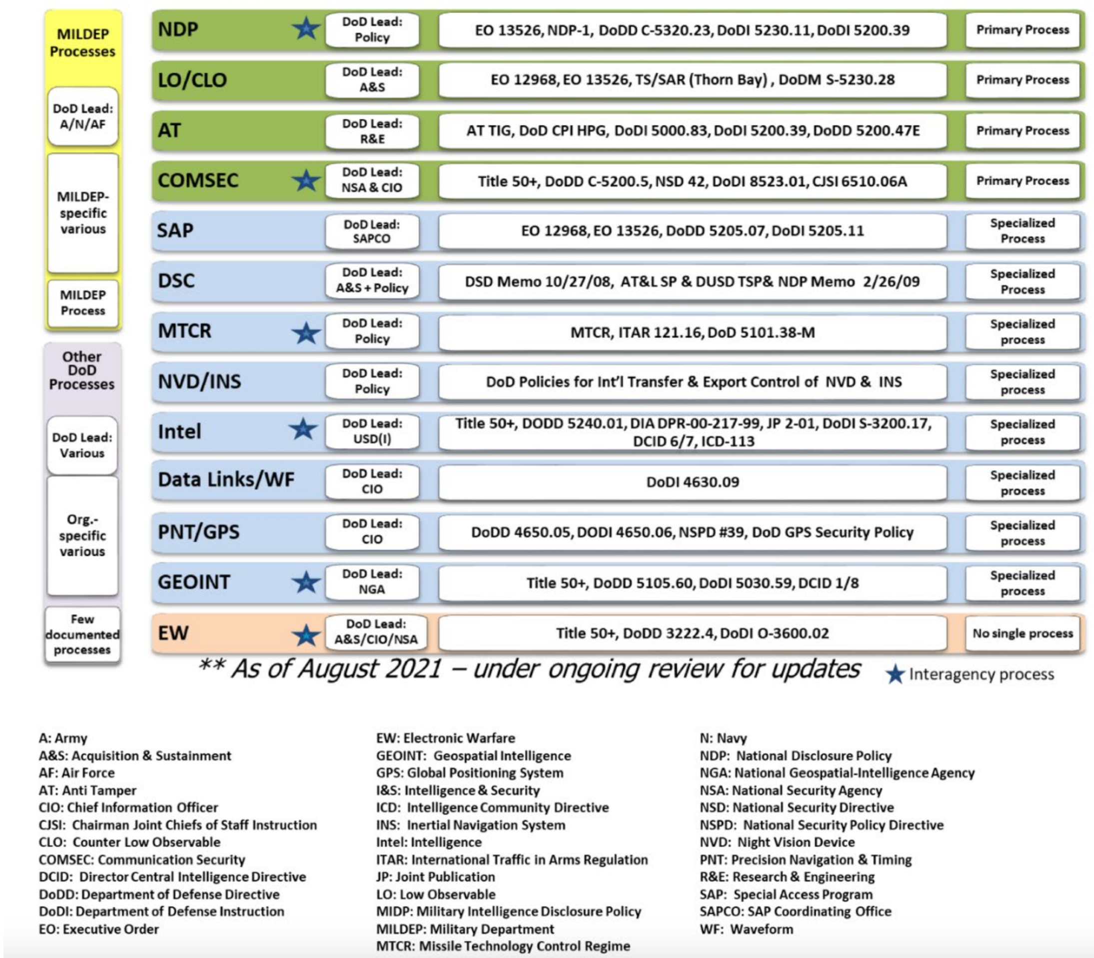


Figure 1. Technology Security and Foreign Disclosure Processes

Balancing these reviews as part of international cooperative efforts is challenging, and the DoD established the Arms Transfer and Technology Release Senior Steering Group in 2013 to coordinate guidance and timely address technologies under review in the "pipes" (*Arms Transfer and Technology Release*, 2020).

These technology reviews generally occur at the front end of the export control process and are essential for determining the level of technology sharing for particular programs. AUKUS Pillar I and Pillar II efforts will require TSFD reviews, and it is therefore promising to hear that DoD has initiated a review of these processes in light of AUKUS (Harris, 2023).

Defense Acquisition System

Elements of a "Build Allied" approach are part of the defense acquisition system in numerous ways. DoD Directive 5000.01, *The Defense Acquisition System* (2022), directs acquisition professionals to "enable allies and partners to enhance U.S. military capability, collaboration opportunities, potential partnerships, and international acquisition and exportability features and limitations will be considered in the early design and development phase of acquisition programs." Under the DoD Adaptive Acquisition Framework (AAF), program managers (PMs) "are required to consider acquisition strategies that leverage international acquisition and supportability planning to improve economies of scale, strengthen the defense industrial base, and enhance coalition partner capabilities to prepare for joint operations" (*Operation of the Adaptive Acquisition Framework*, 2022).

The recently revised *Guide to DoD International Acquisition and Exportability Practices* (2022) goes into greater depth on international acquisition issues. The Guide outlines practices such as international cooperative programs, the involvement of international in acquisition strategy, the integration of exportability features, and foreign military sales. There have been many large and small cooperative efforts over the past decades, as will be highlighted in the below case studies.

Despite this broadly supportive framework, however, international acquisition efforts often struggle. Defense acquisition professionals and their industry partners work diligently from source selection and throughout the program life to get things right and build the most capable systems for the warfighter. Incorporating allies and partners into the development, execution, and sustainment of programs is not always a top-level priority, however. In the development of acquisition programs, for example, requirements documents are regularly marked SECRET NOFORN, which makes it difficult to share with non-U.S. firms (McGinn, 2021, p. 4). The constant pressure to maintain cost and schedule during the conduct of a program also inhibits international collaborative efforts. This is changing to a degree, as noted in some of the case studies below, but one specific area that calls out for attention is the rating of Program Executive Officers (PEOs) and Program Managers (PMs). While many PEOs and PMs conduct a significant amount of FMS and DCS business in their portfolios, they are not evaluated on how well they conduct these cooperative efforts in their performance reviews (Webster, 2023).

Tension Between Domestic Manufacturing and Buy America

Multiple whole-of-government reviews of the defense industrial base during the Trump (*Assessing and Strengthening*, 2018) and Biden (*Securing Defense-Critical Supply Chains*, 2022) Administrations underscored significant shortcomings in U.S. manufacturing capabilities. These shortfalls had been recognized for some time, but these and other efforts increased the focus on strengthening domestic American manufacturing. Numerous investments in areas such as rare earths processing, batteries, castings, and, in particular, microelectronics have been targeted to help on-shore or re-shore these important capabilities.

At the same time, however, this focus on domestic manufacturing has led to calls in some quarters for increased Buy America legislation or regulations. Representative Donald Norcross, for example, has attempted to add an amendment to the National Defense Authorization Act the past several years to increase the Buy America requirement on major defense acquisition programs (McGinn, 2020). The addition of a dedicated Buy America office in the Executive Office of the President has similarly worked to strengthen these requirements through regulation.[5]

These efforts are counterproductive. Aerospace and defense manufacturing is already one of the strongest domestic sectors because of existing Buy America requirements and the need for these national security capabilities to be delivered from the United States. Focusing on Buy America also ignores the principal industrial base challenge—too many single and sole source suppliers, largely from China and other

[5] https://www.madeinamerica.gov (retrieved April 1, 2023)

unreliable markets. Moreover, there are some areas where close allies and partners have competitive advantages, such as mining or magnets. Finally, it is challenging for American officials to argue for increased international sales of U.S. defense systems when pushing for increased Buy America thresholds.[6]

Case Studies

To create a solid approach, we examined several past and current programs that have "Build Allied" components to understand what worked well and what did not. Specifically, we examined the F-35 Lightning II, NATO Air Ground Surveillance, Three-Dimensional Expeditionary Long-Range Radar, Next Generation Jammer, Ramjet, NATO Sea Sparrow consortium, the second engine for the Advanced Medium-Range Air-to-Air Missile, the Mine-Resistant Ambush-Protected vehicle, and NATO tanker. For each case study, we examined the purpose of the program, its development and deployment, and made findings relevant for future "Build Allied" efforts.

F-35 Lightning II

Purpose

The F-35 Lightning II program is simply the biggest program in history. The United States alone will spend $400 billion procuring nearly 2,500 aircraft and then spend another $1.27 trillion sustaining the fleet over 66 years (GAO, 2021). In the early days of the program, DoD officials and the international community—both governments and industrial bases—recognized the significant benefits to partnering in every aspect of the program.

> The F-35 program is DOD's largest international cooperative program. DOD has actively pursued allied participation as a way to defray some of the cost of developing and producing the aircraft, and to "prime the pump" for export sales of the aircraft. Allies in turn view participation in the F-35 program as an affordable way to acquire a fifth-generation strike fighter, technical knowledge in areas such as stealth, and industrial opportunities for domestic firms. (Congressional Research Service, 2022)

Development and Production

The United Kingdom was the only international partner involved in the early days of concept development and demonstration. In 1995, by agreeing to contribute $200 million, the British earned a seat at the DoD's table for requirements definition and aircraft design. Four years later, the British committed to spending another $2 billion for system development and demonstration, making them the largest non-U.S. contributor to the developmental effort, which would have a significant effect on industrial base rewards as the program progressed (Congressional Research Service, 2022, p. 31). The bilateral partnership for the development effort quickly grew. Denmark, Netherlands, and Norway were the next countries to join the effort, followed by Canada and then Italy (Kenlon, 2021). Collaborating and financially contributing to the development effort then led to production agreements.

Turkey and Australia joined the seven original countries in signing an MOU for JSF Production, Sustainment, and Follow-on Development (PSFD), committing each nation to shared non-recurring costs and non-financial contributions, which also provided some assurances for their industrial bases, stating "…industries that are in the nations of Participants procuring JSF Air Systems under this MOU and that were awarded SDD subcontracts will normally also be awarded subcontracts for low rate initial production and

[6] For a more detailed treatment of this issue, see McGinn (2020) and Daniel Fata and Jerry McGinn (2022).

full rate production work, as well as for related sustainment and follow-on development work" (*Memorandum of Understanding*, n.d.). This benefitted industrial bases around the world. In the United Kingdom, BAE provides the aft fuselage, empennage, and electronic warfare suite; Rolls-Royce is a partner on the engine and is a subcontractor for the lift system; and other firms serve as suppliers (Congressional Research Service, 2022, p. 32). Alenia Aeronautica is the largest aeronautical company in Italy, and so it naturally had a significant part to play with the JSF, a role which started with aircraft wing construction. Italy and Japan would earn final assembly production line work, which also translated into sustainment efforts. As described next, Italy's production path came through the JSF International Cooperative Program, whereas Japan's production path came through Foreign Military Sales.

Cooperative Production Through the Cooperative Program

U.S. law provides authority to enter into cooperative projects with friendly foreign countries for concurrent production in the U.S. and in another member country of a defense article jointly developed (*Authority of President*, n.d.). The authority for international agreements relating to cooperative research, development, test, evaluation, production, follow-on support, information exchange, and related personnel exchange and standardization agreements is delegated to the Director, International Cooperation in USD(A&S; *International Agreements*, 2019). This cooperative project path provided the legal framework for Italy to contribute to the development of the program and then produce aircraft. Italy's production and sustainment opportunity was realized when the Italian Parliament approved $775 million for the construction of the Final Assembly and Check Out (FACO) line in Cameri (Nones et al., 2009). Italy's F-35 FACO is owned by the Italian Ministry of Defense and is operated by Alenia Aermacchi, in conjunction with Lockheed Martin. Its success has been highlighted not only by aircraft rolling off the assembly line but also its selection by the DoD as the F-35 Heavy Airframe Maintenance Repair, Overhaul and Upgrade facility for the European region as well (*The First Italian F-35*, 2015). Investments in the Cameri facility led to new production opportunities, too. In 2019, the first Dutch F-35 rolled off the Cameri line (*F-35 for the Netherlands*, n.d.).

Co-Production Through Foreign Military Sales (FMS)

Japan's production path came through FMS. U.S. law provides authority for coproduction or licensed production outside the United States of defense articles of U.S. origin when such production best serves the foreign policy, national security, and economy of the United States (Foreign Relations and Intercourse, n.d.). Authority for co-production using FMS procedures is conducted under the oversight of the Defense Security Cooperation Agency (*Security Assistance Management Manual*, 2023). The JSF prime, Lockheed Martin, partnered with Japan's Mitsubishi Heavy Industries (MHI) to stand up the Komaki South FACO facility for the F-35 in Nagoya, Japan (*Japan Air Self-Defense Force's*, n.d.). And similar to Italy's Cameri FACO, the Japanese FACO provided valuable high-tech work in the country, and the DoD selected it as the North Asia-Pacific regional heavy airframe Maintenance Repair Overhaul & Upgrade facility (*First Japanese-Built F-35*, 2017). Two additional Japanese companies contribute to the program, further expanding the industrial base. Mitsubishi Electric Company produces mission systems radar and electro-optical components, while IHI Corporation produces F135 engine components and supports the FACO.[7]

[7] Japan 5th Generation Fighter

Findings

- **Negotiating commitments early sets the stage for production.** The bilateral development agreement between the U.S. and the UK led to multilateral development agreements that added Denmark, Netherlands, Canada, and Italy, that led to multilateral production agreements that added Turkey and Australia. All of these agreements paved the way for FMS to Israel, Japan, Korea, Belgium, Poland, Singapore, Finland, Switzerland, and Germany (*F35 Lightning II Program Status*, 2023). While the United States will buy the lion's share of F-35s, the international community will buy another 800 of the aircraft (GAO, 2021).
- **Large international production programs are very hard but very sticky.** Negotiating agreements like the F-35's PSFD MoU is exceedingly difficult, and keeping the program together can likewise be very challenging. In 2015, for example, Canadian Prime Minister candidate Justin Trudeau campaigned on ending the country's participation in the program (Malenic, 2015). After Trudeau's election, withdrawal seemed like a real possibility; however, Canada remained in the program (Blatchford, 2022). The Turkish scenario was quite different. Following its plan to acquire the S-400 Russian-made air defense system, Turkey was removed from the F-35 program ("Turkey Officially Kicked Out," 2019). Fortunately, plans were in place to address the possibility as the F-35 Production, Sustainment, and Follow-On Development MOU, which spans 45 years, specifically addresses amendment, withdrawal, and termination (*Memorandum of Understanding*, n.d.). In addition, the sheer size of the program and the respective national commitments through the PSFD MOU enabled it to survive and even thrive despite regular turbulence.
- **Cooperative production is beneficial for increased resilience and capacity.** The international FACOs developed for the F-35 program created additional capacity and resilience. Having them created inherent surge capacity for the program as well as more of an "in-theater" base for repair and sustainment work. This is especially critical given the cost of sustainment work, which for the United States will cost more than three times the amount to acquire the system. This is typical for fixed wing aircraft, in which the United States averages spending 64% of life cycle costs for operations and support (Office of the Secretary of Defense, Cost Assessment and Program Evaluation, 2020).
- **International programs can significantly increase the world-wide industrial base.** The F-35 program has suppliers in nearly every U.S. state, with an economic impact in the United States of $72 billion (*Evaluating the Impact of the F-35*, n.d.). The value of F-35 work in the United States alone would place the program in the Gross Domestic Product top 70 list (*GDP by Country*, n.d.). The world-wide effort includes over 1,700 companies at various tiers of work worldwide. These companies, moreover, are doing more than providing widgets. The collaboration specifically targets sustainment, upgrades, and collaborative initiatives among fleets and supporting industries (*Memorandum of Understanding*, n.d.).

NATO Alliance Ground Surveillance (AGS)

Purpose

NATO Defense Ministers identified the need for an Alliance-owned and -operated integrated ground surveillance capability for unrestricted and unfiltered access to ground surveillance data in near real-time. Consisting of air, ground, and core mission support segments, the Alliance Ground Surveillance (AGS) provides that integrated ISR capability (*Alliance Ground Surveillance [AGS]*, 2022). Fifteen participating nations—Bulgaria, Czech Republic, Denmark, Estonia, Germany, Italy, Latvia, Lithuania, Luxembourg, Norway, Poland, Romania, Slovak Republic, Slovenia, and the United States—all contribute to the AGS (*NATO Alliance Ground Surveillance Management Agency*, n.d.).

Development and Production

During the Cold War, the NATO Integrated Air Defence System (NATINADS) provided a one directional look for the well-defined threat of manned aircraft. As challenges changed to a less predictable environment, this system evolved into the NATO Integrated Air and Missile Defence System (NATINAMDS) to address the full range of air and missile threats (*NATO Integrated Air and Missile Defence*, 2022).

In 1995, NATO Defence Ministers agreed to a new acquisition effort; however, over the next several years, multiple approaches based on existing assets or a development program based on an American or European radar failed to obtain sufficient support. In 2007, consensus was gained for an air segment based on Global Hawk Block 40 Unmanned Air Vehicle and a ground segment to largely be developed and built by European and Canadian industry. In 2009, the NATO AGS Memorandum of Understanding was signed, establishing the NATO Alliance Ground Surveillance Management Agency (NAGSMA) and serving as the basis for the procurement.[8] NAGSMA then became critical to managing the AGS program effectively, obtaining and sustaining international operational efficiency, as well as establishing and maintaining good working relations with all stakeholders.[9]

Organizing and funding the effort were obviously keys to success. Each of the 15 participating members had a seat at the table, financially contributed to the program, and supported through their industrial bases. Overall coordination was conducted through the NATO Alliance Ground Surveillance Management Organisation, which included a Board of Directors (*NATO Alliance Ground Surveillance Management Organisation*, n.d.). All members financially contributed to establishing the AGS Main Operating Base, communications, and life-cycle support of the AGS fleet; however, some replaced part of their financial contribution through contributions-in-kind (*NATO AGS Factsheet*, 2014). All NATO members, not just the 15 participating AGS members, now contribute to the on-going capability, and the overall program management and life cycle support responsibility is now in the hands of the NATO Support and Procurement Agency as NATO common funds for infrastructure, communications, operation and support follows the Alliance's normal funding authorization procedures.[10]

The industrial bases of all acquiring countries were also engaged. The team included Northrop Grumman, Germany's Airbus Defence and Space, Italy's Leonardo, Norway's Kongsberg, and other defense companies from each of the members.[11] Northrop Grumman was the prime contractor, who also manufactured the Global Hawk air vehicle, supporting systems, and payloads, including an advanced ground surveillance radar sensor radar (*NATO at Chicago Summit*, 2012). Airbus built the Mobile General Ground Stations (*Airbus Defence and Space*, 2016). Leonardo provided the Sigonella Mission Operations Support system, Transportable General Ground Stations, application software for those functionalities, and Wide Band Data Link; the Italian company was also responsible for industry contributions for Bulgaria and Romania (*Leonardo NATO AGS program*, n.d.).

---

[8] AGS
[9] NAGSMA
[10] AGS
[11] Ibid

Kongsberg provided the System Master Archival/Retrieval Facility (SMARF) for storing, managing and disseminating Joint ISR data (*NATO AGS SMARF*, n.d.). A host of other international industry team members included Cassidian, Selex Galileo, ICZ, A.S., ComTrade d.o.o, BIANOR, Technologica, Zavod Za Telefonna Aparatura Ad, SELEX ELSAG, Elettra Communications, UTI Systems, and SES (*NATO at Chicago Summit*, 2012).

Findings

- **Multilateral cooperative development programs are really challenging to pull off.** AGS took an inordinate period of time to come to fruition. It took almost 15 years from a NATO Ministerial decision in 1995 until the PMOU was signed by 15 nations in 2009. It then took another 12 years, until early 2021, before NATO AGS declared initial operating capability.[12] That 27 years (!) demonstrates the challenges with negotiating workshare, changing national priorities, maintaining consensus, and numerous other factors in a multilateral effort. The F-35 case demonstrated some of these same challenges, but it is an order of magnitude harder to manage a group effort like AGS compared to a U.S.-led program like F-35.
- **Gaining consensus on a governance model is critical.** The 2009 MOU, along with the AGS Charter, sets the legal, organizational, and budgetary framework needed for ultimate success (*NATO's Allied Ground Surveillance Program*, 2009). This laid the framework to address problems as they surfaced and created a life cycle management philosophy. In AGS's case, the consensus led to the NATO Support and Procurement Agency being designated as the life cycle manager, with responsibilities to include sustainment, system upgrades, and ensuring system safe for flight compliance.[13] This life cycle approach is a best practice in the Defense Acquisition System and helped to make a large program like AGS sticky (*The Defense Acquisition System*, 2022).

Three-Dimensional Expeditionary Long Range Radar (3DELRR)

Purpose

The Three-Dimensional Expeditionary Long Range Radar (3DELRR) program will provide the U.S. Air Force their principal "long-range, ground-based sensor for detecting, identifying, tracking and reporting aerial tracks for the Joint Force Air Component Commander through the Theater Air Control System" (*Air Force Budget Exhibit*, 2019). 3DELRR participates in the DEF program described earlier to increase exportability with the intent of increasing production quantities and lowering life cycle costs (*Air Force Budget Exhibit*, 2019). This approach has already resulted in one sale to a foreign customer, and there is additional interest by other potential customers.

Development and Production

When the Air Force began the process of replacing the outdated AN/TPS-75 radar system, its request for proposals included the need for bidders to address exportability, as the service would evaluate this aspect as a source selection factor (*GAO Decision*, 2016). Raytheon, Lockheed Martin, and Northrop Grumman submitted proposals, and they all included exportability features in their designs (Albon, 2014). Unfortunately, progress on the program was halted for several years while legal action took place in the courts (GAO, 2018). However, the ground work for embracing the exportability concept in the program had been laid. The Air Force's subsequent request for bids called for implementing anti-

---

[12] AGS
[13] NSPA's AGS website at https://www.nspa.nato.int/about/life-cycle-management/ags

tamper design and applying differential capabilities aligned with the DoD Anti-Tamper guidelines as well as identifying the bidder's costs with and without foreign purchases (*Request for Proposal FA8730*, 2016). Lockheed Martin won the ensuing competition with its TPY-4 long-range radar (*3DELRR to Move Forward*, 2022). Eight months later, the Norwegian Armed Forces selected the same TPY-4 because, first, Norwegian industry has been a crucial partner in the radar's development as Lockheed Martin leveraged an extensive Norwegian supplier-base, and second, it lowered the foreign partner's risk by integrating into the prime's production line for the Air Force (*Royal Norwegian Air Force Selects*, 2022).

A subsystem of the TPY-4 provides an excellent example of the importance of the relationship between U.S. primes and the international supplier base. The Platform Electronics SubSystem, built by KONGSBERG Defense & Aerospace, is critical for TPY-4's long-range surveillance (*Royal Norwegian Air Force Selects*, 2022). Lockheed Martin is in talks with multiple additional international customers to purchase TPY-4 and anticipates generating $1.3 billion in future sales over the next 10 years (Katz, 2022).

Findings

- **DEF was a key enabler for the 3DELRR program**. 3DELRR officials acknowledged increased competition for the program which resulted from participating in the DEF program (*GAO Report on Defense Acquisitions*, 2017). DEF, described earlier, encourages government program managers to design and develop technology protection features in systems early in their acquisition life cycle to facilitate foreign sales (*Defense Exportability Features*, n.d.).
- **Focused bilateral partnership efforts set up future success**. The early involvement of the Norwegian government and industry in the development of 3DELRR through DEF helped secure the prompt engagement of an international partner and created a framework for future nations as well. This will advance interoperability over time.

Next Generation Jammer (NGJ)

Purpose

The Next Generation Jammer (NGJ) is an evolutionary acquisition program providing Airborne Electronic Attack capability in three increments for each of the low, middle, and high frequency bands. NGJ Mid Band and NGJ Low Band Programs are joint cooperative programs between the U.S. Navy and the Australian Department of Defence (*Next Generation Jammer*, n.d.).

Development and Production

The NGJ Mid-Band program focuses on providing Airborne Electronic Attack capability the middle frequency bands of the electromagnetic spectrum. Recognizing the benefits of working together to address a common requirement, the United States and Australia signed a cooperative development agreement in October 2017 and, based on the program's success, signed a PSFD MOU in May 2020 (*Next Generation Jammer Mid-Band Selected Acquisition Report [SAR]*, 2021). The program has continued to make progress, earning a Milestone C decision in 2021, which enabled the award of initial production contracts (*Next Generation Jammer Mid-Band Selected Acquisition Report [SAR]*, 2021). Production pods are scheduled to be delivered in September 2023 (*DOT&E FY2021 Annual Report*, n.d.).

The NGJ Low Band program addresses advanced and emerging threats in the lower frequency bands. It is also a joint cooperative program between the United States and

Australia and currently in the Engineering and Manufacturing Development acquisition phase.[14]

Cooperation benefits are widely known. For the NGJ, the Navy has specifically identified them as sharing of best technologies in the world, strengthening technology capabilities, increasing military effectiveness at home and abroad, reducing duplication of effort across nations, and overall reducing costs (*U.S. and Australia Expand*, 2020).

These NGJ programs support Australia's overall Advanced Growler Airborne Electronic Attack Capability (AEAC) Project, which introduces enhancements to airborne electronic attack by investing up to $6 billion between 2016 and 2035 (*Advanced Growler Airborne Attack Capability*, 2020). This large investment has benefitted both the U.S. and Australian industrial bases. Raytheon Australia works with the U.S.- based prime contractor Raytheon on advanced technologies which enable interoperability for the allies, and for the NGJ there is a special focus on the companies providing real-world training scenarios and services (*Thousands of Missions*, 2017). Test ranges are also an important element of delivering a capability, and the cooperative programs have realized benefits in this aspect, too. Supporting the NGJ program, the AEAC Project awarded Australia's CEA Technologies a contract to provide advanced capabilities for electronic warfare ranges, which is supporting training exercises that also include U.S. forces (*CEA Technologies to Upgrade*, 2023).

Findings

- **Focused bilateral partnership efforts set up future success.** The Next Generator Jammer program re-emphasizes overall cooperative benefits such as sharing of the best technologies, increasing military effectiveness, reducing duplication of effort, and reducing costs. It also highlights the connections between partner industrial bases due to the global nature of multinational corporations, transnational enterprises, and joint ventures. Additionally, NGJ highlights ancillary benefits in terms of training scenarios and test ranges.

Tactical High-Speed Offensive Ramjet for Extended Range (THOR-ER)

Purpose

Tactical High-Speed Offensive Ramjet for Extended Range (THOR-ER) is an effort to develop advanced solid fuel ramjet technologies applicable to long range high-speed and hypersonic weapons. Fruit of the DoD's (2020a) Allied Prototyping Initiative, this partnership program between the United States and Norway provides cooperative opportunities in co-development and co-production for the governments and industrial bases of both nations.

Development and Production

THOR-ER is an effort of the DoD's Allied Prototyping Initiative, launched in 2020 to identify and develop high impact prototyping projects in which the United States and partner nations share technologies and resources for their industries to co-develop leap-ahead capabilities (Office of the Secretary of Defense for Research and Engineering, 2020). The ramjet technical program relies upon collaborative research efforts involving multiple U.S. and Norwegian organizations including the Office of the Under Secretary of Defense for Research and Engineering (R&E), the R&E's Joint Hypersonics Transition Office, Naval Air Warfare Center Weapons Division, the Norwegian Defence Research Establishment, and the Norwegian company Nammo (DoD, 2022).

[14] Next Generation Jammer

THOR-ER's test program reached a notable milestone in 2022 with a successful in-flight demonstration of ramjet propulsion technology with "new high energy fuels, advanced air injection, and throttling methodologies" which are critical for the program's success (DoD, 2022). The technical success in accelerating to above Mach 2 was noted by Under Secretary of Defense for Research and Engineering Heidi Shyu and Norwegian Armaments Director Morten Tiller, who praised the collaboration and demonstration of the power of bilateral cooperation (DoD, 2022). THOR-ER's development is also distinguished by each partner providing equitable contributions, and both will consider the potential for co-production ("DoD and Norway Working on Ramjets," 2020).

The senior leadership engagement and funding sponsorship through the Allied Prototyping Initiative has been a critical enabler for THOR-ER. This OSD (R&E) program lays the foundation for decision-making with sharing philosophies in terms of funding, technologies, subject matter expertise, and industrial base strengths while pursuing the endgame of maximizing modernization through better ideas together; increasing interoperability by starting with a common specification, and reducing vulnerabilities by collectively addressing challenges and enabling flexibility in the supply chain.[15] As an Under Secretary effort, the Allied Prototyping Initiative is not constrained to just one technical area and so can address any of the OSD (R&E)'s critical technology areas, including Biotechnology, Quantum Science, Future Generation Wireless Technology, Advanced Materials, Trusted AI and Autonomy, Integrated Network Systems-of-Systems, Microelectronics, Space Technology, Renewable Energy Generation and Storage, Advanced Computing and Software, Human-Machine Interfaces, Directed Energy, Hypersonics, Integrated Sensing and Cyber (Under Secretary of Defense for Research and Engineering, n.d.).

THOR-ER is the first effort announced under the Allied Prototyping Initiative, which notes the importance the DoD has placed in promoting co-development and co-production for lead-ahead capabilities. The second effort, the Southern Cross Integrated Flight Research Experiment (SCIFiRE), also advances technology, but in partnership with Australia (DoD, 2020b).

Findings

- **Importance of senior leader sponsorship.** The Allied Prototyping Initiative is managed by the Directorate for Advanced Capabilities within the Office of the Under Secretary of Defense for Research and Engineering, which provides the top-level support critical to coordinating and earning signatures on the government-to-government International Agreements necessary for international collaboration. The same is true on the industry side. And industry executives see the value in how one effort can create prospects for another, as evidenced in Nammo partnering with Boeing to jointly develop and produce the next generation of extended-range artillery projectiles, based on Nammo's ramjet technology ("DoD, Norway Partner on Ramjets," 2020).
- **Focused bilateral partnership efforts set up future success.** In 1905, the United States established diplomatic relations with Norway, and the two nations have enjoyed a long tradition of friendly relations for many years (U.S. Department of State, 2023). Nammo has built a workforce with the technical skills involved in developing and producing specialty ammunition and rocket motors for customers

[15] API Briefing

around the world (*Nammo*, n.d.). For the THOR-ER program, the U.S.-Norway partnership has proven very successful.

- **Understanding the importance of the production potential.** The Allied Prototyping Initiative specifically highlights the importance of co-development efforts leading to co-production. The industrial bases understand the importance of production to their ability to make money, and Pentagon acquisition chief Bill LaPlante has also emphasized the importance of co-production and licensed production (McGinn, 2023). LaPlante has further stressed this criticality: “All that matters is getting into production” (“Strategy & Policy,” 2020).

NATO Sea Sparrow Consortium

Purpose

The NATO Sea Sparrow Surface Missile System Project started as a four-country international technology development effort for anti-ship missile defense capabilities more than 50 years ago and has grown to be “the largest and longest running cooperative smart defense initiative in NATO history” with 12 participating nations—Australia, Belgium, Canada, Denmark, Germany, Greece, Netherlands, Norway, Portugal, Spain, Turkey, and the United States—benefitting from the progression over the years of the RIM-7 Sea Sparrow to today’s RIM-162 Evolved Sea Sparrow (*NATO Sea Sparrow*, n.d.).

Development and Production

In the early 1960s, the U.S. Navy began work with the Applied Physics Laboratory at Johns Hopkins University on a Basic Point-Defense Missile System to defend against Soviet advances in anti-ship missiles (Wildenberg, 2018). This work spurred multiple proposals in NATO, which led to Denmark, Italy, Norway, and the United States Signing an International Development MOU, which established the NATO Sea Sparrow Surface Missile System project (*NATO Sea Sparrow*, n.d.). Raytheon was the prime contractor for a 3-year development effort which led to successful operational testing by the Americans and Norwegians, clearing the way to production (Roe, 1991). This set the stage for decades of use and upgrades, culminating with today’s Evolved Sea Sparrow Missile (ESSM).

ESSM planning and consensus building for the development effort has led to benefits across industrial bases into production efforts, too. The 1999 agreement for cooperative engineering and manufacturing development included workshares and cost shares by country. For example, Australia earned thrust vector control work while Canada’s was in the control section (*DOD IG Report*, 2002). That development partnership became the baseline for the production effort, which is governed by the Production MoU that also outlines another workshare arrangement by participating nations (*Evolved Sea Sparrow Missile [ESSM]*, 2020). The ESSM Consortium crosses multiple industrial bases, including Australia’s BAE Systems, Canada’s Honeywell, Denmarks’ Terma, Germany’s RAMSYS, Diehl BGT Defence, and MBDA-LFK, Greece’s ELFON, INTRACOM, and HAI, Netherlands’ Thales, Norway’s Nammo Raufoss, Spain’s Indra, Turkey’s Roketsan, and the United States’ Raytheon, Alliant Techsystems, BAE Systems Land and Armament, and Lockheed Martin (Smolny, n.d.).

The production effort is significant. Figure 2 below shows that the U.S. Navy has been buying the missile for decades.

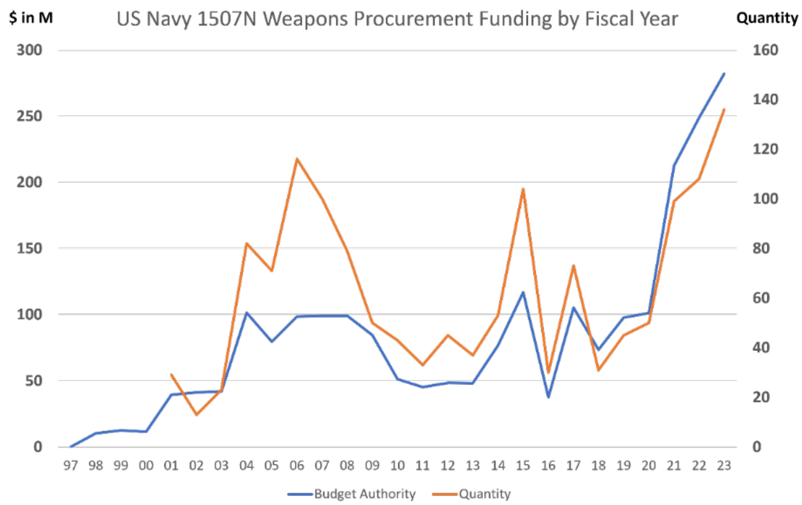


Figure 2. U.S. Navy Procurement Funding: $2.2 Billion in FY97-23 for 1,450 Missiles[16]

Additionally, Raytheon expects to produce and deliver another 1,500 rounds based on customer requirements, which will make the missile a staple for many years yet to come (*ESSM Missile*, n.d.). The ESSM is a model answer for Under Secretary for Acquisition and Sustainment Dr. Bill LaPlante's call for an increase in co-production, licensed production, and cooperative programs (McGinn, 2023).

Findings

- **Starting small can pay off big in the long run.** The initial partnership of the 1960s focused on the threat of Soviet anti-ship missiles. The general missile threat lasted for decades, and will into the foreseeable future, which has led to long-term success and NATO's largest and longest running cooperative smart defense initiative. While technology changed over time, Sea Sparrow demonstrated that the collective approach over time works. Also, Sea Sparrow's development agreements led to production agreements, which now have spanned decades.
- **Workshare agreements can be enablers.** While the United States generally seeks a best value procurement without guarantees of specific workshares, sometimes the workshare approach is needed to encourage international participation, which will, in the end, provide the greatest overall benefits.

Advanced Medium-Range Air-to-Air Missile (AMRAAM) Alternate Engine

Purpose

The AIM-120 AMRAAM is an all-weather, beyond-visual-range missile used on U.S. Air Force F-15, F-16, F-22 and F-35A aircraft and the U.S. Navy and Marine Corps' F/A-18, F-35B/C, EA-18G and AV-8B aircraft (*AMRAAM*, n.d.). In 2011, AMRAAM's rocket motor experienced technical problems, which led to the program office and prime contractor Raytheon to seek and ultimately certify an alternative rocket motor supplier (*Director of Operational Test and Evaluation*, n.d.). This alternate engine came from Nammo, a Norwegian provider of rocket motors for both military and civilian customers.[17] AMRAAM

[16] Based on P-1 documents in each Fiscal Year for 1507N Weapons Procurement for ESSM. Available at https://comptroller.defense.gov/Budget-Materials/.
[17] Nammo

has led to procurement by 40 countries and other opportunities by integration efforts (*Modern, Versatile, and Proven*, n.d.).

Development and Production

AMRAAM rocket motor problems began in 2011, when acceptance testing experienced unpredictable performance at low temps due to propellant hot spots and burn-through failures (*Director of Operational Test and Evaluation*, n.d.). Problems escalated, the prime contractor (Raytheon) and the rocket motor supplier (ATK) took legal action against each other, and no AMRAAMs were delivered for two years (Judson, 2016).

Nammo saw an opportunity and after an investment of $12 million of internal and Norwegian government funds developed and delivered an alternative engine to Raytheon in Tuscon, Arizona (Judson, 2016). Raytheon and Nammo then quickly worked through the process to qualify the engine (*Raytheon Partners with NAMMO*, 2011). Their work was soon rewarded with a successful Live-Fire Test (Host, 2013). Within the first year after the test, Nammo had produced and delivered 1,000 motors to get the program back on schedule (*Director of Operational Test and Evaluation*, n.d.). This alternate engine has been a significant contributor to AMRAAM's upgrades, testing and production; capabilities fully demonstrated in 4,900 shots and 13 air-to-air combat victories; and its selection as the baseline weapon for the National Advanced Surface-to-Air Missile System, NASAMS (*Modern, Versatile and Proven*, n.d.).

NASAMS itself represents another international success. This air defense system consists of Raytheon's Sentinel A3 radar and a suite of effectors, including AMRAAM, AMRAAM-ER, and AIM-9X plus the Norwegian Kongsberg Defence & Aerospace's fire distribution center and launcher, providing safety for the U.S. National Capital Region as well as 12 other countries (Norway, Finland, Spain, The Netherlands, Oman, Lithuania, Indonesia, Australia, Qatar, Hungary, Ukraine, and one undisclosed; *NASAMS*, n.d.). Of special note is the recent military aid package to the Ukraine which included two NASAMS from the United States (Bertuca, 2022).

Findings

- **Developing a second source can unlock new capabilities and capacity.** The AMRAAM case provides an excellent example of tapping into the best technological capabilities, regardless of borders. NAMMO, with substantial host government support, developed an alternative engine and thereby gained access to the U.S. market. The Norwegian company's alternate rocket motor not only brought the U.S. program back from a 2-year schedule slip, but it advanced the platform beyond the program to integrate with another system-of-systems. Most importantly, the alternate engine helped establish additional capacity that has been critical as the demand for AMRAAM has skyrocketed. The program office's willingness to consider international solutions is an enabler for the Build Allied approach.

Mine-Resistant, Ambush-Protected (MRAP) Vehicle

Purpose

MRAPs were developed in the mid- to late-2000s to address the dramatic increase in casualties in Iraq and Afghanistan resulting from improvised explosive devices (IEDs; Wilson, 2007). Then Secretary of Defense Bill Gates personally led the effort to rapidly increase the production and deployment of MRAPs, based principally off existing foreign designs, during this period (Hasik, 2021). The late Ashton Carter highlighted the success of the MRAP program, explaining that forces in MRAP vehicles were 14 times more likely to survive roadside explosions in Afghanistan and Iraq than forces riding in Humvees (Vanden Brook, 2012). The Army and Marine Corps had a limited number of MRAP vehicles for specialized missions, but in 2006 "US combatant commanders identified the urgent operational need for an increased number of MRAP vehicles in theater to provide better protection against underbody mines, improvised explosive devices, rocket-propelled grenades and small arms fire" (Browne, 2016).

Development and Production

MRAP's Engineering Origins

The MRAP solution dates back decades. During the Rhodesian Civil War of the 1970s, mining of roads brought casualties and in South Africa, guerilla groups began to mine roads as well. The engineering solution was for a high ground clearance, V-shaped hull, and wide wheelbase which would direct the blast's energy away from occupants of the vehicle; the design quickly demonstrated success. Rhodesian forces suffered only one fatality from the first 99 blasts against this new design and the South Africans adapted quickly, producing 19,000 vehicles with V-shaped hulls. The story of IED lethality also unfortunately spread, so much so that in the 1980s in Sri Lanka, Indian troops—who did not have the newly designed vehicles—preferred to walk (Hasik, 2021, pp. 45–47).

While the high ground clearance, V-shaped hull, and wide wheelbase design had been in place from decades, it was not one company who owned the design in the following years. After the South African conflicts, the industry for this new design was concentrated in the Olifant Manufacturing Company, which was then acquired by Reunert, which was later acquired by Vickers, who sold a 20-year license to General Dynamics Land Systems (GDLS), and on a parallel path, Vickers merged with Alvis, which BAE Systems then acquired (Hasik, 2021, p. 47).

SECDEF Leadership, Simplified Requirements, and Rapid Industry Engagement

It cannot be overstated how critical Secretary Gates's direction and engagement throughout the MRAP was to its success. He drove a radically different acquisition approach focused on an extremely limited set of requirements centered on improving soldier survivability.

Building upon the proven technology, the MRAP program office was able to deliver at tremendous speed to concurrently produce, test, and field the vehicles (GAO, 2009). On November 9, 2006, the MRAP program office's Request for Proposal solicited bids in three categories. Urban areas were the focus for Category I, the smallest version, which would be capable of carrying four troops. Category II's mission sets were convoys, medical evacuations, and explosive ordnance disposal (EOD) and would carry up to 13 troops. Category III, the largest size with the most hazardous mission, targeted IED clearing operations and EOD (Hasik, 2021, pp. 131–132).

Manufacturers responded with bids, and the MRAP program office awarded multiple initial contracts. Designs which passed tests for maintainability, mobility, and survivability were rewarded with more contracts (Hasik, 2021, p. 135). The government was able to quicken deployment of the vehicles as it elevated the program's priority, which paved the way for industry to invest of their own capital to purchase critical components before delivery options were exercised, as well as retained integration responsibilities for mission equipment packages (GAO, 2009). This approach was not business as usual. "Not since the beginnings of the nuclear submarine production in the late 1950s and early 1960s had the US military run so many parallel designs for the same purpose" (Hasik, 2021, p. 8).

Multiple Designs From a Variety of Manufacturers

The Buffalo Mine-Protected Clearance Vehicle was manufactured by Force Protection, which later acquired by General Dynamics. This design was inspired by the Casspir, a South African landmine-protected armored personnel carrier (APC; *Buffalo Mine-Protected Clearance Vehicle*, 2021). The Caiman vehicle came from Armor Holdings, which was later acquired by BAE Systems (Hasik, 2021, p. 138). Cougars, which included Command and Control, EOD, Patrol, Convoy Support, Forward Observation, Reconnaissance, and Medical Evacuation configurations, came from Force Protection, which was later acquired by General Dynamics (*Cougar 6x6*, n.d.; Hasik, 2021, p. 135). The MaxxPro MRAP came from Navistar (*MaxxPro MRAP*, n.d.). The RG-31, which served as an Armored Personnel Carrier, Command Vehicle, Ambulance, Armored Utility Vehicle, Surveillance Vehicle, EOD and Combat Engineer, was manufactured by GDLS through the Vickers license (*RG-31*, n.d.), and BAE Systems manufactured the RG-33, which was not covered by the Vickers license to GDLS (Hasik, 2021, p. 132).

In less than 3 years from the government's proposal request, 16,204 vehicles were produced and 13,848 were fielded (GAO, 2009). These MRAPs saved thousands of lives and had a tremendous impact on the survivability of military servicemen and women during their use (Vanden Brook, 2012).

Findings

- **Importance of senior leader sponsorship.** The Secretary drove the Department's MRAP effort, and he regularly and personally intervened to ensure that the program stayed on track to deliver life-saving capabilities with speed to deployed warfighters.
- **Use of existing foreign designs.** Decades ago, the Rhodesian Civil War and conflicts in South Africa served as the impetus for a design solution marked by high ground clearance, a V-shaped hull, and a wide wheelbase which would direct the blast's energy away from occupants of the vehicle. That design served well the coalition forces subject to roadside explosions in Afghanistan and Iraq in the post 9/11 operations. The U.S. acquisition system embraced that design approach and then successfully turned to industry for multiple solutions – which led to great success.
- **Rapid development and fielding.** The MRAP decision to use only proven technologies, emphasized in the government's invitation for industry to offer non-developmental solutions, proved to be key in taking the foreign design of a high ground clearance, V-shaped hull, and wide wheelbase to U.S. production in a very short time frame, even earning a "very good overall" assessment for schedule and performance results by the Government Accountability Office (GAO; 2009). MRAP's schedule success runs contrary to a typical DoD program in which schedule delays are the norm. The GAO has found that more than half of major programs report schedule delays and not one of the programs reviewed had reported accelerating any deliveries (GAO, 2022). For the MRAP, the government's decision to start with a non-U.S. design not only did not slow things down, it accelerated fielding, which was most critical in times of war.
- **Multi-sourcing.** With the MRAP, the government recognized that no single firm had the capacity to meet the demand in a timely manner, and so the source selection strategy discounted the traditional one-winner approach. The government awarded contracts to nine commercial sources, thereby expanding production capacity to the maximum extent (GAO, 2009). This multi-sourcing approach allowed firms to focus

on their best value solutions for the three requirement categories. Bids were requested for Category I (small vehicles primarily intended for operations in urban combat environments), Category II (medium sized vehicles for convoys, transporting troops, and ambulatory purposes), and Category III (large vehicles for IED clearing operations and Explosive Ordnance Disposal; Hasik, 2021, p. 132). This provided firms the flexibility to match their proven solution to a specific need, without having to develop a comprehensive solution for all MRAP needs in a winner-take-all environment.

NATO Multinational Multi Role Tanker and Transport Fleet

Purpose

NATO's Multinational Multi Role Tanker Transport (MRTT) fleet provides Belgium, the Czech Republic, Germany, Luxembourg, the Netherlands, and Norway strategic transport, air-to-air refueling, and medical evacuation capabilities. In this partnership, the six participating nations benefit from economies of scale by pooling the MRTT aircraft and sharing costs (*Multinational Multi Role Tanker Transport [MRTT] Fleet [MMF]*, n.d.).

Procurement

In 2012, the European Defence Agency initiated the project and 4 years later, the acquisition phase began with the signing of a procurement contract with Airbus for two A330 aircraft plus the first 2 years of support. The number of participating nations as well as the fleet size has grown over the years. The Netherlands and Luxembourg were the original partners in 2016, Germany and Norway joined a year later, followed by Belgium and the Czech Republic, each in subsequent years. The fleet size currently stands at seven aircraft, with two more expected in 2024 and a 10th in 2026 (*Multi-Role Tanker Fleet [MMF] Expands*, n.d.).

Two important agreements laid the foundation for the program's success. The program Memorandum of Understanding documents the participating nations' promise to pool the aircraft and share costs. The MRTT Fleet Support Partnership agreement documents the NATO Support and Procurement Agency's commitment to acquire and own on behalf of NATO the aircraft and related support equipment, provide in-service support, manage follow-on support, administer finances, and manage host nation support arrangements (*Multinational Multi Role Tanker Transport [MRTT] Fleet Support Partnership*, n.d.).

Findings

- **Cooperative procurement is a lot easier than cooperative development**. The MRTT Fleet case provides an excellent example of cooperating to benefit from economies of scale by pooling aircraft and sharing costs to *purchase* existing aircraft rather than *developing* bespoke cooperative programs like NATO AGS. Initial capabilities were delivered in four years as opposed to 27, and NATO support of the fleet provided stability. While the fleet of seven obviously has limitations, it provides significant capabilities for participating NATO members.

Conclusions and Recommendations

The case studies and preceding analysis illustrate that we clearly have many of the building blocks in place for a robust "Build Allied" approach. There have been and are in development a number of co-development, co-production, second sourcing, licensed production, and sustainment efforts involving our allies and partners. The case study findings show that these successful efforts have largely been driven by strong leadership, focused cooperative efforts, and effective enablers. Moreover, there is clearly an increased appetite for “Build Allied” efforts in the wake of defense industrial capacity shortfalls that have become starkly evident since the start of the Ukraine war last year.

In addition to the principles identified in the case study findings, getting to a vigorous “Build Allied” approach requires accelerating the enablers for true international industrial collaboration, thereby overcoming the barriers that threaten the desired NDS objectives. The following recommendations are focused in that manner.

A “Build Allied” approach is ultimately a win-win proposition for all parties involved. Pursuing programs, initiatives, and recommendations like those described below will help to accelerate international industrial collaboration to build the industrial base capacity and resilience we need to face the national security challenges of tomorrow.

Recommendations

	Recommendation
Defense acquisition system	- The Deputy Secretary should issue a memo to Service Secretaries and DoD components outlining the importance of partnering with allies and partners in acquisition to achieve NDS objectives, highlighting principal enablers such as AUKUS, RDP MOUs, the Allied Prototyping Initiative, and DEF.
	- The Office of the Assistant Secretary of Defense (Acquisition) should prioritize, promote, and perhaps even modify existing DoD 5000.01 guidance to better emphasize international collaboration opportunities such as co-development, co-production, second-sourcing, licensed production, and sustainment.
	- The military departments should examine requirements development processes to facilitate the early involvement of allied and partner companies in DoD programs (e.g., avoid citing classified, U.S.-only documents in either informal or formal requests for information or solicitations where possible).
	- The military departments should add international cooperation evaluation factors to annual performance appraisals for PEOs and PMs to foster greater prioritization of international acquisition activities.
RDP MOUs	- Congress should request a study in the FY24 NDAA of the impact of RDP MOU countries’ contributions to the U.S. defense industrial base through participation in DoD programs *and* the purchase of U.S. defense systems through foreign military or direct commercial sales to increase Congressional awareness of the benefits of RDP MOUs and counterproductive nature of additional Buy America legislation.
	- Using DAU and other venues, the DoD should educate acquisition professionals across the Department about the Buy America exemption for RDP MOU countries to help spur international collaboration opportunities.
SoSAs	- The Office of the Assistant Secretary of Defense (Industrial Base Policy) should work with SoSA signatories to modify the respective arrangements to address specific capability areas (e.g., materials, microelectronics, magnets, unmanned systems) where bilateral industrial cooperation can strengthen industrial resilience.
DEF	- Building off 2022 Ukraine supplemental reprogramming, the OUSD (A&S) should increase DEF base funding to $50 million in FY24 budget submission focused on capabilities being developed for the pacing China challenge.
	- The Office of the Assistant Secretary of Defense (Acquisition) should work with the military departments to increase the awareness and effectiveness of DEF in acquisition program development efforts.
NTIB	- The Office of Defense Pricing and Contracting should establish DFARS clauses focused on facilitating NTIB participation in solicitations for acquisition programs.
	- Once finalized, the DoD use DAU and other venues to educate the acquisition workforce on the use of NTIB clauses for use in programs across the DoD.
	- Once finalized, NTIB country trade associations should advertise NTIB clauses to NTIB-based companies to facilitate additional collaborative initiatives.
AUKUS	- The military departments should build on specific and focused Pillar II activities in hypersonics and unmanned systems to accelerate collaboration and demonstrate

	Recommendation
	capabilities as soon as feasible in FY24 to maintain investment momentum and stakeholder engagement.
	- Congress should grant Australia and the United Kingdom ITAR waivers under the FY24 NDAA for AUKUS classified and unclassified programs.
	- Congress should direct the Department of State in the FY24 State Department Authorization to review and update the Canada ITAR waiver to make it more applicable for today's national security threat environment as well as expand that revised waiver to include Australia and the United Kingdom.
TSFD	- The OUSD (Policy) and OUSD (A&S) should reinvigorate the ATTR SSG to measure and report the effectiveness of TSFD efforts in support of AUKUS initiatives.

Acknowledgements

In addition to cited primary and secondary sources, this paper has benefited enormously from numerous discussions with current and former senior defense officials and foreign government officials in the preparation of this paper. Most of those discussions were conducted under Chatham House rules, so we have only cited those where we have been given explicit permission.

References

Advanced Growler airborne electronic attack capability. (2020, December). https://www.defence.gov.au/project/advanced-growler-airborne-electronic-attack-capability

Aerospace Industries Association. (2023, March 8). *Operationalizing AUKUS: Recommendations for the U.S. system*. https://www.aia-aerospace.org/wp-content/uploads/Operationalizing-AUKUS-AIA-Release.pdf

Air Force budget exhibit R-2 of program element 0207455F for president's budget for fiscal year 2020. (2019, February). https://www.dacis.com/budget/budget_pdf/FY20/RDTE/F/0207455F_52.pdf

Airbus Defence and Space presents its Mobile General Ground Station at the 2016 Warsaw NATO summit. (2016, July 11). https://www.airbus.com/en/newsroom/news/2016-07-airbus-defence-and-space-presents-its-mobile-general-ground-station-at-the

Albon, C. (2014, October 9). Air Force: International market drove desire for 3DELRR exportability. *Inside the Pentagon; Arlington*, *30*(41).

Alliance Ground Surveillance (AGS). (2022, July 20). https://www.nato.int/cps/en/natohq/topics_48892.htm

AMRAAM. (n.d.). https://www.navair.navy.mil/product/AMRAAM

Arms transfer and technology release senior steering group and technology security and foreign disclosure office (DoD Directive 5111.21). (2020, July 14). https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/511121p.pdf

Assessing and strengthening the manufacturing and defense industrial base and supply chain resiliency of the United States: Report to President Donald J. Trump by the Interagency Task Force in fulfillment of executive order 13806. (2018, September). https://media.defense.gov/2018/Oct/05/2002048904/-1/-1/1/ASSESSING-AND-STRENGTHENING-THE-MANUFACTURING-AND%20DEFENSE-INDUSTRIAL-BASE-AND-SUPPLY-CHAIN-RESILIENCY.PDF

Authority of President to Enter into Cooperative Projects with Friendly Foreign Countries, 22 U.S.C. § 2767 (n.d.). https://www.govinfo.gov/app/details/USCODE-2011-title22/USCODE-2011-title22-chap39-subchapII-sec2767/context

Barbara McQuiston, chair, DIANA board of directors, remarks at ComDef 2023, "Marshalling technology towards common goals." (2023, February 10).

Bertuca, T. (2022, July 1). New U.S. weapons package for Ukraine includes Norwegian surface-to-air missile systems. *Inside Defense*. https://insidedefense.com/insider/new-us-weapons-package-ukraine-includes-norwegian-surface-air-missile-systems

Blatchford, A. (2022, March 28). *Canada circles back to Lockheed for F-35s*. Politico. https://www.politico.com/news/2022/03/28/canada-lockheed-air-force-upgrade-00020974

Bridging the Valley of Death fireside chat. (2022, November 9). 2022 GMU-DAU Government Contracting Conference. https://coursemedia.gmu.edu/media/Fireside%20Chat%20Bridging%20the%20Valley%20of%20Death/1_mdvurwh0

Browne, M. (2016, September 1). *MRAP program celebrates 10 years of protecting those who protect US*. U.S. Marine Corps Systems Command. https://www.marcorsyscom.marines.mil/News/News-Article-Display/Article/932752/mrap-program-celebrates-10-years-of-protecting-those-who-protect-us/

Buffalo mine-protected clearance vehicle. (2021, April 26). https://www.army-technology.com/projects/buffalo/

CEA Technologies to upgrade Growler training ranges. (2023, February 6). https://www.australiandefence.com.au/news/cea-technologies-to-upgrade-growler-training-ranges
Center for Strategic and International Studies. (2023, March 30). *The future of AUKUS with Admiral Harry Harris Jr., USN (Ret.)*. Center for Strategic and International Studies. https://www.csis.org/events/future-aukus-admiral-harry-harris-jr-usn-ret
Christensen, L., & Goldstein, M. (n.d.). *Working successfully with ITAR in U.S. Canadian defence industry technology transfers.* Miller Chevalier. https://www.millerchevalier.com/sites/default/files/news_updates/attached_files/christensen20and20goldstein20-20quebec20itar20canadian20exemptions20guide.pdf
Clark, C. (2023, March 3). Eye on AUKUS, Aussie defense minister pushes US on ITAR – gently. *Breaking Defense.* https://breakingdefense.com/2023/03/eye-on-aukus-aussie-defense-minister-pushes-us-on-itar-gently/
Congressional Research Service. (2022, May 2). *F-35 Joint Strike Fighter (JSF) program*. https://crsreports.congress.gov/product/pdf/RL/RL30563/85
Cougar 6x6. (n.d.). https://www.gdls.com/cougar-6x6/
Dean, S. E. (2023, January 23). SITREP – The Army's optionally manned fighting vehicle (OMFV). *European Security and Defence*. https://euro-sd.com/2023/01/articles/29128/sitrep-the-us-armys-optionally-manned-fighting-vehicle-omfv/
The defense acquisition system (DoD Directive 5000.01). (2022. July 28). https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/500001p.pdf
Defense Counterintelligence and Security Agency. (n.d.). *Foreign ownership, control or influence*. https://www.dcsa.mil/mc/ctp/foci/
Defense exportability features. (n.d.). https://www.acq.osd.mil/ic/def.html
Defense Pricing and Contracting. (n.d.). *Reciprocal defense procurement and acquisition policy memoranda of understanding*. https://www.acq.osd.mil/asda/dpc/cp/ic/reciprocal-procurement-mou.html
Definitions for co-development, co-production, and second sourcing from Defense Acquisition University (DAU) glossary. (n.d.). Retrieved April 2, 2023, from https://www.dau.edu/glossary/Pages/Glossary.aspx
DFARS 225.872-1. (n.d.). https://www.acq.osd.mil/dpap/dars/dfars/html/current/225_8.htm#225.872-1
Director of Operational Test and Evaluation report on AMRAAM. (n.d.). https://www.dote.osd.mil/Portals/97/pub/reports/FY2013/af/2013amraam.pdf?ver=2019-08-22-111345-300
DoD. (2020a, April 20). *DOD announces new allied prototyping initiative effort with Norway to continue partnership in advancing solid fuel ramjet technologies*. https://www.defense.gov/News/Releases/Release/Article/2156251/dod-announces-new-allied-prototyping-initiative-effort-with-norway-to-continue/
DoD. (2020b, November 30). *Department of Defense announces new Allied Prototyping Initiative effort with Australia to continue partnership in developing air breathing hypersonic vehicles*. https://www.defense.gov/News/Releases/Release/Article/2429061/department-of-defense-announces-new-allied-prototyping-initiative-effort-with-a/
DoD. (2022, October 5). *Tactical High-speed Offensive Ramjet for Extended Range (THOR-ER) team completes ramjet vehicle test*. https://www.defense.gov/News/Releases/Release/Article/3180755/tactical-high-speed-offensive-ramjet-for-extended-range-thor-er-team-completes/
DoD and Norway working on ramjets for hypersonic missiles. (2020, April 20). *Defense Daily*. https://www.defensedaily.com/dod-norway-working-ramjets-hypersonic-missiles/advanced-transformational-technology/
DoD AT&L. (2012, November 13). *Better buying power 2.0: Continuing the pursuit for greater efficiency and productivity in defense spending* [Memorandum]. https://www.acq.osd.mil/fo/docs/USD(ATL)%20Signed%20Memo%20to%20Workforce%20BBP%202%200%20(13%20Nov%2012)%20with%20attachments.pdf
DoD IG report – Acquisition of the evolved SEASPARROW missile. (2002, July 5). https://media.defense.gov/2002/Jul/05/2001715839/-1/-1/1/02-126.pdf
DoD international acquisition guide. (n.d.).
DoD, Norway partner on ramjets for Navy hypersonic missiles. (2020, April 20). *Breaking Defense*. https://breakingdefense.com/2020/04/dod-norway-partner-on-ramjets-for-navy-hypersonic-missiles/
DOT&E FY2021 annual report – Next Generation Jammer Mid-Band. (n.d.). https://www.dote.osd.mil/Portals/97/pub/reports/FY2021/navy/2021ngj.pdf?ver=ahlNpCgYYKKs_UtJ2JO1lA%3d%3d#:~:text=No%20operational%20testing%20has%20been%20conducted%20on%20the,IOT%26E%20and%20likely%20extend%20the%20planned%20IOT%26E%20schedule
Easley, M. (2023, March 20). US Air Force hopes to learn from Australia's robotic wingmen efforts as it pursues collaborative combat aircraft. *Defense Scoop.* https://defensescoop.com/2023/03/20/us-air-force-hopes-to-learn-from-australias-robotic-wingmen-efforts-as-it-pursues-collaborative-combat-aircraft/

ESSM missile. (n.d.). https://www.raytheonmissilesanddefense.com/what-we-do/naval-warfare/ship-self-defense-weapons/essm-missile
Evaluating the economic impact of the F-35. (n.d.). https://aerodynamicadvisory.com/wp-content/uploads/2022/09/Aerodynamic-Advisory-White-Paper_v8.pdf
Evolved Sea Sparrow missile (ESSM). (2020, July 3). https://www.naval-technology.com/projects/evolved-sea-sparrow-missile-essm/
Fact Sheet: Implementation of the Australia – United Kingdom – United States partnership (AUKUS). (2022, April 5). https://www.whitehouse.gov/briefing-room/statements-releases/2022/04/05/fact-sheet-implementation-of-the-australia-united-kingdom-united-states-partnership-aukus/
Fata, D., & McGinn, J. (2022, May 19). Why a “Build Allied” approach matters. *Defense News.* https://www.defensenews.com/opinion/commentary/2022/05/19/why-a-buy-allied-approach-matters/
First AN/TPY-4 air defense radar completed production. (2022, May 11). https://www.key.aero/article/first-antpy-4-air-defence-radar-completes-production
The first Italian F-35 rolls out of the hangar. (2015, March 16). https://www.leonardo.com/en/news-and-stories-detail/-/detail/the-first-italian-f-35-rolls-out-of-the-hangar
First Japanese-built F-35A officially unveiled at Nagoya facility. (2017, June 5). https://news.lockheedmartin.com/2017-06-05-First-Japanese-Built-F-35A-Officially-Unveiled-at-Nagoya-Facility
Foreign Relations and Intercourse, 22 U.S.C. § 2791 (n.d.). https://www.govinfo.gov/app/details/USCODE-2008-title22/USCODE-2008-title22-chap39-subchapIV-sec2791/summary
F-35 for the Netherlands. (n.d.). https://www.f35.com/f35/global-enterprise/netherlands.html
F-35 Lightning II program status and fast facts. (2023, March 1). https://www.f35.com/content/dam/lockheed-martin/aero/f35/documents/March%202023%20F-35%20Fast%20Facts.pdf
GAO. (2009, October 8). *Rapid acquisition of MRAP vehicles*. https://www.gao.gov/assets/gao-10-155t.pdf
GAO. (2018, April). *Report on weapons system annual assessment*. https://www.gao.gov/assets/gao-18-360sp.pdf
GAO. (2021, April 22). *F-35 sustainment.* https://www.gao.gov/assets/gao-21-505t.pdf
GAO. (2022, June). *Weapons system annual assessment.* https://www.gao.gov/assets/gao-22-105230.pdf
GAO decision, File B-410719.10; B-410719.11. (2016, November 15). https://www.gao.gov/assets/b-410719.10%2Cb-410719.11.pdf
GAO report on defense acquisitions: Assessments of selected weapon programs. (2017, March). https://www.gao.gov/assets/files.gao.gov/assets/gao-17-333sp.pdf
GDP by country. (n.d.). https://www.worldometers.info/gdp/gdp-by-country/
Greenwalt, B. (2022, June 1). The NTIB is dying: Is AUKUS next? Congress must apply life support soon. *Breaking Defense*. https://breakingdefense.com/2022/06/the-ntib-is-dying-is-aukus-next-congress-must-apply-life-support-soon/
Guide to DoD international acquisition and exportability practices. (2022, March 29). https://www.acq.osd.mil/ic/docs/def/Guide-to-International-Acquisition-and-Exportability_mjv.pdf
Harris, B. (2023, March 22). Congress lays groundwork for AUKUS export control reform. *Defense News.* https://www.defensenews.com/congress/2023/03/22/congress-lays-groundwork-for-aukus-export-control-reform/
Hasik, J. (2021). *Securing the MRAP – Lessons learned in marketing and military procurement*. Texas A&M University Press.
Host, P. (2013, January 13). Air Force successfully tests AMRAAM with Nammo rocket motor. *Defense Daily*. https://www.defensedaily.com/air-force-successfully-tests-amraamwith-nammorocket-motor/air-force/
International agreements (DoD Instruction 5530.03). (2019, December 4). https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/553003p.PDF
Japan Air Self-Defense Force's 5th generation fighter. (n.d.). https://www.f35.com/f35/global-enterprise/japan.html
Joint leaders statement on AUKUS. (2021, September 15). https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/15/joint-leaders-statement-on-aukus/
Judson, J. (2016, May 13). Tactical rocket motor business takes fight to Congress. *Defense News*. https://www.defensenews.com/air/2016/05/13/tactical-rocket-motor-business-takes-fight-to-congress/
Katz, J. (2022, April 28). Fresh off Air Force 3DELRR win, Lockheed eyes Norway, other international buyers. *Breaking Defense*. https://breakingdefense.com/2022/04/fresh-off-air-force-3delrr-win-lockheed-eyes-norway-other-international-buyers/
Kenlon, F. (2021, June 26). *The international acquisition & exportability aspects of JSF – Concept demonstration phase*. https://www.dau.edu/training/career-development/intl-acq-mgmt/blog/The-International-Acquisition-and-Exportability-(IAandE)-Aspects-of-JSF-%E2%80%93-Concept-Demonstration-Phase-
Leonardo NATO AGS program. (n.d.). https://unmanned.leonardo.com/en/products/nato-ags

Lockheed Martin to hire 300 in Salina, swelling workforce to biggest in 10 years. (2023, February 17). https://www.aviationpros.com/aircraft/defense/news/21296138/lockheed-martin-to-hire-300-in-salina-swelling-workforce-to-biggest-in-10-years
Malenic, M. (2015, September 23). Canada liberal party would end F-35 participation. *IHS Jane's Defence Weekly*, *52*(45).
MaxxPro MRAP. (n.d.). https://www.navistardefense.com/navistardefense/vehicles/maxxpromrap/maxxpro_mrap
McGinn. (2021, June 5). *Building industrial resilience with a little help from our friends: Adapting DoD acquisition processes to facilitate allied and partner engagement* (George Mason Center for Government Contracting White Paper Series, No. 8). https://business.gmu.edu/news/2021-10/no-8-building-industrial-resilience-little-help-our-friends-adapting-dod-acquisition
McGinn, J. (2020, September 15). Reshoring does not mean buy America only. *Defense News*. https://www.defensenews.com/opinion/commentary/2020/09/15/reshoring-does-not-mean-buy-america-only/
McGinn, J. (2023, March 17). America needs to grow its capacity to produce weapons. Here's four steps to do it. *Breaking Defense*. https://breakingdefense.com/2023/03/america-needs-to-grow-its-capacity-to-produces-weapons-heres-four-steps-to-do-it/
Memorandum of understanding among Australia, Canada, Denmark, Italy, the Netherlands, Norway, Turkey, UK, and US concerning the production, sustainment, and follow-on development of the joint strike fighter, signature dates on November 14, 2006, December 11, 2006, December 12, 2006, January 25, 2007, January 31, 2007, February 7, 2007, and February 27, 2007. (n.d.). https://www.state.gov/wp-content/uploads/2019/02/06-1231-Multilateral-Defense-JSF.pdf
Modern, versatile and proven. (n.d.). https://www.raytheonmissilesanddefense.com/what-we-do/air-warfare/air-to-air-missiles/amraam-missile
Multinational Multi Role Tanker Transport (MRTT) Fleet (MMF). (n.d.). https://www.nspa.nato.int/about/life-cycle-management/MMF
Multinational Multi Role Tanker Transport (MRTT) Fleet support partnership. (n.d.). https://www.nspa.nato.int/about/life-cycle-management/MMF/multinational-multi-role-tanker-transport-fleet-support-partnership
Multi-Role Tanker Transport Fleet (MMF) expands significantly. (2017, September 25). https://eda.europa.eu/news-and-events/news/2017/09/25/multi-role-tanker-transport-fleet-(mmf)-expands-significantly#
Murray, R. (2023, February 3). *NATO can learn from Ukraine's military innovation*. Chatham House. https://www.chathamhouse.org/publications/the-world-today/2023-02/nato-can-learn-ukraines-military-innovation
Nammo. (n.d.). https://www.nammo.com/
NASAMS: National Advanced Surface-to-Air Missile System. (n.d.). https://www.raytheonmissilesanddefense.com/what-we-do/missile-defense/air-and-missile-defense-systems/nasams
National Defense Authorization Act for Fiscal Year 2011. (n.d.). https://www.congress.gov/bill/111th-congress/house-bill/6523
NATO AGS factsheet. (2014, September). https://www.nato.int/nato_static_fl2014/assets/pdf/pdf_2014_09/20140901_140901-Factsheet-AGS_en.pdf
NATO AGS SMARF. (n.d.). https://www.kongsberg.com/kda/what-we-do/defence-and-security/c4isr/nato-alliance-ground-surveillance-ags/
NATO Alliance Ground Surveillance Management Agency. (n.d.). https://www.nagsma.nato.int/About/nagsma/Pages/default.aspx
NATO Alliance Ground Surveillance Management Organisation. (n.d.). https://www.nagsma.nato.int/About/NAGSMO/Pages/default.aspx
NATO at Chicago summit signs contract with Northrop Grumman. (2012, May 20). https://news.northropgrumman.com/news/releases/photo-release-nato-at-chicago-summit-signs-contract-with-northrop-grumman-to-lead-trans-atlantic-team-delivering-new-isr-capability-to-alliance-forces
NATO integrated air and missile defence. (2022, November 28). https://www.nato.int/cps/en/natohq/topics_8206.htm#:~:text=NATO%20IAMD%20incorporates%20all%20necessary,emanating%20from%20all%20strategic%20directions
NATO Sea Sparrow surface missile system project. (n.d.). https://www.natoseasparrow.org/
NATO's Allied Ground Surveillance programme signature finalized. (2009, September 25). https://www.nato.int/cps/en/natolive/news_57711.htm?mode=pressrelease
Next Generation Jammer. (n.d.). https://www.navair.navy.mil/product/Next-Generation-Jammer

Next Generation Jammer Mid-Band selected acquisition report (SAR). (2021, December). https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/FY_2021_SARS/22-F-0762_NGJ_MB_SAR_2021.pdf

Nones, M., Gasparini, G., & Marrone, A. (2009, July). *Europe and the F-35 Joint Strike Fighter (JSF) program*. Quaderni IAI. https://www.iai.it/sites/default/files/quaderni_e_16.pdf

NSPA AGS. (n.d.). https://www.nspa.nato.int/about/life-cycle-management/ags

Office of the Secretary of Defense. (2022, April). *DoD fiscal year (FY) 2023 budget estimates: Defense-wide justification book* (Vol. 3). https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/03_RDT_and_E/OSD_PB2023.pdf

Office of the Secretary of Defense, Cost Assessment and Program Evaluation. (2020, September). *Operating and support cost-estimating guide*. https://www.cape.osd.mil/files/OS_Guide_Sept_2020.pdf

Office of the Under Secretary of Defense for Research and Engineering. (2020, June 16). *Allied Prototyping Initiative (API) briefing*. https://ac.cto.mil/wp-content/uploads/2020/08/api_overview_06_16_2020_cleared.pdf

Operation of the adaptive acquisition framework (DoD Instruction 5000.02). (2022, June 8). https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2019-05-01-151755-110

Raytheon partners with NAMMO for second source of AMRAAM motors - Additional source assures AMRAAM supply for U.S. and allies. (2011, June 20). https://www.prnewswire.com/news-releases/raytheon-partners-with-nammo-for-second-source-of-amraam-motors-124181804.html

Reprogramming action – Exportability funding from Ukraine supplemental #2. (2022, July 21). https://comptroller.defense.gov/Portals/45/Documents/execution/reprogramming/fy2022/ir1415s/22-36_IR_Exportability_Funding_Ukraine_Sup_2.pdf

Request for proposal FA8730-13-R-0001, attachment 13. (2016, July 26). https://www.defensedaily.com/wp-content/uploads/post_attachment/139139.pdf

RG-31. (n.d.). https://international.gdls.com/english/products/MRAP/RG-31_MK5.pdf

Roe, C. (1991, November 4). The NATO SeaSparrow surface missile system. *Johns Hopkins APL Technical Digest*. https://secwww.jhuapl.edu/techdigest/Content/techdigest/pdf/V12-N04/12-04-Roe_NATO.pdf

Royal Norwegian Air Force selects the Lockheed Martin TPY-4 radar to enhance homeland defense. (2022, November 17). https://news.lockheedmartin.com/2022-11-17-Royal-Norwegian-Air-Force-Selects-the-Lockheed-Martin-TPY-4-Radar-to-Enhance-Homeland-Defense

Securing defense-critical supply chains – An action plan developed in response to President Biden's executive order 14017. (2022, February). https://media.defense.gov/2022/Feb/24/2002944158/-1/-1/1/DOD-EO-14017-REPORT-SECURING-DEFENSE-CRITICAL-SUPPLY-CHAINS.PDF

Security assistance management manual. (2023, March 31). https://samm.dsca.mil/

Security of supply. (n.d.). https://www.businessdefense.gov/security-of-supply.html

Smolny, D. (n.d.). *NATO SeaSparrow program: Cooperation based on trust*. https://www.pfp-consortium.org/articles/nato-seasparrow-program-cooperation-based-trust

Strategy & policy: Production matters. (2020, December 2). *Air & Space Forces Magazine*. https://www.airandspaceforces.com/article/strategy-policy-production-matters/

Thousands of missions build success – Raytheon Australia trains the nation's defenders for electronic warfare. (2017, March 1). https://www.raytheonaustralia.com.au/news/2017/03/01/ewtsmission

3DELRR to move forward with Lockheed Martin's long-range radar system. (2022, March 9). https://www.hanscom.af.mil/News/Article-Display/Article/2955550/3delrr-to-move-forward-with-lockheed-martins-long-range-radar-system/

Turkey officially kicked out of F-35 program, costing US half a billion dollars. (2019, July 17). *Defense News*. https://www.defensenews.com/air/2019/07/17/turkey-officially-kicked-out-of-f-35-program/

2022 national defense strategy. (2022, October 27). https://media.defense.gov/2022/Oct/27/2003103845/-1/-1/1/2022-NATIONAL-DEFENSE-STRATEGY-NPR-MDR.PDF

2022 national security strategy. (2022, October 12). https://www.whitehouse.gov/wp-content/uploads/2022/10/Biden-Harris-Administrations-National-Security-Strategy-10.2022.pdf

Under Secretary of Defense for Research and Engineering. (n.d.). *Critical technology areas*. https://www.cto.mil/usdre-strat-vision-critical-tech-areas/

United Kingdom and Australia defense trade cooperation treaties. (n.d.). DDTC. https://www.pmddtc.state.gov/ddtc_public?id=ddtc_kb_article_page&sys_id=2d21e8b3dbb8d300d0a370131f96190b

U.S. and Australia expand Next Gen Jammer cooperative partnership. (2020, July 14). https://www.navair.navy.mil/news/US-and-Australia-expand-Next-Gen-Jammer-cooperative-partnership/Tue-07142020-0812

U.S. Department of State. (2023, February 28). *U.S. relations with Norway*. https://www.state.gov/u-s-relations-with-

norway/#:~:text=The%20United%20States%20and%20Norway,operations%20with%20Allies%20and%20Partners
U.S. Department of State, Directorate of Defense Trade Controls. (n.d.). *The ITAR Canadian exemption*. https://www.pmddtc.state.gov/ddtc-public?id=ddtc_kb_article_page&sys_id=31002473dbb8d300d0a370131f9619b0
Vanden Brook, T. (2012, September 30). Officials say MRAPs made the difference in wars. *USA Today*. https://www.usatoday.com/story/news/world/2012/09/30/mraps-saved-lives/1600693/
Webster, K. (2023, April 5). *Interview with Keith Webster, former director of international cooperation, OUSD (A&S)*.
Wildenberg, T. (2018, December). The Seasparrow surface-to-air missile system. *Naval History Magazine*. https://www.usni.org/magazines/naval-history-magazine/2018/december/seasparrow-surface-air-missile-system
Wilson, C. (2007, November 21). Improvised explosive devices (IEDs) in Iraq and Afghanistan: Effects and countermeasures. Congressional Research Service. https://apps.dtic.mil/sti/pdfs/ADA475029.pdf

Competition Versus Sole Sourcing in Defence Procurement: What Are the Factors that Determine Tendering Methods in Government Contracting for Delivering "Value for Money"?

Dr. Kogila Balakrishnan—Director, Client and Business Development, WMG University of Warwick. [kogila.balakrishnan@warwick.ac.uk]

Dr. Ahmed Tarek El-Said—Assistant Professor, Warwick Manufacturing Group. Leading the Procurement and Inventory Management Module at WMG, University of Warwick**.** [ahmed.el-said@warwick.ac.uk]

Zsolt Lazar—[zsoltlazar@zsoltlazar.se]

Abstract

Competitive tendering has been the gold standard for government procurement contracts. Nevertheless, this is not the case for the defence sector. Globally, the number of sole source contracts has been exponential. Some argue that sole source procurement is much more effective for the defence sector compared to competitive tender. Yet, there is a lack of publicly available data to prove this claim. Further, there is minimal empirical evidence to substantiate this argument on whether sole source is a better method for procurement in defence compared to competitive tendering. This paper defines public procurement and critically evaluates government contracting methods in defence. The paper discusses the key features of defence contracts and compares the costs and benefits of competitive tendering versus sole sourcing for delivering "value for money" in defence procurement. The paper offers a framework that highlights the factors that could be used to determine the choice of tendering in defence procurement. This is exploratory research and uses the pragmatist philosophical approach.

Keywords: Defence procurement, competitive tender, value for money; sole sourcing.

Introduction

Competition is set as the optimal choice for delivering "value for money" through lowest costs, superior quality, best performance and greater innovation (OECD, 2011). The UK Government's preferred method of procuring defence equipment for the Armed Forces is by open competition (Ministry of Defence, 2017). The prevailing belief in the procurement community is that government procurement should rely on competitive tendering as it is seen as the most optimal option for any procurement contract. This is because competitive bidding is believed to provide the best value for money, with its focus on lowest costs, superior quality, and greater innovation. However, some argue that competitive tendering is not always the best choice for defence procurement due to the risk of transactional activity, which could hinder the development of indigenous critical technologies and result in the use of inferior materials. Furthermore, the process can be extremely slow.

In the defence sector, sole sourcing and restricted tendering have become increasingly important in defence contracting. Sole source procurement refers to the non-competitive purchase of goods and services after negotiating with only one supplier. In 2015, a joint study by Transparency International Defence and Security Programme UK (TI-DSP) and the International Defence Acquisition Resource Management program of the U.S. Naval Postgraduate School (IDARM) reported that the UK had the highest non-competitive tendering rate at 55%, followed by Poland at 49%, and the United States at 40% (Mustafa, 2014).

The National Audit Office UK reported that during COVID 19, out of the £17.3 billion new contracts awarded to suppliers, £10.5 billion were awarded without competitive tender process. The NAO also found various evidence where departments had failed to disclose key decisions as to why they chose a particular supplier, used emergency procurement and failed to document considerations of risks especially how the supplier was identified, and conflict management (National Audit Office, 2020). Similarly, the 2020 House of Commons Briefing highlighted that the UK MOD had spent £8.6 billion or 35% on non-competitive or single source contract between 2018 and 2019 (UK Ministry of Defence, 2017).

The House of Common report justified single sourcing on the pretext of national security and that there is only one specialist for that specific product or services (House of Commons, 2020). However, there is a lack of publicly available data to empirically validate whether a specific government procurement contract should opt for competitive tendering versus restricted tender or sole sourcing. There is continuous debate within procurement agencies and stakeholders on what should be the standard reliable and trustworthy criteria in determining the correct process for tendering.

To achieve this objective, this paper reviews the relevant literature on defence procurement and tendering processes. The literature critically compares the costs and benefits of sole sourcing versus competitive tendering. By analysing this information, we develop a comprehensive understanding of the factors that influence the effectiveness of different procurement methods and the criteria that should be used to determine the most appropriate procurement strategy for a given contract. This analysis uses the literature to develop a policy framework for determining the factors that contribute to determining tender method for delivering “value for money” in defence procurement contracting. The framework is a work in progress and is expected to become a policy tool that could be used by procurement officials as a guidance in deciding the type of tender to opt for when making a contract bid decision.

The research question is “What are the factors that determine the most appropriate method of tendering that delivers the best value for money in defence procurement?

The research objectives are as follows:

- To define the features of defence procurement and government contracts.
- To critically evaluate the costs and benefits of the different government contracting methods
- To analyse the challenges for the current process in determining defence contracting processes.
- To develop a framework that could be used to determine the choice of tendering for defence procurement contracting.

Research Design

This research design uses a pragmatic inductive approach to address a real-world problem. The research takes a mono method approach and will focus on qualitative data. The research involves data collection from literature review to develop the framework. In the next stage in the research is to be able to develop a semi-structured questionnaire as the data collection method, which can be distributed to defence procurement stakeholders in the government and industry to obtain primary data. The data will be analysed using content and thematic analysis to substantiate and validate the arguments on the variables that determine the tender process choice. The unit of analysis will compromise defence procurement officials from government and industry in the UK engaged with the UK MOD in the tender processes. The key stakeholders are those based in the Defence and Equipment

Support Organisation in Abbey Wood (DE&S). The data will be analysed using thematic and content analysis. The structured interview questions will be distributed to 50 participants based on random sampling and another 10 questionnaires will be distributed to key procurement officials to obtain in-depth data to substantiate the quantitative data. The challenge is to compare the secondary literature argument and primary data to compare the findings to validate the reliability of the framework. The research will adhere to ethical standards and compliance to research ethics for non-disclosure of participants identity in line with UK GDPR.

Literature Review

There are some academic works on public procurement that addresses wider issues and the impact on business, economy, and society to support and lead broader government policy implementation, stimulate innovation, encourage small business entrepreneurship, deliver better social outcome, sustainability, and promote competitiveness (AdjeiBamfo et al., 2019; Glas et al., 2017; Grandia & Meehan, 2017; Harland et al., 2019). However, there is a lack of discussion and academic work that debates on the topic of defence procurement and choice of contracting methods except several published government reports on procurement in the United States, UK, and Europe (Duddy et al., 2020).

Defining Public Procurement Feature

Organisation for Economic Cooperation and Development (OECD) defines public procurement as the process of purchasing goods or services by the public sector with the aim of securing best value for public money (OECD, 2011). Public procurement involves the expenditure of huge sums of public money and the magnitude of this outflow can have an impact on the structure and functioning of competition in a market more generally (OECD, 2011). By the virtue of protecting taxpayers' money, the public service promotes economic efficiency and effectiveness in public procurement, contracting, and selection of suppliers. Hence, competitive bidding becomes the preferred method used in public sector procurement. Public procurement has specific inherent features which are unique. First, the custodian of the funding is taxpayers as opposed to shareholders in the private sector. Hence, the objective of the purchase is to benefit the citizens who will enjoy the social dividends from the outcome of the procurement, be it investment in defence for safety and security, healthcare for better hospitals and equipment, or in network rail or road building for better infrastructure and ease of travel. Next, public procurement is bound by legislation and detailed administrative regulations and procedures. Often, the regulations and processes can be construed as bureaucratic and creating layers of red tape. From the public service perspective, this practise avoids abuse of power and discretionary values by arbitrary uses. Third, the large volume, high value of projects and multiple stakeholders makes monitoring more difficult. The financial procedures and payment systems in public procurement is also complex and often the need to manage the layers of approval (Marvel & Marvel, 2008). Defence procurement relates to the public process of contracting with a provider to buy a good or services. The activity relates to buying and selling of goods or services. The procurement activity is often transactional and can be one-off.

It is also worthwhile to not the difference between procurement and acquisition from the perspective of the defence industry. Acquisition is more complex and relates to the entire process of defining, expressing, and translating requirement into technical specification, to programme implementation and monitoring, risks management, and performance input until acceptance prior to entry into force (Keating, 1999). Defence acquisition specifically is a much more complex process that involves the process of purchasing military equipment, technology, and services locally or from foreign countries or international suppliers. This can range from the procurement of weapons systems and vehicles to the development of innovative technologies and training programs. Defence acquisitions are critical for maintaining a country's military readiness and capability, and they play a significant role in national security and defence strategy.

In this paper, we refer to defence procurement as the activity of buying and selling of equipment and services between the government and the contractor. To successfully acquire the necessary equipment and services, governments must employ effective procurement strategies and tendering processes that deliver value for money while upholding ethical standards. Defence procurement can be challenging due to a range of factors, including political considerations, cost, technology, supplier selection, access to quality suppliers, and long-term sustainment. The UK Government's approach to defence procurement is encapsulated in the 2012 White Paper *National Security Through Technology* where UK's defence and security requirements through open competition in the domestic and global market, buying off-the-shelf where appropriate, with national security considerations for operational advantage where appropriate in accordance with the policies set out in the White paper (2012). The procurement strategy was further reaffirmed in the 2015 Strategic Defence and Security Review (SDSR) and the 2017 Defence Industrial Policy.

Defence Procurement Approaches for Contracting

There are several defence procurement approaches. The question that is often raised by procurement agencies is whether to buy the product off-the-shelf, collaborate with other partners in-country or internationally, or make the whole product in-country. A national procurement decision making on whether to make or buy is not as simple as it seems for many states. Often, states with limited defence industrial capabilities are willing to bear a higher cost of procurement due to national aspiration to retain and expand Indigenous technological and industrial capability in strategic sectors deemed as important for national security. Hence, in such instances, the make decision becomes important. Kluth refers to the structural, institutional and actor level theories to explain the complexity of procurement decision making and he used the case study of Denmark and Norway. According to Kluth, Norway that has a much stronger and more capable defence industrial base went with a buy decision, as opposed to Denmark with a smaller and comparatively limited capable industrial base but decided to go with a make decision. Kluth argues that Denmark's decision to make is based on the absence of urgency since it ceased to be a frontline state against the Russian threat, while for Norway the decision to buy was made based on the urgency to acquire for reasons of imminent threat, the need to source systems from a key ally whose future is committed to Norway and Western European security, and also the question of commonality and interoperability with other allies who are using similar systems (Kluth, 2022).

Further, Figure 1 illustrates how security of supply and aspiration for indigenisation can motivate a nation to move from a buy decision to a make decision. Dorman, et al. (2015) technological dependence model explains how a nation's defence policy defines the aspiration of a country to move away from total dependence and off-the-shelf procurement of imported equipment for military capability to collaboration and eventually developing a defence industrial base that has the capability to make the product in-country. The major considerations are based on the defence industrial strategy, potential risks and economic of affordability and opportunity costs of investing in a defence industrial base as opposed to investing in other industrial sectors in-country. This would also mean investing into building human capital development and infrastructure for the defence industrial sector.

Self-sufficiency	Collaboration	Licensed production/ co-production	Off-the-shelf
Indigenous research, development, production	Joint research, development and production	No indigenous R&D Indigenous manufacture	No indigenous development or production

Self-sufficiency ⟷ Technological dependence on other states

Figure 1. Technological Dependence of States.
(Dorman et al., 2015).

Another crucial factor in public procurement decision making is the focus on whether to make or buy which is dictated by transaction costs economics (TCE). Transactional costs are the costs involved in the transaction activity that occurs between buyers and sellers. The costs can be higher when there is a higher level of risks, when the selling is much riskier and there is lack of history or experience dealing with the seller. Other factors also include lack of information about the product, price, and technicality. Hence, the TCE will be higher in economies and markets where there is information asymmetry and less transparency (Patterson et.al, 2021).

Value for Money (VFM) in Defence Procurement and Contracting Activities

There is a dearth of literature that discusses the context of VFM. The arguments often anchor on the challenges in obtaining products at the best VFM and in measuring VFM especially for procurement organisations (Dimitri, 2013). Nevertheless, VFM is a compulsory component of procurement policy and is often used to describe the balance between quality and cost (Single Source Regulation Office, 2016). According to the Asian Development Bank, VFM refers to the overall effectiveness and efficiency of a procurement process in terms of the goods or services acquired, their quality, and their cost (Figure 2). Value for money is said to be achieved through a procurement process is transparent, competitive, and fair, and that the goods or services acquired meet the user's requirements. Procurement professionals are entrusted to evaluate the total cost of ownership of the goods or services being acquired, including the initial cost, ongoing maintenance, and disposal costs. This practise is suggested to support them to make informed decisions about which supplier to select and which product to choose, based on the best value for money (Balakrishnan, 2021). To achieve value for money, procurement professionals are expected to obtain goods or services that are fit for purpose, reliable, and of high quality. This means that the goods or services must meet the user's requirements, be easy to use, and perform to the required standards. They must also be available when needed, and any issues or defects must be quickly and efficiently resolved. By achieving value for money, procurement professionals can maximize the benefits of their procurement process and ensure that the goods or services acquired provide the best possible value to the organization. In government contracting, VFM is a key determinant in the selection of suppliers. Often the issue is setting the criteria as to what is VFM for each product or services in the context of the specific contracting activities.

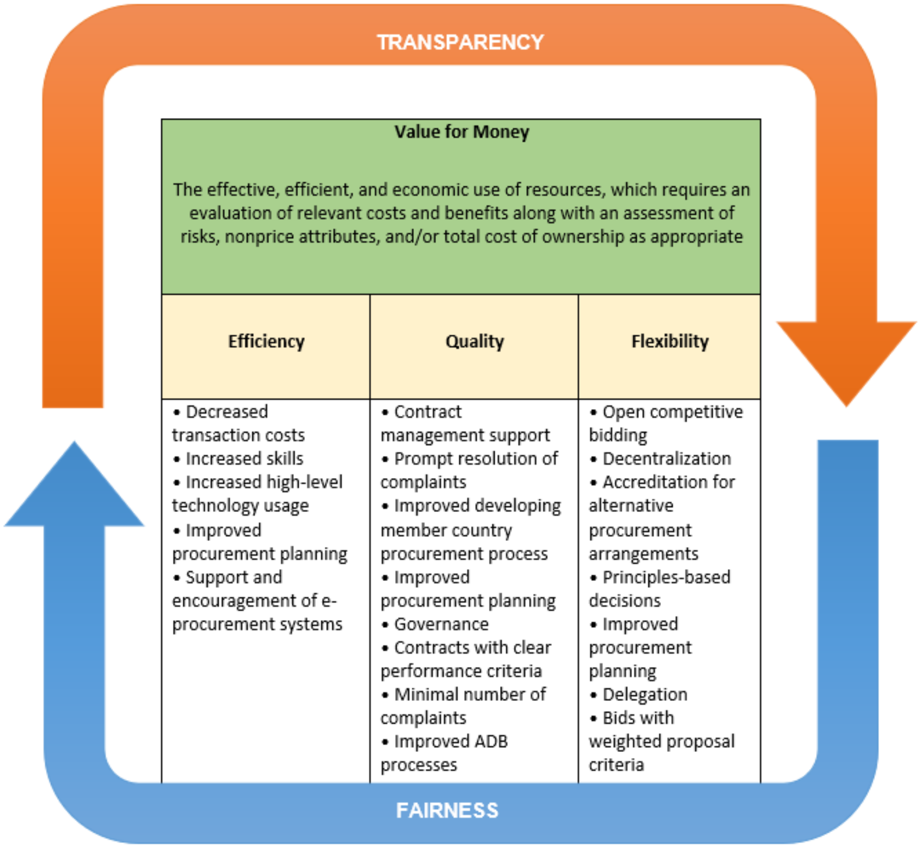


Figure 2. Value for Money.
(Asian Development Bank [ADB], 2021).

Tendering Options in Defence Contracting

Contracting is an essential element in procurement management. Contracts are explicitly written, often detailed, formal documents that specify the legally binding obligations and roles of both buyers and sellers in the business relationship. Contracts are meant to reduce uncertainty (transaction costs rationale) and provide clear specification of what is and what is not allowed within a relationship and minimise the risk of opportunism through enforcement of legal rules, standards, and other remedies implied in law (Peterson et al., 2021). There are many types of contracts (such as long term or short term), and the type of contract is usually categorised according to the type of payment. Buyers are bound by specific conditions to achieve effective control of a contract. These include codification where a formal contract needs to be defined with up-front measurable outcomes. Second, formal contracts require monitoring to determine supplier behaviour with regards to the rules set out in the contract. Finally, to safeguard the contract, the need to put in place structures to enforce the contract.

Although in theory, every buyer and seller would expect to have a full proof contract but in practise this is rarely the case as parties entering a contractual exchange face information asymmetry—that is, imperfect and incomplete information about their suppliers' preferences and characteristics (Keating, 1999). This reinforces the tendency to incur additional contract-related costs, such as up-front supplier search and selection costs (adverse selection risk) and ongoing monitoring and enforcement costs (moral hazard and hold-up risks).

Culture plays a dominant role in how buyers and sellers view contracts. In some cultures, it is vital to hold and strictly adhere to the contract and deliver according to the contract specifications. This is a common practise in the west especially in the United States, UK, and Europe. However, in some cultures, contracts are merely a gesture of formalising a relationship. Once the contract is signed, then the contract is set aside, and projects are implemented based on trust and the relationship that has been built over the years. This is a common practise in East and Southeast Asia as well as Middle East. Such type of practise is also labelled as partnership supply relationships which is based on social processes such as personal bonding. In this case, they tend to be "emergent" arrangements, developing over time, which are not readily accessible through written documents and often cannot be directly observed (Marvel & Marvel, 2008).

In procurement contracting, tendering is a formal process where businesses are invited to bid for contracts from public or private sector organisations, which need specific skills for a project, or goods and services on an ongoing basis. Tendering involves the solicitation of bids from potential suppliers and the evaluation of those bids to determine which supplier to select. The tendering process requires commitment to being fair, transparent, and competitive to ensure that the selected supplier offers the best value for money. This involves developing clear and comprehensive procurement documents, ensuring that all potential suppliers have equal access to information, and using objective evaluation criteria to assess the bids. Effective tendering processes can help to ensure that governments obtain the best possible equipment and services at a fair price, while also promoting competition and innovation in the defence industry.

There are several tendering strategies that governments can use, including competitive bidding, sole sourcing, and restricted tendering. Each strategy has its own advantages and disadvantages, and the choice of strategy will depend on factors such as the complexity of the equipment or service being procured, the urgency of the need as in urgent operational requirement, and the strategic importance of the procurement. For example, competitive bidding can result in lower costs and increased innovation, but it can also be time-consuming and may not be suitable for all types of procurement. On the other hand, sole sourcing can offer greater control and certainty, but it can also result in higher costs and reduced competition.

Defence procurement is considered unusual in that a sizeable proportion of contracts for defence materiel are awarded non-competitively. The government often exempt contracts from the usual procurement requirements of open competition for reasons of national security, to maintain sovereign capabilities, and to protect a nation's operational advantage and freedom of action. This act of sole source tender preference has created dissatisfaction and uneasiness amongst the procurement stakeholders who view competitive bidding as a more fair and transparent method to select suppliers (UK Cabinet Office, 2020).

Costs and Benefits of Competitive Tendering

Competitive tender creates an incentive for contractors to provide goods and services at a lower price (economic efficiency), spurs innovation of transformational technologies, which allows for the procurement of best weapon systems for warfighting. Competition can also yield improvements in the quality of products delivered and services rendered. Competition promotes the opportunity to acquire performance improvements in terms of faster, lighter, and more sustainable products. Competitive bid gives access of buyers to multiple supply source and at the same time to accumulate a wide source of knowledge about the product and supplier credibility. Competitive tender can be a good avenue for small business and start-ups to enter new markets. Competition is said to enhance a strong defence industrial base that can meet operational requirements and support the capability demand of the military at speed and to the quality and performance. On the other hand, competition may force suppliers to compromise on quality of material to be able to meet the lowest price point to win a bid. This act can be detrimental in defence sector where the end-users of the products and services are putting their lives at stake and that the product is being used for defence. Failure of an equipment due to the lack of reliability and not being able to produce up to the specific military standards can be detrimental and jeopardising the operational effectiveness.

Costs and Benefits of Sole Source Tendering

Sole sourcing is a preferred choice in cases where the choice of contracting is dependent on national security and sovereignty of technology. Considering that defence equipment takes a long lead time to develop and introduce, when the product is complex, such as in defence, a sole source option is favoured to build the relationship between the buyer and supplier. Sole source also helps with attaining economies of scale especially if the government (buyer) wants to develop a local defence industry. In a sole source option, the buyer and seller may be able to collaborate with a long-term plan to develop product and further improvement such as upgrades and retrofits. There is also a higher level of confidentiality in the business arrangements but also this becomes a key criterion for countries that have mutual political and strategic geo-political interests to building military capability.

According to some sources, restricted tender and sole sourcing are necessary for the development of critical domestic industrial capabilities. This is supported by reasons such as equipment complexity, interoperability, urgent operational requirements, and the importance of trust and long-term partnerships with suppliers. On the other hand, sole sourcing is said to stifle innovation and creativity, and often leads to increased costs due to cost-plus contract options. Many academic papers, government reports, and parliamentary debates have discussed the benefits of sole sourcing versus competitive bidding. In 2018–2019, the UK Ministry of Defence spent £8.6 billion or 35% on non-competitive or sole source contracts (Holland, 2020). The TI report found that only three countries, including the United States, UK, and Slovakia, have been transparent about their sole sourcing practices (Davies, 2015). The UK acquisition practice community argues that there is greater oversight with sole sourcing, while many developing countries do not provide any transparency as to why they choose sole sourcing.

Sole sourcing has various inherent challenges including the likely of a cost-plus contract that can inflate the overall price of the contract, dependence on one or two suppliers for the success of the project which makes the relationship between the buyer and supplier vulnerable and fragile especially if there is an embargo or political sanction. In such cases where the information is not available, the choice of contracting becomes important. A sole source option may put the buyer at a disadvantage as the seller may not be offering all the information required to make decision and determine. Further, the seller has the upper hand in controlling and determining the price of the product.

Table 1. Comparison of Advantages and Disadvantages to Sole Source Versus Competitive Bidding

	Sole Sourcing	Competitive tendering
Advantages	Stronger buyer supplier relationship	Economic efficiency
	Helps economies of scale	Quality products and services
	Long-term cooperation and strategy building	Multiple supply sources
	Higher level of confidentiality	Enhance strong defence industrial base
Disadvantages	Undermines innovation and creativity	Price competition can undermine product quality
	Higher price	

Determinants of Defence Procurement Contract for Tendering Method

What are the factors that can be considered for whether a specific procurement contract should opt for sole sourcing or competitive bid? Based on the various literature on the costs and benefits of both methods, a defence procurement tendering method is developed. The policy framework is meant to support the defence procurement stakeholders when deciding on what are the available options and considerations when deciding a tender bid. This framework has not included the third option which is collaboration.

It is argued that cost of the product can be one of the factors that determines sole sourcing or competitive bid. The question of high costs versus low costs of product as a determinant of tender bid choice. For example, procurement of uniforms as opposed to fighter aircraft. High costs product also involves higher risks which may suggest that the buyer partner with a single or few suppliers with whom they already have a track record.

Choice of tender in contracting process is also determinant on the security of supply chain that is associated to national security and sovereignty of technology. Specific products that need to be developed in country due to geographical proximity to prime tier one level suppliers and buyers may require a sole source single supplier who is reliable and accessible. This is contradictory to a competitive bid when the product can be sourced from anywhere and there are many suppliers selling the same product.

The framework also identified technology as another determinant where the level of technological sophistication, the need to develop in-country capability in the specific technology area and affordability to invest in R&D as a consideration for sole source versus competitive tendering. Technology transfer is not only about investment, skilled workers and absorptive capability (Balakrishnan, 2018). Successful technology transfer involves intrinsic factors such as time, effort, patience, and understanding of each other's values. A country that wants to build a sustainable defence industrial base will need to consider long term technology and industrial acquisition strategy and develop a strategy for selection of suppliers whether through sole sourcing or competitive bid.

Relationship and trust are another key consideration in the choice of tendering option for products. For complex military products, reliability and maintainability is a key perquisite to ensure that the equipment purchased is also supported during and after the warranty period. This will include military to military joint exercises on the usage of the equipment, training, and education of the equipment and the services being bought. Hence, it is vital that there is good relationship, cultural understanding, and the availability of documents and language translation if required. Sole sourcing is said to allow the option of building a long-term relationship and trust for when considering aspects of maintainability and reliability of equipment between buyer and seller as opposed to a transactional relationship where that level of trust and relationship may not be present.

Next is the type of product tied to costs benefit and level of risk as per Figure 3. For low costs benefits and low risks such as computers, non-secure communication equipment, and white-fleet vehicles, the option is to go with competitive bid. Similarly, generic military items like GP frigates and support helicopters which has high costs benefits but low risks, the option is to enter competitive bid. Finally, for specialised military products such as typhoon and Type 45 Frigate naval warship which has high costs benefits and high risks, the option is to go with sole sourcing.

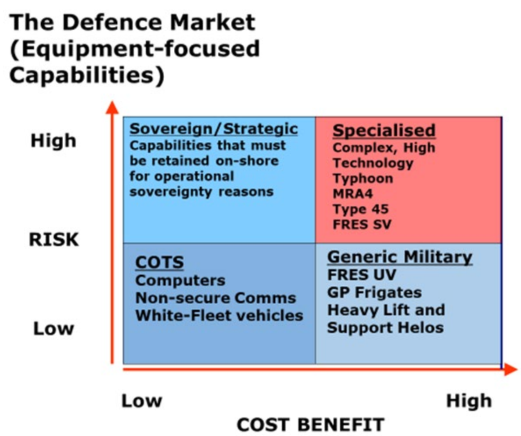


Figure 3. Tendering Option Based on Type of Products

In the defence context, standardization is also a critical factor when considering the type of tendering. If there are well established standards in a technical field, this indicates that an open tender process is viable. However, if there are few or no well-established standards in a technical area, this indicates that a close tender process may be more suitable.

One of the key drivers for a fully open tender process where there is a drive to achieve maximum interoperability. For example, where in the case of NATO standards which form the basis for interoperability across the NATO members nations.

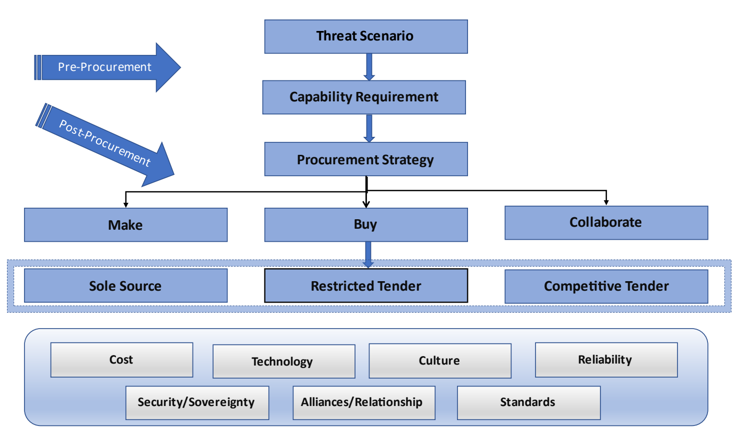


Figure 4. Procurement Contracting Framework for Tendering Method

Future

Looking at the future of defence procurement and tendering, there is an inherent tension between growing demands for cost reduction with stretched defence budget, leaning towards open-source tendering. At the same time, there is the power of emerging technologies such as AI and space technologies that is creating a push towards sole source bespoke suppliers. The challenge of future defence procurement is therefore in addressing the path to reconcile this growing tension. In addition, there is an increasing pan- defence requirement to address sustainability and environmental factors.

As the defence budget shrink, there is also a move towards multi state partnerships to deliver complex weapon platforms, for example sixth generation fighter jets such as the Tempest (UK-Japan-Italy) alliance. This move to multi-state platforms brings with it significant complexity and technical challenges. In addition, the existence of the need to align between the relevant states specific tender processes. This was also the case in previous fifth generation fighter programmes such the Eurofighter programme and the A 400M (Directorate-General for External Policies of the Union, 2013). In the final analysis, each state must choose its own priorities in relation to defence tender processes. This will often reflect cultural and political preferences.

Conclusion

The choice of tendering in defence procurement contracting is a complex issue that cannot be addressed with a one-size-fits-all solution. Therefore, further inductive and deductive research is necessary to determine the specific factors that drive and determine tendering choices. In addition, these factors must be contextualized to reflect the specific needs and requirements of each country. As this research is focused on defence procurement, access to key stakeholders such as procurement officials, policy makers, and military personnel may be limited. Obtaining data from the defence industry may also present challenges. Given the limited resources available for this desk-based research, the researchers will have to carefully allocate their time and identify the most effective ways to obtain data. They should consider using a combination of primary and secondary data sources, as well as leveraging their professional networks to gain access to relevant information.

The proposed framework , a work in progress informs the determinants or variables for choice of tendering in defence procurement contract. The range of factors include political and economic issues, operational requirements, resource, and procurement planning processes. The framework also considers costs, technology, products, or services being procured. The framework provides a systematic process for determining the choice between competitive, restricted, and sole source bids.

This research is to contribute to the body of knowledge in defence procurement strategy and help government procurement officials and defence contractors to make informed decisions that deliver “value for money” from defence procurement spending.

References

Adjei-Bamfo, P., Maloreh-Nyamekye, T., & Ahenkan, A. (2019). The role of e-government in sustainable public procurement in developing countries: A systematic literature review. *Resources, Conservation and Recycling, 142*, 189–203.

Balakrishnan, K. (2018). *Technology offsets in international defence procurement*. Routledge.

Balakrishnan, K. (2021). How to measure value from defence spending? The case of Malaysia. *Journal of Defence and Security Analysis, Francis and Taylor, Routledge, 34*(4), 387–413. https://doi.org/10.1080/14751798.2021.1995966

Brooke-Holland, L. (2020, June). *The defence single source contract regulation framework under review* [Briefing paper]. House of Commons Library (Number 08930).
Davies, C. (2015). Competition in defence procurement. *Conference of Defence Association Institute*, 26.
Dimitri, N. (2013). “Best value for money” in procurement. *Journal of Public Procurement, 13*(2), 149–175.
Directorate-General for External Policies of the Union. (2013, June). *The development of a European defence—Technological and industrial base (EDTIB).* https://www.europarl.europa.eu/RegData/etudes/etudes/join/2013/433838/EXPO-SEDE_ET%282013%29433838_EN.pdf
Dorman, A., Uttley, M., & Wilkinson, B. (2015). *A benefit, not a burden* [King’s Policy Institute Paper], p. 25. King’s College London.
Duddy, B., Londucci, T., & Kretchel, J. A. (2020). Delivering capability through competition in defence contracting: Does policy drive results? *Defence AR Journal*, *27*(4), 436–474. doi.org/10.22594/dau.20-855.27.04
Grandia, J., & Meehan, J. (2017). Public procurement as a policy tool: Using procurement to reach desired outcomes in society. *International Journal of Public Sector Management, 30*(4), 302–309.
Glas, A. H., Schaupp, M., & Essig, M. (2017). An organizational perspective on the implementation of strategic goals in public procurement. *Journal of Public Procurement, 17*(4), 572–605.
Guarnieri, P., & Gomes, R. C. (2019). Can public procurement be strategic? A future agenda proposition. *Journal of Public Procurement*, 295–321.
Harland, C., Telgen, J., Callender, G., Grimm, R., & Patrucco, A. (2019). Implementing government policy in supply chains: An international coproduction study of public procurement. *Journal of Supply Chain Management, 55*(2), 6–25.
Harland, M. C., Essig, M., Lynch, J., & Patrico, A. (2012). Policy-led public procurement: Does strategic procurement deliver? *Journal of Public Procurement, 21*(3), 221–228.
Holland, L. B. (2019a). *An introduction to defence procurement* [Briefing paper]. House of Commons Library. file:///C:/Users/balakr_k/Desktop/MONTERAY%20PAPER%202023/introduction%20to%20defence%20procurement%20HOC.pdf.
Holland, L. B. (2019b). *The defence single source contract regulatory framework under review* [Briefing paper CBP09486]. House of Commons.
Keating, E. G. (1999).Government contracting options: A model and application. *Journal of Defence and Peace Economic, 10*(2), 191–223. https://doi.org/10.1080/10430719908404923
Kluth, M. (2022). Make or buy? Explaining diverging frigate procurement approaches in Denmark and Norway, *Journal of Defence and Security Analysis*, *38*(2), 190–209. https://doi.org/10.1080/14751798.2022.2063995
Marvel, M. K., & Marvel, P. H. (2008). Government to government contracting: Stewardship, agency, and substitution. *International Public Management Journal, 11*(2), 171–192.
Ministry of Defence. (2012, February). *National security through technology: Technology, equipment, and support for UK defence and security.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/27390/cm8278.pdf.
Ministry of Defence. (2017). *National security through technology, and “industry for defence and a prosperous Britain: Refreshing defence industrial policy.*”
Ministry of Defence. (2023). Doing business with defence: Opportunities and innovation in the defence supply chain. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1144189/DBWD_Brochure_2023.pdf.
National Audit Office. (2020). *Investigation into government procurement during the COVID-19 pandemic* [Press release]. https://www.nao.org.uk/press-releases/government-procurement-during-the-covid-19-pandemic/.
OECD, competition and procurement: key findings. (2011). https://www.oecd.org/daf/competition/sectors/48315205.pdf dated 4 April 2023.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. (2014). *Guidelines for creating and maintaining a competitive environment for supplies and services in the Department of Defense*. https://www.acq.osd.mil/asda/dpc/cp/policy/docs/comp/BBP_2-0_Comp_Guidelines_Update_%283_Dec_2014%29.pdf

Peterson, H., Poliski, M., & Brown, L. T. (2022). Businesses' transaction costs when contracting with governments: The impact of product complexity and public contract management experience. *International Public Management Journal, Francis and Taylor, 25*(5), 741–766. https://doi.org/10.1080/10967494.2021.1898500

Saad M., Samantha, S., Pyman, M., & Wright, E. (2014). Single sourcing: A multi country analysis of non-competitive defence procurement. *Transparency International, Defence and Security.*

Single Source Regulation Office. (2016). *Accessing value, building confidence—Perspective on non-competitive defence spending*.

UK Government. (2021). *National security and investment act*. https://www.gov.uk/government/collections/national-security-and-investment-act

PANEL 10. NEW TECH IN ACQUISITION: ADDITIVE MANUFACTURING AND ARTIFICIAL INTELLIGENCE

Wednesday, May 10, 2023	
2:15 p.m. – 3:30 p.m.	**Chair: Amela Sadagic,** Research Associate Professor, Co-Director of the Center for Additive Manufacturing, Naval Postgraduate School ***Decision Making for Additive Manufacturing in Sustainable Defense Acquisition*** Waterloo Tsutsui, Purdue University Qian (Alex) Shi, Purdue University Ian Walter, Purdue University Amanda Wei, Virginia Tech Christopher Williams, Virginia Tech Daniel DeLaurentis, Purdue University Jitesh Panchal, Purdue University ***Bridging the AI / Acquisition Divide: Why the Government Needs an Acquisition Revolution in the Coming Age of Artificial Intelligence*** Tim Cooke, ASI Government, LLC William (Will) Roe Roberts, ASI Government, LLC Michael Arendt, Independent Consultant ***Leveraging Machine Learning and AI to Identify Novel Additive Manufacturing Technological Capabilities to Improve Fleet Readiness*** Rebecca DeCrescenzo, Govini Mihiri Rajapaksa, Govini

Amela Sadagic, Ph.D.—is a Research Associate Professor at the Naval Postgraduate School (NPS) with 30 years long research experience in interactive computer graphics and Virtual Reality. In the past she coordinated the National Tele-immersion Initiative (NTII) research consortium, and was a Director of Programs responsible for designing and directing projects for K-12 education that employed emerging technologies. Her research interests include human factors in VR/AR; coupling and evaluation of emerging technologies in support of systems for operation, training, and learning; additive manufacturing and diffusion and large-scale adoption of technical innovations. Her research efforts at NPS have been supported by $10M in funding, and involved over 4500 US Marine Corps and US Navy personnel as subjects in user studies. Dr. Sadagic holds PhD degree in Computer Science from the University College London, UK.

Decision Making for Additive Manufacturing in Sustainable Defense Acquisition

Waterloo Tsutsui—is a Senior Research Associate in the School of Aeronautics and Astronautics at Purdue University, IN. Tsutsui received his PhD in aeronautics and astronautics from Purdue University in 2017. Before Purdue, Tsutsui practiced engineering in the automotive industry for more than 10 years, with the last position involving the research and development of lithium-ion battery cells for electric vehicles. Tsutsui's research interests are systems engineering, mission engineering, energy storage systems, multifunctional structures and materials design, and the scholarship of teaching and learning.

Qian (Alex) Shi—is a PhD student and a Graduate Research Assistant at the School of Aeronautics and Astronautics at Purdue University. Her research interests are in developing methods and tools for addressing challenges in distributed space systems such as satellite constellations. Shi obtained her bachelor's and master's degrees in mechanical engineering from the University of Cambridge, UK, on a Singapore Public Service Commission scholarship. Prior to joining Purdue University, she was a Policymaker with years of experience designing and implementing policies in economic development, climate change, and research and innovation development.

Ian Walter—is a PhD student in the Elmore Family School of Electrical and Computer Engineering, advised by Dr. Jitesh Panchal of the School of Mechanical Engineering and Dr. Philip Paré of the Elmore Family School of Electrical and Computer Engineering. His research focuses are networked spreading processes and demand prediction.

Amanda Wei—is a PhD student in the Department of Mechanical Engineering at Virginia Tech. Her research interests are in metal binder jetting with a focus on developing infill pattern design strategies for the process. Wei obtained her master's in mechanical engineering from Virginia Tech and her bachelor's in mechanical engineering from the University of Florida.

Christopher Williams—is the L. S. Randolph Professor in the Department of Mechanical Engineering at Virginia Tech. He is the Director of the Design, Research, and Education for Additive Manufacturing Systems (DREAMS) Laboratory, which has published over 250 peer-reviewed articles on topics spanning innovations in additive manufacturing processes and materials, Design for Additive Manufacturing methodologies, and cyber-physical security for AM. He is a recipient of a National Science Foundation CAREER Award (2013) and the 2012 International Outstanding Young Researcher in Freeform and Additive Manufacturing Award. He was inducted as a Senior Member of the National Academy of Inventors in 2022.

Daniel DeLaurentis—is Vice President for Discovery Park District Institutes and Professor of Aeronautics and Astronautics at Purdue University. He leads the Center for Integrated Systems in Aerospace (CISA) activities on research problem formulation, modeling, and systems engineering methods for aerospace systems and system-of-systems. DeLaurentis also serves as Chief Scientist of the DoD's SERC UARC to understand the systems engineering research needs of the defense community (primarily) and translate that to research programs that are then mapped to the nation's best researchers in the SERC's university network. He is a Fellow of the INCOSE and the AIAA.

Jitesh Panchal—is a Professor of Mechanical Engineering at Purdue University. He received his BTech from Indian Institute of Technology (IIT) Guwahati, and MS and PhD from Georgia Institute of Technology. He is a member of the Systems Engineering Research Center (SERC) Council. He is a recipient of an NSF CAREER award, Young Engineer Award and three best paper awards from ASME, and was recognized by the Schaefer Outstanding Young Faculty Scholar Award, the Ruth and Joel Spira Award from Purdue University. He is a co-author of two books and a co-editor of one book on systems design.

Abstract

The research team developed a model-based acquisition decision support tool (i.e., the decision engine) for additive manufacturing materials and technologies selection. In order to

develop the framework, the team focused on a use case involving aircraft single-component (i.e., an aileron bellcrank) design and manufacturing. In the use case, the team identified the key decision factors in considering additive manufacturing alternatives against traditional manufacturing methods. Preliminary findings indicate that the decision engine provides the users with an algorithmic view of the variables to make an optimized decision regarding where and how additive manufacturing can have the most impact. To this end, the team designed the user interface in such a way that the decision engine visualizes the relative performance of each alternative considered, thereby assisting a stakeholder in the decision-making process. More specifically, the decision engine provides quantitative information about the usefulness of each alternative relative to others. As a result, the decision engine supports stakeholders in making informed decisions on additive manufacturing opportunities throughout the mission engineering and sustainment defense acquisition.

Introduction

Additive manufacturing provides an alternative approach to manufacturing products across the supply chain. Some of the benefits of using additive manufacturing are inventory reduction in the supply chain, increase in supply chain resilience through alternate options, quicker response to surge demands and warfighter readiness, and manufacturing products with complex design while actively reducing the number of serviceable components. From a sustainable acquisition standpoint, the team needed to figure out how to quantitatively approach the decision-making process of additive manufacturing for defense-related acquisition. That is, it is crucial to develop a model-based decision-support tool for the defense-related acquisition of additive manufacturing components and equipment.

As the team initiated the research effort of producing the decision framework, some of the questions we asked ourselves were as follows: Can the whole supply chain and sustainment strategy change, given the use of additive manufacturing instead of traditional manufacturing? In what timeframe? What are the limits (e.g., materials science, systems engineering, cost, reliability, infrastructure)? Obviously, these are open-ended and difficult questions to answer. To address these questions adequately while also ensuring component readiness through additive manufacturing in mission engineering, the team realized the importance of having a sufficiently narrowed-down digital environment with the capabilities we need. Thus, to narrow the scope of the research, the team focused on the digital data and framework surrounding the opportunity to exploit additive manufacturing as follows:

- Identification of necessary data in digital system models to understand how additive manufacturing could support system readiness and sustainment;
- Isolation of the most critical system elements from the perspective of sustainment; identification of the variables that are key to understanding criticality from this point of view;
- Development of a framework that would allow the focused allocation of additive manufacturing to impact system readiness and sustainment; and
- Development of a framework of items and contractual elements that would be critical for the DoD to negotiate during the contract phase (e.g., any intellectual property rights or options needed to support an additive manufacturing strategy for certain types of supplies and equipment).

Accordingly, we explored additive manufacturing as a systems engineering problem as follows: First, we identified the critical decision and analysis variables and created a framework to understand how these variables impact each other. Second, we transferred the above framework into an algorithmic view of these variables to make an optimized decision regarding where and how additive manufacturing can have the most impact. Third, we developed an interactive decision support tool (i.e., the decision engine in additive manufacturing) and tested its use in a user case. As a result, this research paper starts with the conceptual background of decision engine development. Then, the discussions transition to a use case, "Aircraft Single Component Design," to demonstrate the decision engine's effectiveness.

Decision Support Tool for Additive Manufacturing: Overall Scenario

Additive Manufacturing (AM) is playing an increasingly important role in DoD acquisition and sustainment. Decisions about additive manufacturing technology are made within various agencies ranging from the USD(A&S) to individual military departments. Decision makers range from high-level decision makers interested in overall mission effectiveness to field engineers who are responsible for operating specific equipment. There is a wide range of decisions related to additive manufacturing, such as decisions about whether to use additive manufacturing or traditional manufacturing, supplier selection, a decision on contract type; AM technology selection, machine and material selection, and process parameter selection (e.g., layer thickness, speed, part orientation).

Furthermore, the decision-making criteria vary widely from high-level attributes such as resilience and mission effectiveness to technical attributes such as part accuracy and structural performance. Other decision factors may include material availability, machine availability, machine maintainability, competition, technology capability, technology maturity, cost, number of parts, intellectual property ownership, and supply chain resilience.

While there are several initiatives to support specific types of decisions within the AM domain, there is a lack of a decision support tool that can be adopted or customized to support different decision makers for a range of AM-related decisions. Thus, in this task, the team addresses this limitation by developing the decision engine and demonstrating it using use cases that are relevant to mission engineering. The activities carried out in this project are illustrated in Figure 1. Please note that this research paper focuses on the decision support tool (decision engine) development, followed by the demonstration of the decision engine using "Aircraft Single Component Design," which is shown in Figure 1 as the "AM Use Case 2." For the "AM Use Case 1," please see a separate paper (Q. Shi et al., 2022).

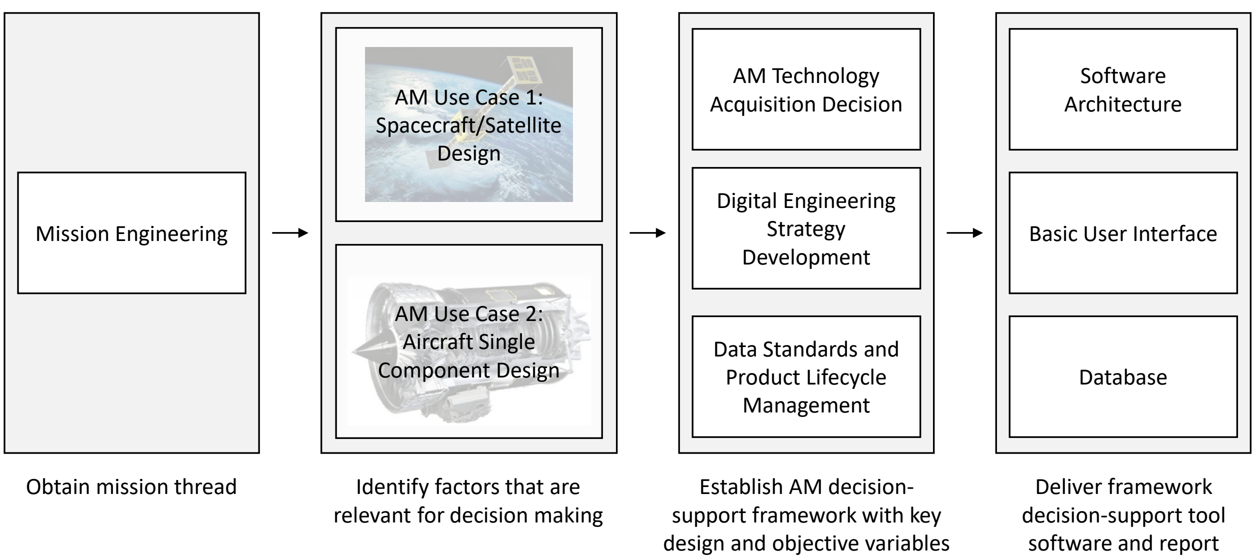


Figure 1. Overall Development Process

Visualization of Decision Engine

Each decision to be made by a decision maker can be split into two types of components: the objectives of the decision maker (e.g., what their goals are, what they want to improve, minimize, and prevent from happening) and the alternatives (the different options the decision maker can choose from). Each alternative is composed of the relevant attributes to the decision problem, examples of which can be seen in the use cases. The final output from the decision engine is a bar chart displaying the expected utility values of each alternative considered and is intended to assist the decision maker by providing them with quantitative information about the usefulness of each alternative relative to others.

For this project, we make several assumptions that impact the implementation of the decision engine. One assumption is that each decision has a finite number of alternatives. This assumption implies that the decision engine tool would not be suitable for choosing the optimal parameters in a continuous design space. However, if the options could be constrained to a finite subset of parameters, then this tool could be used. Another assumption is that the attributes of any alternative are utility-independent. If two attributes were not utility independent, then as the value of one attribute changes, the utility that the decision maker gets from another attribute will change. The assumption of utility independence is standard in the literature (Fernández et al., 2005) and greatly reduces the complexity of implementation and makes the process of using the engine significantly easier for an end-user.

The process of using the decision engine is described in the context of decisions being made in a hierarchy, with one individual making the final decision and an individual or team of technical engineers who determine the information relevant to the decision context. The general steps for the decision-making process are outlined in Fernández et al. (2005). In the context of a hierarchy, we assume that the decision makers and technical engineers are distinct groups, but they could, in practice, be the same. The decision maker should set out the specifics of the decision, answering questions such as:

- What exactly is the decision being made?
- What are the specific objectives or goals that want to be achieved from this decision?
- What kind of attributes will be important when comparing multiple alternatives?

Once the decision context has been clearly established by the decision maker, the technical engineers may begin translating this information into data usable by the engine. The information about the decision scenario is fed into the decision engine via .json files, which are a type of structured data file that is human-readable. There are two categories of files used by the decision engine: the decision objective file and the alternative information files.

Decision Objective File

The first type of file is the decision objective file, and there is typically only one of these in each decision-making context. The decision objective file contains information specific to the decision context and the decision maker. In this file, each attribute being considered by the final decision maker has some general information listed, such as its name, description, and units of measurement, as well as information relating to the utility function of the decision maker. This information describes the general shape of the utility function, such as the risk attitude of the decision maker and whether it is monotonically increasing, decreasing, or neither. Lastly, specific numerical data about each utility function is provided. Each utility function takes the form of the equation $u_i(x) = a + bx + ce^{dx}$, where i is the index of the attribute being considered, x is the attribute's value, $u_i(x)$ is the utility of attribute i with value x, and a, b, c, and d are the specific parameters of the utility function. The decision objective file contains these parameters a, b, c, and d. The information about the decision context must be collected from the final decision maker or someone else with a clear understanding of the goal of the decision.

Alternative Information Files

The other files used by the decision engine contain information about the alternatives being considered. Each file contains information about the attributes relevant to the specific decision being made. For the alternative attribute information, the data can either be collected manually by technical engineers or automatically if there is access to a relevant database. Currently, each attribute is given either as a constant value or as a uniform distribution if there is uncertainty about the attribute's value. We plan to implement additional distributions in the future to enable a more accurate representation of the uncertainty in various attributes. Figure 2 shows the way information flows into the two types of files and then into the decision engine. Figure 3 depicts the main screen of the decision engine's user interface, which allows the selection of use cases for analysis. These use cases come from folders containing JSON data files, so these can be added to, removed from, or updated as needed. After the user selects a use case on the main screen (Figure 3), another user interface appears. The use case specific user interface is shown in the Use Case section below.

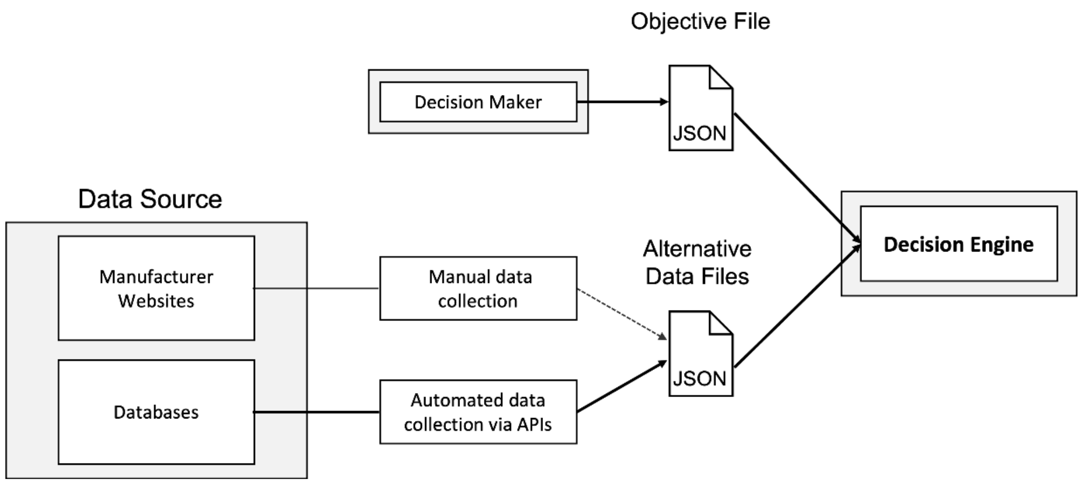


Figure 2. Decision Engine Information Flow

Figure 3. Main Screen for "Decision Engine for Additive Manufacturing"

Use Case: Aircraft Single Component Design

Background/Overview

The research team was approached by a large aerospace original equipment manufacturer (OEM) looking to leverage additive manufacturing (AM) to replace damaged, out-of-production parts for fleet sustainment. Specifically, this OEM is looking for a means to produce 100 replacement aileron bellcranks on a legacy aircraft. Traditionally made through metal casting, the original part supplier has discontinued production. Because the continuous operation of the fleet is critical, the company is eager to find a new means of sourcing the part quickly. In this transition period, the company is interested in assessing the utility of the traditional manufacturing metal casting approach against those of metal additive manufacturing methods, as additive manufacturing typically has lower lead times and supply chain costs (Gradl et al., 2022). The goal of this use case study is to apply the decision engine to compare the utility of several manufacturing approaches for low-volume production of a custom aircraft part for fleet sustainment. The information of this use case was adapted from past collaborative work with the OEM, and thus the simulated decisions represent an example of a real issue modern companies may face with respect to the desire to cut rising costs and/or sourcing parts that have become obsolete on the market.

Problem Statement

The original design of the bellcrank is shown on the left side of Figure 4. The dimensions of the bellcrank used in this case study have been augmented from the actual part so as to protect the OEM's intellectual property. The decision engine is used to evaluate the utility of producing these parts using *traditional metal casting* and several different additive manufacturing solutions, including:

Hybrid wire arc additive manufacturing (hWAAM): In this hybrid process, a wire arc welding head selectively deposits metal in a layer-wise fashion. A CNC milling spindle selectively removes material at each layer to refine the part quality and surface finish. Following fabrication, the fully dense metal part needs moderate heat treatment prior to use.

Metal binder jetting (mBJT): In this process, the binder is selectively ink-jetted into a metal powder bed to fabricate a green part. Following printing, post-processing steps include binder curing, part de-powdering, binder pyrolysis, and metal sintering.

Sand Binder Jetting (sBJT): In this process, binder jetting is used to 3D print molds from foundry sand. Following printing, the printed molds are de-powdered and assembled for traditional metal casting processing.

Metal laser powder bed fusion (L-PBF): In this process, a laser selectively melts the metal powder in a layer-wise fashion. The printed part is fully dense and can be inserted into the application following post-processing steps, including de-powdering, heat treatment, support removal, and surface finishing.

This case study is separated into two decision scenarios as follows:

Scenario 1: Part Replication

In the first scenario, the company is comparing the utility of different manufacturing techniques to produce 100 replicates of the bellcrank geometry using 6061 Aluminum. In this decision, the company is only evaluating alternative manufacturing processes to replicate the same geometry and material as in the original design shown on the left side of Figure 4.

Scenario 2: Topology Optimized Redesign vs. Original Design

In the second scenario, the company is evaluating the utility of different manufacturing techniques to produce 100 redesigned bellcranks, which have been optimized for lightweighting. Specifically, topology optimization software (Autodesk Fusion 360, n.d.) has been employed in which part mass is generatively removed from the original design as guided by an iterative evaluation of the stresses within the part (Shanmugasundar et al., 2021). The optimization algorithm sought to minimize part mass while still retaining sufficient part stiffness to meet the load specifications. The resulting topology optimized geometry is shown on the right side of Figure 4. In this scenario, the effects of a change in part geometry enabled by additive manufacturing are explored while the material (Aluminum 6061) is held constant.

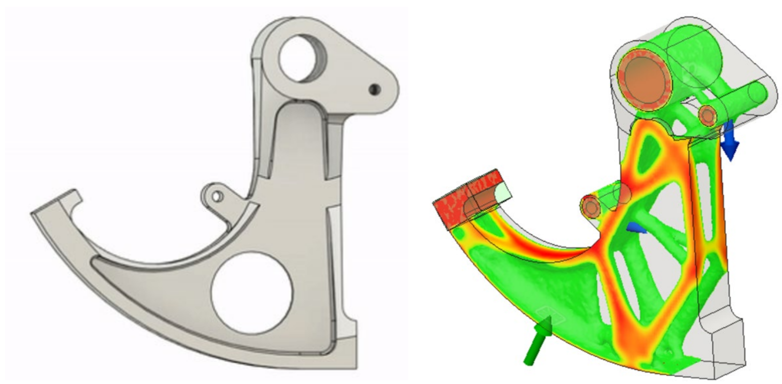


Figure 4. Aileron bellcrank

(Left) CAD model of the original aileron bellcrank. The bellcrank is traditionally manufactured through the traditional metal casting of 6061 Aluminum.

(Right) Topology optimization was used to redesign the aileron bellcrank for mass minimization. Colored regions indicate where material should be placed within the volume. Red regions represent regions of high stress; green regions represent areas of low stress. The material used in the optimization is the same as that in the original design, 6061 Aluminum. The grey bounding box around the optimized geometry is included to illustrate the mass savings enabled by topology optimization.

Attributes

In decreasing order of importance, the customer is concerned with the minimization of cost, time, and part mass. These customer concerns form the attributes of the decision. In addition to these customer concerns, part bounding box size was added as an attribute to ensure that the part could fit within the allowable build volume of each additive manufacturing process. Thus, the attributes of the decision are part bounding box size, total cost, total time, and part mass.

Utility Functions

Utility functions generated for each attribute are shown in Table 1. A minimum point, an intermediate point, and a maximum point were used to fit the functions. A utility function was not fitted for the part bounding box attribute. Instead, this function had the form of a binary "on/off" condition where, if the bounding box volume of the manufacturing process being considered is below the requirement, the utility of that process is zero regardless of the utility values.

For the *total cost*, a monotonically decreasing linear function was chosen because utility for the customer decreases proportionally as manufacturing cost increases. For both *total time* and *part mass*, a concave function was chosen because utility for the customer decreases more sharply as each of these attributes increases. The utility functions are summarized in Table 1. Figure 5, Figure 6, and Figure 7 show the points used to fit utility functions for cost, time, and mass, respectively. In these figures, please note that the data points were obtained from customer surveying.

Table 1. Utility Functions

Attribute	**Utility Function Type**	**Utility Function: $u(x) = a + bx + ce^{dx}$**			
		a	***b***	***c***	***d***
Part Bounding Box (mm x mm x mm)	On/Off	-	-	-	-
Total Cost ($)	Linear	1	-2e-6	0	0
Total Time (hours)	Exponential (Concave)	0	0	1.002	-0.00198
Mass (kg)	Exponential (Concave)	0	0	1.019	-0.41000

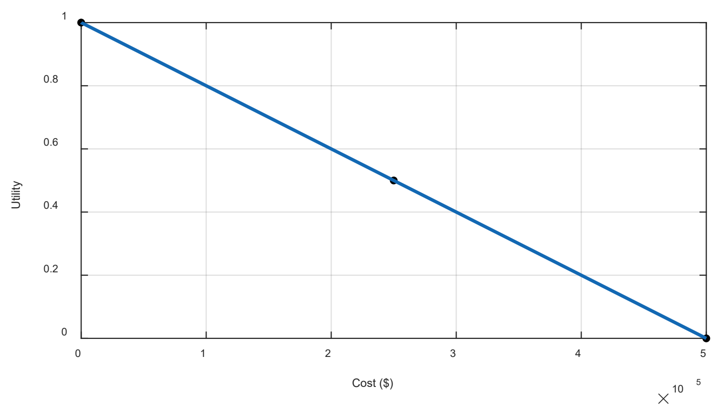


Figure 5. Fitted Utility as a Function of Cost

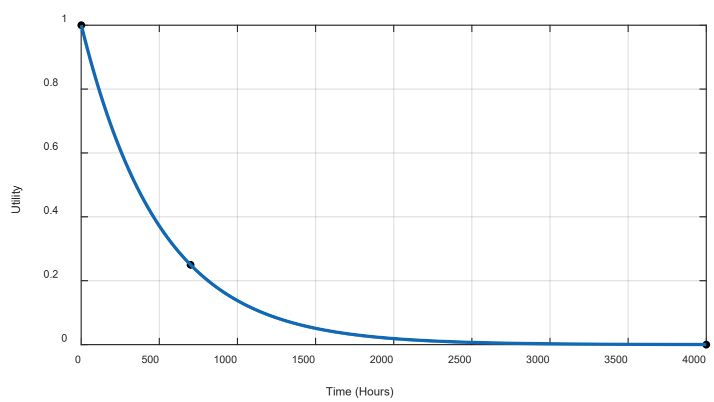


Figure 6. Fitted Utility as a Function of Time

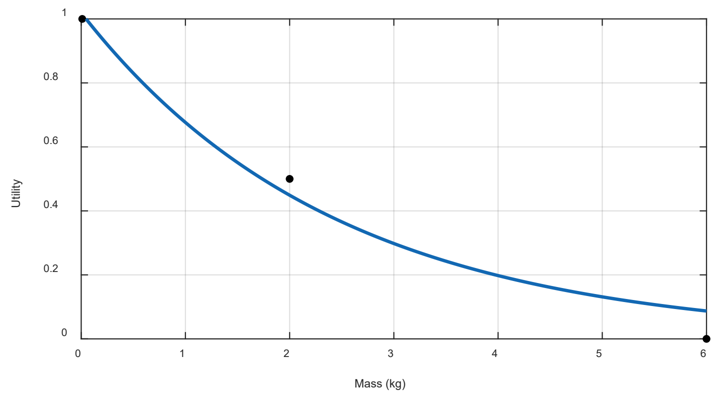


Figure 7. Fitted Utility as a Function of Mass

A weight was assigned to each attribute's utility function to represent the customer's preferences for the relative importance of each attribute. In Scenario 1, in which manufacturing processes are evaluated for their utility to replicate the original part geometry and material, the customer has a slightly stronger preference for reducing cost than time. On the other hand, in Scenario 2, in which the utility of replicating the original part geometry via metal casting is compared to the additive manufacturing processes' ability to fabricate the topology optimized part geometry (Figure 4, right), the customer has a near equal preference for minimizing cost, time, and part mass. These weighting values are shown in Table 2.

Table 2. Weights of Attributes Generated From Customer Requirements

Attribute	Scenario 1: Weight	Scenario 2: Weight
Total Cost	0.6	0.4
Total Time	0.4	0.3
Mass	-	0.3

Decision Engine Data Inputs

Part Bounding Box

The bounding box size of the part was obtained by measuring the length, width, and height of the part's computer-aided design (CAD) model. The bounding box of the bellcrank measures 350 mm x 350 mm x 87 mm; thus, the requirements for this attribute are these dimensions. The bounding box size is the same for both scenarios.

Total Cost

Cost estimates for traditional metal casting were obtained from a vendor's website (Liaoning Borui Machinery Co., n.d.). The estimated cost for manual green sand casting of a large complex shape is $2,500 per part. Cost estimates for the additive manufacturing processes were generated by a cost model from *Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing* (Gibson et al., 2015) given by:

$$Cost = P + O + M + L$$

where

P is the prorated machine purchase cost;

O is the machine operation cost;

M is the material cost; and

L is the labor cost.

In order to calculate these four sub-costs, information on part geometry, material specification from suppliers, and machine process parameters are needed. At a high level, the model first uses part geometry information to calculate total scan length (the total linear distance traveled by the print head during fabrication), which is estimated from the part volume, the average cross-sectional area of each layer, and deposition diameter. The estimated scan length is then used in combination with known process parameters (i.e., scan speed, deposition head diameter, and layer height) to estimate the total part build time. Once the build time is obtained, estimates for the cost of machine purchase, operation, materials, and labor can be calculated. Process parameters were sampled from works in the literature for each manufacturing process. Process parameters for hWAAM were adapted from X. Shi et al. (2017). Process parameters for binder jetting were adapted from Bai et al. (2017). Process parameters for powder bed fusion were adapted from Uddin et al. (2018). Cost estimates were rounded to the nearest hundred dollars, and an error of ±10% in estimated cost is assumed in order to account for discrepancies.

Total Time

Times estimates for traditional metal casting were obtained from information published on the Impro website (Impro). Time estimates for the additive manufacturing processes were calculated using build time models from the *Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing* textbook (Gibson et al., 2015). Build time is estimated from the total printing scan length and process parameters specific to each additive manufacturing process, such as layer height, hatch spacing, deposition head diameter, and scan speed. Values for hWAAM process parameters were adapted from X. Shi et al. (2017). Values for binder jetting process parameters were adapted from Bai et al. (2017). Values for powder bed fusion process parameters were adapted from Uddin et al. (2018).

In addition to machine build time, the time required for human hands-on labor, which includes printer facilitation and post-processing, is accounted for in each process. The estimated human time varies for each process and depends on the process and post-processing needs. The pertinent assumptions are listed in Table 3 and Table 4 for Scenario 1 and Scenario 2, respectively.

Part Mass

The part mass is obtained from the CAD model of the bellcrank. In Scenario 1, since the part design and material are unchanged from that of the original, the part mass produced by each process is the same as the original part, 4.02 kg.

In Scenario 2, the additive manufacturing processes' utility is re-evaluated for their ability to fabricate topology optimized design with reduced mass (Figure 4, right). According to Maurer (n.d.), topology optimization can be used to reduce the mass of components by up to one-third. Thus, the topology-optimized design has an estimated part mass of 2.68 kg. The more complex geometry generated from topology optimization is not manufacturable using traditional metal casting, and thus the part mass for the casting process is kept at 4.02 kg. An uncertainty of 1% in mass is assumed to account for discrepancies and tolerances in manufacturing.

Table 3. Data Inputs for Scenario 1

Attribute (units)	Requirement	AM: hWAAM DMS 2Cubed Al6061[1]	AM: Binder Jet ExOne X160Pro Al6061[2]	AM: Binder Jet ExOne X160Pro Sand+Al6061	AM: PBF DMP Factory 500-LaserForm Al6061[3,4]	TM: Casting Al6061
Part Bounding Box (mm x mm x mm)	87 x 350 x 350	610 x 610 x 610	800 x 500 x 400	800 x 500 x 400	500 x 500 x 500	-
Parts per batch (no.)	-	6	8	5	5	-
Part Mass (kg)	-	4.02	4.02	4.02	4.02	4.02
Total Cost ($)	$100,000	$34,600	$98,500	$58,900	$164,100	$250,000[5]
Prorated Machine Cost ($)	-	$1,000	$500	$800	$5,700	-
Operation Cost ($)	-	$11,800	$5,700	$9,100	$51,700	-
Materials Cost ($)	-	$9,800	$85,100[6]	$32,800	$90,5006	-
Labor Cost ($)	-	$11,900	$7,300	$16,200	$16,200	-
Total Time for 100 Parts (hours)	900	930	774	1,377	2,186	2,000[7]
Machine Time (hours)[8]	-	590	566	915	1,724	-
Human Time (hours)	-	340[9]	208[10]	462[11]	462[12]	-

(Uncertainty assumptions: ±10% for cost and time, ±1% for mass)

---

[1] 2Cubed printer information from Diversified Machine Systems (n.d.)

[2] X160Pro printer information from *ExOne X1 160PRO Review - Industrial Metal and Ceramic 3D Printer* (n.d.)

[3] Factory-500 printer information from GF Machining Solutions (n.d.)

[4] Data from Uddin et al. (2018)

[5] Sand mold cost estimate from Liaoning Borui Machinery Co. (n.d.)

[6] Data from MSE Supplies (n.d.)

[7] Data from Impro Precision (n.d.)

[8] Gibson (Gibson et al., 2015)

[9] Estimate roughly 10 hours of post-processing per batch of printed parts. Includes time for print set up, part removal, and finishing machining

[10] Estimate roughly 15 hours of post-processing per batch of printed parts. Includes time for print set up, de-powdering, and time to set up curing and sintering of parts

[11] Estimate roughly 22 hours of post-processing per batch of printed parts. Includes time for print set up, de-powdering, curing, and casting

[12] Estimate roughly 8 hours of post-processing per batch of printed parts. Includes time for print set up, part removal, and machining

Table 4. Data Inputs for Scenario 2

Attribute (units)	Requirement	AM: hWAAM DMS 2Cubed Al6061	AM: Binder Jet ExOne X160Pro Al6061	AM: Binder Jet ExOne X160Pro Sand+Al6061	AM: PBF DMP Factory 500-LaserForm Al6061	TM: Casting Al6061
Part Bounding Box (mm x mm x mm)	87 x 350 x 350	610 x 610 x 610	800 x 500 x 400	800 x 500 x 400	500 x 500 x 500	-
Part Mass (kg)	4.02	2.68[13]	2.6813	2.6813	2.6813	4.02
Total Cost ($)	$100,000	$31,300	$79,000	$48,000	$134,000	$250,000
Prorated Machine Cost ($)	-	$1,000	$500	$800	$5,700	-
Operation Cost ($)	-	$11,800	$5,700	$9,100	$51,700	-
Materials Cost ($)	-	$6,500	$56,700	$21,900	$60,400	-
Labor Cost ($)	-	$11,900	$7,300	$16,200	$16,200	-
Total Time for 100 Parts (hours)	900	930	774	1,377	2,186	2,000
Machine Time (hours)	-	590	566	915	1,724	-
Human Time (hours)	-	340	208	462	462	-

(Uncertainty assumptions: ±10% for cost and time, ±1% for mass)

Results: Decision Engine Recommendations

Scenario 1: Part Replication

The attribute weights, attribute data, and utility functions were input into the decision engine in order to calculate the utility of each manufacturing process for Scenario 1. The Scenario 1 data inputs for the decision engine are summarized in Table 3. The expected utility of each process is plotted in the bar graph in Figure 8.

It is observed from these results that traditional casting has the lowest utility (0.31), while hybrid wire arc additive manufacturing (hWAAM) has the highest utility (0.62). This result follows expectations, as the total cost and time for hWAAM are lower than those of the other processes (Table 3). Because the customer prioritizes cost minimization in their attribute weighting, it is reasonable to expect a process that has a lower cost to have a higher utility.

The expected utility of each manufacturing technique is plotted. The hWAAM process offers the highest utility, while traditional casting offers the lowest utility.

Scenario 2: Topology Optimized Redesign vs. Original Design

The attribute weights, attribute data, and utility functions were input into the decision engine in order to calculate the utility of each manufacturing process for Scenario 2. The Scenario 2 data inputs for the decision engine are summarized in Table 4. The expected utility of each process is plotted in the bar graph in Figure 9. Once again, traditional casting has the lowest utility (0.22), while hybrid wire arc additive manufacturing (hWAAM) has the highest utility (0.52).

However, note that the gap in utility between hWAAM (0.52) and binder jetting with 6061 Aluminum (0.51) has decreased significantly, suggesting that the two manufacturing

[13] Data from Maurer (n.d.)

processes are now comparable in this scenario. Between Scenario 1 and Scenario 2, the difference in utility between the two processes is 0.04, indicating that the introduction of topology optimization into the decision process can have an impact on recommendation output by the engine. This change is largely due to the fact that the bulk of the cost for the binder jetting process comes from the powder material feedstock, which can be quite expensive (~$185/kg; MSE Supplies, n.d.). However, in hWAAM, the cost of material is substantially less (~$20/kg) as it uses conventional welding wire (*WeldingSupply 1100-116-3*, n.d.).

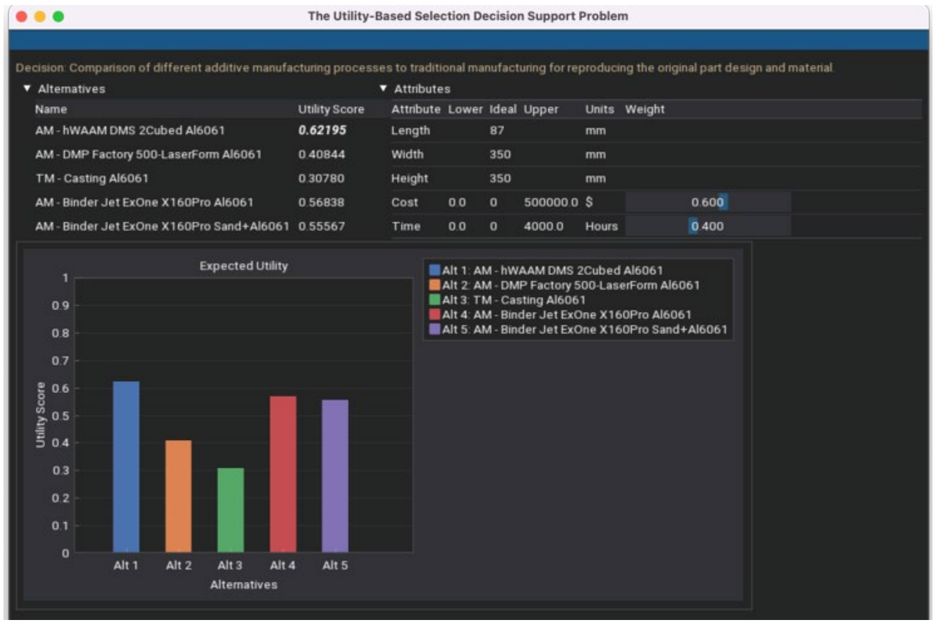


Figure 8. Decision Engine Outputs for Scenario 1

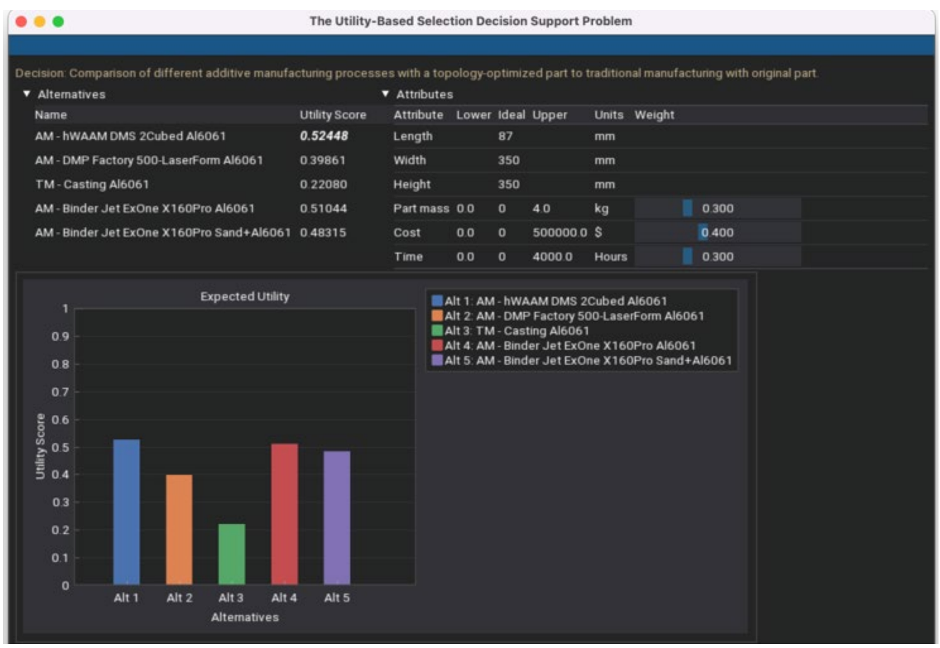


Figure 9. Decision Engine Outputs for Scenario 2

The expected utility of each manufacturing technique is plotted. The hWAAM process still offers the highest utility; however, due to decreased material costs from design mass reduction, the binder jetting process now has comparable utility. Traditional casting is still predicted to have the lowest utility.

Mass reduction of the bellcrank design through topology optimization has reduced the amount of material required to manufacture the part by one-third, which in turn has driven the total cost of the binder jetting process down by roughly 20%. An image of the optimized component, manufactured with hWAAM, is provided in Figure 10. Thus, this particular scenario highlights the possible changes in utility ranking of different processes as a result of subtle changes in the attributes by the introduction of topology optimization enabled in additive manufacturing processes.

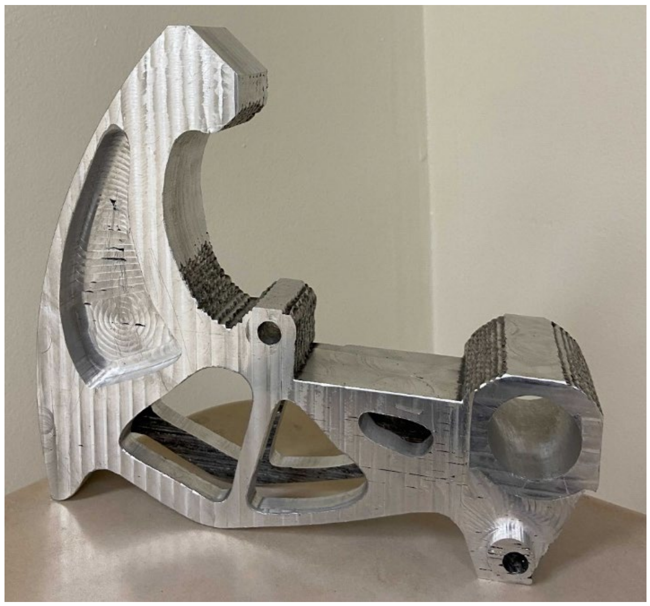


Figure 10. Topology Optimized Bellcrank Produced by hWAAM

(Note: The surface finish indicates that the AM part was post-processed using a milling machine.)

Final Thoughts on the Use Case: Aircraft Single Component Design

In this use case, a fleet sustainment decision by an aerospace company was explored. Within this decision, two possible scenarios for the design and manufacturing of an aileron bellcrank were explored. The first scenario enabled a comparison between traditional casting and different additive manufacturing processes' utilities in replicating the original bellcrank geometry and material.

In Scenario 2, the decision was re-evaluated with considerations that additive manufacturing processes can be used to produce a redesigned bellcrank geometry that was optimized for lightweighting. In both scenarios, the hybrid wire arc additive manufacturing process had the highest utility as it offered a sufficiently large build volume and offered the lowest cost and lead time among the alternatives. Between Scenario 1 and Scenario 2, a decrease in the relative ranking in utility between the two top manufacturing processes, hWAAM and binder jetting, was observed, indicating that additional consideration of additive manufacturing's ability to manufacture topology optimized parts in the decision process can impact engine outputs.

In the future, a third scenario that could be explored would be looking at how changing both the design and the material of the part for each process changes the utility. The change in material would change the design output by topology optimization, so each process/material combination would be tied to a unique design. Integration of the topology optimization process with the decision tool in an iterative fashion would also be a natural extension of this work.

Conclusions

The research focused on the data and framework surrounding the opportunity to exploit additive manufacturing as a systems engineering problem. The discussion started with a description and conceptual background on the decision support tool. Then, we discussed the use case, Design, Manufacturing, and Maintenance of Aircraft Components. To further understand use case, we identified the critical decision and analysis variables and created a framework to understand how these variables impact each other. Then, we transferred the above framework into an algorithmic view of these variables to make an optimized decision regarding where and how additive manufacturing can have the most impact. Finally, we developed an interactive decision support tool (i.e., the decision engine) in additive manufacturing so that the decision makers can use the quantitative data to make a proper decision.

As future work, further possibilities of the decision engine development include: (1) driving the decision engine using Model-based Systems Engineering (MBSE); (2) Integration of the decision engine with System-of-Systems (SoS) Analytic Workbench (AWB) for Mission Engineering; (3) Integration of the decision engine with AM machine/material databases (e.g., Senvol, PW Communications); (4) Integration of the decision engine with generative design tools to explore part redesign opportunities (and associated savings) via the use of AM (e.g., Autodesk Fusion 360); and (5) Expansion of decision engine to other DoD's area of interest, such as crisis management as discussed during the Additive Manufacturing Workshop in June 2022 at the MxD Headquarters in Chicago, IL (Brown, 2022).

References

Autodesk Fusion 360. (n.d.). *Cloud-based 3D modeling, CAD, CAM, CAE, and PCB software*. https://www.autodesk.com/products/fusion-360

Bai, Y., Wagner, G., & Williams, C. B. (2017). Effect of particle size distribution on powder packing and sintering in binder jetting additive manufacturing of metals. *Journal of Manufacturing Science and Engineering*, *139*(8). https://doi.org/10.1115/1.4036640

Brown, D. (2022). *Additive manufacturing workshop*. https://ammo.ncms.org/events/2022-additive-manufacturing-workshop/

Diversified Machine Systems. (n.d.). *Hybrid manufacturing benefits – 5-axis possibilities*. https://dmscncrouters.com/blog/hybrid-manufacturing-benefits-5-axis-possibilities/

ExOne X1 160PRO review - industrial metal and ceramic 3D printer. (n.d.). https://www.aniwaa.com/product/3d-printers/exone-x1-160pro/

Fernández, M. G., Seepersad, C. C., Rosen, D. W., Allen, J. K., & Mistree, F. (2005). Decision support in concurrent engineering – The utility-based selection decision support problem. *Concurrent Engineering*, *13*(1), 13–27. https://doi.org/10.1177/1063293X05050912

GF Machining Solutions. (n.d.). *DMP factory 500 - Discover our game-changer for the AM world*. https://www.gfms.com/en-nl/machines/additive-manufacturing/dmp-factory-500.html

Gibson, I., Rosen, D., & Stucker, B. (2015). Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing, second edition. In *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing* (2nd ed.). Springer New York. https://doi.org/10.1007/978-1-4939-2113-3/COVER

Gradl, P., Tinker, D. C., Park, A., Mireles, O. R., Garcia, M., Wilkerson, R., & Mckinney, C. (2022).

Robust metal additive manufacturing process selection and development for aerospace components. *Journal of Materials Engineering and Performance, 31*(8), 6013–6044. https://doi.org/10.1007/S11665-022-06850-0

Impro Precision. (n.d.). *Typical lead times for sand casting*. https://www.improprecision.com/typical-sand-casting-lead-times/

Liaoning Borui Machinery Co. (n.d.). *Mould and pattern cost for cast iron sand casting, and lost wax cast steel castings*. http://www.iron-foundry.com/mould-pattern-cost-cast-iron-sand-castings-steel-castings.html

Maurer, M. (n.d.). *Topology optimisation leads to an increased stiffness and mass reduction*. https://www.cadfem.net/en/industries-topics/references/reference/topology-optimisastzion-leads-to-an-increased-stiffness-and-mass-reduction.html

MSE Supplies. (n.d.). *6061 aluminum based metal powder for additive manufacturing*. https://www.msesupplies.com/products/6061-aluminum-based-metal-powder-for-additive-manufacturing-3d-printing?variant=39456073515066

Shanmugasundar, G., Dharanidharan, M., Vishwa, D., & Sanjeev Kumar, A. P. (2021). Design, analysis and topology optimization of connecting rod. *Materials Today: Proceedings*, *46*, 3430–3438. https://doi.org/10.1016/J.MATPR.2020.11.778

Shi, Q., Tsutsui, W., Bekdache, D., Panchal, J. H., & DeLaurentis, D. (2022). A system-of-systems (SoS) perspective on additive manufacturing decisions for space applications. *2022 17th Annual System of Systems Engineering Conference (SOSE)*, 282–288. https://doi.org/10.1109/SOSE55472.2022.9812665

Shi, X., Ma, S., Liu, C., Wu, Q., Lu, J., Liu, Y., & Shi, W. (2017). Selective laser melting-wire arc additive manufacturing hybrid fabrication of Ti-6Al-4V alloy: Microstructure and mechanical properties. *Materials Science and Engineering: A*, *684*, 196–204. https://doi.org/10.1016/J.MSEA.2016.12.065

Uddin, S. Z., Murr, L. E., Terrazas, C. A., Morton, P., Roberson, D. A., & Wicker, R. B. (2018). Processing and characterization of crack-free aluminum 6061 using high-temperature heating in laser powder bed fusion additive manufacturing. *Additive Manufacturing*, *22*, 405–415. https://doi.org/10.1016/J.ADDMA.2018.05.047

WeldingSupply 1100-116-3. (n.d.). https://weldingsupply.com/cgi-bin/einstein.pl?PNUM::1:UNDEF:X:1100-116-3

Acknowledgments

The authors acknowledge financial support from the U.S. Department of Defense through SERC/AIRC on research task WRT 1049.4, contract no. HQ0034-19-D-0003, and report no. AIRC-2022-TR-006.

In addition, the authors thank the following individuals who have contributed to the AIRC WRT-1049.4 project: Dr. Nathan Hartman, Dr. Ananth Iyer, Mr. Steven Dunlop, Ms. Dalia Bekdache, Mr. Clint Hanthorn, Mr. Dutt Thakkar, Ms. Ashritha Setlur, Mr. Atharva Sonanis, and Dr. Lindsey Bezek.

Bridging the AI / Acquisition Divide: Why the Government Needs an Acquisition Revolution in the Coming Age of Artificial Intelligence

Tim Cooke, Ph.D.—is a veteran of the government professional services industry and an active contributor to better government organizations. As owner, President and CEO of ASI Government, LLC, he helps government clients leverage the marketplace through innovative outcome-focused acquisition to create mission essential capabilities. Prior to joining ASI, Cooke was a long-time executive at SRA International.

William (Will) Roe Roberts—is director of Acquisition Solutions for ASI, Government. He was most recently the Director of Acquisitions for the Joint Artificial Intelligence Center (JAIC), Office of the Department of Defense Chief Information Officer in Arlington, Virginia. As the first Acquisition Director for a DoD component focused on AI delivery, will was responsible for ensuring that acquisition pathways and methodologies are centered on the JAIC mission of providing AI capabilities to the warfighter and DoD workforce.

Michael Arendt, Ph.D.—is an executive-level consultant with proven technical expertise, domain experience, and business acumen to successfully transform commercial Artificial Intelligence (AI) and Machine Learning (ML) technologies into products, systems, and services for Government customers. Arendt has more than 18 years of experience in all facets of the business and program management life cycle, including identifying needs as well as defining program scope, resources, quality, costs, and ultimately the success/enablement of cutting-edge emerging technologies. Arendt received his PhD in Public Policy from the University of Maryland, College Park and has spent his career working across Government, Industry, and Academia.

Abstract

Artificial Intelligence technologies should be considered unique compared with the typical types of hardware and software solutions acquired by the Department of Defense (the Government). While at their heart, AI capabilities are indeed software, the journey required to build and deploy them successfully is very different. As a result, the Government must adapt its acquisition processes to support the AI development pipeline and include specific considerations for data acquisition, AI capability development, AI solution validation via test and evaluation, as well as ultimate deployment, adoption, and long-term refinement of the fielded AI capability. This research will seek to bridge the AI / acquisition divide by defining a detailed methodology to support execution of the AI acquisition life cycle.

Keywords: Artificial Intelligence, AI, Machine Learning, ML, Deep Learning, DL, acquisition, contracting, culture, technology, incentives, agile contracting

Introduction

The current revolution in conversational AI based on “foundation” or Large Language Models (LLM; e.g., GPT-3+) are capable of being adapted to a wide range of the Government missions and use cases. The disruptive change is rippling through the AI landscape like a hurricane tossing boats like toys. For many tasks, perhaps most, it reduces the need to build specialized systems and potentially replaces them with “prompt engineering” or the ability to interface with the LLMs based on knowledge of relevant domains. Such leverage of existing LLMs is an embryonic and rapidly developing endeavor which has made the need for developing new systems from scratch somewhat obsolete; replacing that work with the higher value, human work of aligning the technology to mission objectives and ensuring cultural values and trust are maintained. Many of the guiding lights and leaders of AI foresaw and started preparing for this day. In March 2023, they called for a moratorium on developing more advanced models than GPT-4 out of caution for the potential to generate dysfunctional and dystopian possibilities.

This revolution in AI demands a revolutionary mindset and rethinking of the Government acquisition of AI capabilities and solutions. Considering the statements and policies of adversaries in China and Russia, the acquisition of AI is the new arms race essential to the next phase of ensuring American democracy. The enduring advantage of the American political experiment now lives in the people who lead our innovative technology industry guided by the aspirations of America's founders and its vibrant values. The acquisition workforce needs to create acquisition processes that attract industry professionals to bridge the gap between the Government and the AI technology community. The Government's ability to acquire AI in this brave new world is the highway to America's future.

This research will seek to bridge the AI / acquisition divide by defining an overall methodology that includes the core processes necessary for acquiring data, developing an AI capability, validation (i.e., test and evaluation) of the AI capability, as well as ultimate deployment, adoption, and refinement of the AI capability within the Government. The methodology will organize the discussion of each of these core processes by presenting insights in four distinct areas that we believe are necessary for successful AI capability delivery. These four areas include organizational culture supportive of the AI acquisition life cycle; AI-centric technical considerations for data acquisition, application development, and capability refinement; flexible contracting approaches suitable for the AI acquisition life cycle; and well-designed incentives to effectively motivate all parties involved throughout the AI acquisition life cycle.

Data Acquisition—The Lynchpin for AI Capability Development

Cultural Keys for Success in Data Acquisition

Data is the lifeblood of AI and should be treated as an incredibly valuable shared asset across the Government. Nobody within the Government individually "owns" data. Instead, there is an incredibly complex hierarchy of "Data Stewards" who reside within various military, civilian, and contractor roles. These Data Stewards are the gatekeepers for access to the lifeblood of AI. For the Government to successfully begin its transformational journey developing and deploying AI, it must clear the way for access to data. The Government must make a concerted effort to change the culture of those who serve as Data Stewards from one that is restrictive and risk-averse, to one that recognizes the untapped potential that the coordination, collaboration, and sharing of data can yield.

Gaining access to this data and being able to share it freely across the Government could potentially lead to groundbreaking improvements vital to Government missions such as warfighting, cybersecurity, supply-chain/logistics and military healthcare and more. For example, from the health perspective, most diseases lack readily accessible, validated data sets in which the "truth" is defined relatively easily. While this tends to be true in the civilian world, within the Government and Department of Veterans Affairs (VA) there is a plethora of data that can be mined to help enable the development of AI tools. By opening access to this data, it could enable the Government to forecast force readiness, develop personalized training regimens, and even anticipate and intervene prior to potential service-member injuries or disabilities. However, the promise of these types of future AI solutions can only be realized if the Government culture supports it. More specifically, obtaining validated data sets for these highly complex problems will require greater flexibility by Data Stewards and the development of tools that can interrogate electronic health records to identify and annotate cases representing specific diagnoses. To achieve this, a shift in how the culture views this information must occur while ensuring protection for patient privacy and personal information. Anonymized data in health records from across the Government, the VA, and even the civilian world for our warfighters and veterans might thus have to be treated as precious resources of potential benefit to warfighter and veteran health, in much the same way as public utilities such as drinking water are currently treated (Pisano, 2020).

The Government must build a "data culture" internally and cultivate one externally with industry and academia. A data culture is one that recognizes the importance of data within the Government's day-to-day business processes and works diligently to harness its value. The bullets below provide some insights into the fundamentals that are needed for the Government to build a world-class data culture, which recognizes the importance of "ours" vs. "mine" to support AI capability development, deployment, and adoption:

- Leadership prioritizes and invests in data collection, management, and analysis/knowledge production. Leadership prioritizes creative data literacy for the whole organization, not just IT personnel or technical staff.
- Staff are encouraged and supported to access, combine, and derive insight from the organization's data.
- Staff recognize data when they see it. They offer creative ways to use the organization's data to solve problems, make decisions and tell stories. (Rahulbot et al., 2017)

Technical Keys for Success in AI Data Acquisition

Along with cultural issues, removing technical barriers to data access is essential for AI because access to large amounts of diverse and high-quality data is critical for the development and training of machine learning models. Machine learning algorithms rely on vast amounts of data to learn and improve, and the availability of such data sets is crucial for the development of accurate and effective models. Unfortunately, many organizations, particularly private sector companies who have been around for decades and the federal government, are in a state of disarray when it comes to data storage and organization. Technical barriers to data access can include challenges such as data fragmentation, inadequate metadata, data privacy and security concerns, lack of data interoperability, and limited access to data storage and computing resources.

Overcoming these technical barriers requires a coordinated effort from a range of stakeholders, including data providers, software developers, policymakers, and researchers. Some strategies for removing these barriers include developing standardized data formats and metadata, implementing data-sharing policies and platforms, robust data quality/data labeling/data curation, and improving data security and privacy protections through both policy and practice. By removing technical barriers to data access, we can ensure that AI technologies are developed and trained on diverse and representative data sets, leading to more accurate and effective models that can be applied to a wide range of real-world problems.

Contracting Considerations to Ensure Successful Data Acquisition

The backbone of any good AI data acquisition strategy will be found in the contracts that transform that vision into reality. While current contracts may be not ideally suited to support the level of data sharing and collaboration that is necessary to achieve wide-spread AI successes in the short run, the structure of future contracts for data are where the Government can make the largest contractual improvements to enable the deployment of AI across the Department. Below are two specific recommendations that the Government should consider employing to ensure contracts are structured to permit successful acquisition of data for AI.

Develop and Leverage Contractual Vehicles Specifically for AI Data Services.

The function of acquiring and accessing data has many tentacles in the life cycle process, but one of the key ingredients to being successful in this effort is to select a well-designed acquisition strategy that is tailored to facilitate data access for AI from the very beginning. To do this, the Government should develop multiple award contracts specifically for AI-relevant data services that give special consideration to:

- The composition of their competitive pool of vendors;
- The methods of defining the data acquisition requirements;
- Development of targeted evaluation criteria that attract strong AI Data Service provider solutions;
- Incentives that reward vendors for efficiently generating quality datasets that lead to impactful AI solutions.

The most important consideration is ensuring that the Government agency has a strong pool of vendors to solicit in their acquisition vehicle. These vendors must have the requisite technical expertise specifically related to data services for AI. In many cases, vendors who excel in this space may not be vendors who have experience in Federal contracting and are thus considered "non-traditional." This pool of vendors should be able to demonstrate their existing capabilities through more than a paper proposal alone. Such an approach levels the playing field for those without extensive past performance with the Federal Government. Moreover, as this technology is ever changing, the vendors within this pool should also be able to demonstrate that they have the capacity to collaborate with a wide variety of partners including other big businesses, small businesses, start-ups, academia, laboratories, or non-profit organizations. The next most important consideration for contract vehicles for AI Data Services is tied to how the Agency defines its requirements and structures its evaluation criteria to best solicit innovative solutions. It is not uncommon that industry and other acquisition partners often understand the Government's AI requirements better than the Government does. Thus, this approach should be employed whereby the requirements are presented in terms of a problem statement or a series of objectives for providing AI related data services to the Government. Such an approach maximizes vendor flexibility in proposed solutions and permits the leveraging of cutting-edge commercial technologies that may be used off the shelf and could be outside the norm of what the Government may typically use. To ensure these considerations are built into the contract, corresponding evaluation criteria must be used that focus on the matureness and those proposed industry solutions and how they may be leveraged specifically in the Government environment with minimal customization.

Instill Best Practices for AI Data Considerations into Other Contracts

Given the importance for data as part of building AI capabilities across the Department, the Government should ensure that best practices for data collection, curation, and sharing across stovepipes are built into future program requirements—even for those programs that don't think they have anything to do with AI. The reason for the breadth of this assertion is because the contracts that are created for programs across the Government ultimately become the brick and mortar of the data stovepipes that desperately need to be torn down. Terms and conditions are sometimes narrowly focused, over-prescribed, and may not have flexibility built into them for an ever-changing technological world. By building AI data considerations into the contracting process from the very beginning for all programs, it ensures that if/when data sharing needs for a future AI project are necessary, access to quality data can be quickly realized.

Data specific contractual requirements to support development of AI solutions can be treated as standard terms and conditions to enable AI much like existing requirements for cyber security or environmental considerations. These considerations must be included within every step of the contracting process starting with the creation of an IP/data right strategy at the beginning of any program. This strategy must then become enacted through the contractual process and any other agreements between parties. In addition, a data rights/IP risk assessment and cost assessment are recommended. Moreover, data for AI should be considered and discussed as part of any RFIs, RFPs, evaluation factors, source selections, and should ultimately work their way directly into the contract line items, work statements, contract clauses, contract data requirements lists, data rights assertion provisions, instructions, conditions, and notices to offerors as well as any quality assurance surveillance plans or related evaluations by Contracting Officers Representatives (CORs) during the contract period of performance.

AI Capability Development—Where the Rubber Meets the Road

Cultural Keys for Success in AI Capability Development

Everyone Can Develop AI Capabilities—No Degree Required!

One way to ensure that these embedded end users can make an immediate impact is by recruiting them to participate in the AI capability development process itself versus simply advising the development team as a subject matter expert. There are several existing examples where this is already being done across the Federal Government. In fact, in the recent report entitled *Government by Algorithm*, a widespread survey was conducted across Federal Civilian agencies to assess the current use of AI solutions. Of the 157 identified instances of civilian agencies using AI to augment their operations, some 84 or 53% of those solutions were developed in-house by current civilian employees in lieu being outsourced to contractors as shown in the figure below (Engstrom et al., 2020).

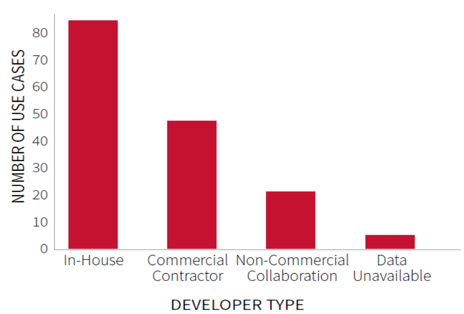


Figure 1. AI Use Cases by Developer Type. (Engstrom et al., 2020).

One shining example of this approach is at the Social Security Administration's Office of Appellate Operations (OAO; Engstrom et al., 2020). Gerald Ray, who spent most of his career at SSA, and served as Administrative Appeals Judge and then deputy executive director of the OAO. During his time at OAO, he led the successful development of prototype AI tools by civilian personnel within his office. Described by one co-worker as the "Steve Jobs of the SSA," Ray realized that AI tools could be used to automate business processes which could be incredibly helpful to support personnel engaged in the SSA adjudication process. Because the OAO was unable to hire outside contractors and was only authorized to employ attorneys, Ray identified attorneys within the organization who had an existing background data analysis and software engineering. These lawyers ultimately became the became the core team that built out SSA's early AI prototypes that were used to improve the SSA adjudication processes within the OAO. (Engstrom et al., 2020)

Ultimately, AI will have to evolve into a low-code, no-code form that is like most common business applications. This would eliminate the need to have specifically skilled AI experts involved in development (Petrocelli, 2018). Further, the emerging ecosystem, consisting of marketplaces for data, algorithms and computing infrastructure, will also make it easier for developers to pick up relevant AI skills. The net result will be lower costs to train and hire talent. The above two factors will be particularly powerful in vertical (industry-specific) use cases such as weather forecasting, healthcare/disease diagnostics, drug discovery, and financial risk assessment that have been traditionally cost prohibitive (Hosanager, 2017).

As a result of these factors, the Government should take advantage of AI development platforms that minimize the need for highly technical training and minimize the gap between warfighter and AI capability developer. Lastly, instead of re-creating a new training program, the Government should leverage as many existing training programs as possible via a series of partnerships with these organizations to streamline access for warfighters and civilians.

Collapse the AI Capability Development Pipeline

When an AI solution is developed in a stovepipe or vacuum without direct end-user involvement, the likelihood that it will be adopted successfully in the field is significantly diminished (Fountaine et al, 2020). Thus, one key to development of meaningful AI capabilities is ensuring that end-users are fully integrated as an active part of the product development team for an AI capability. For some organizations, this could be a potential radical shift in the technology development process where historically there may have been several bureaucratic layers between those who write requirements, develop technological solutions, those who test and evaluate solutions, and those who finally get an opportunity to field test them prior to limited or full rate production.

Thus, for successful AI capability development, the Government should seek to collapse the capability development chain by integrating all core players into an AI capability development product team. Collapsing the capability development chain means that the Government should reduce the distance between those ultimate end users who are in the field and those who develop AI/ML capabilities that can become impactful across a range of use cases. The impact of this approach will be ensuring AI/ML solutions are applicable to the real-world, usable by operators, who can provide meaningful insights prior to initial field testing.

Technical Keys for Success in AI Capability Development

Developing strong AI capabilities requires a marriage of technical expertise and thoughtful strategic planning. Here are some key technical factors that can contribute to success in AI capability development:

- **Understand the Problem You are Solving**. Before pitching a solution, make sure you really understand the use case and the challenges. Talk to experts and the potential customers you want to serve. Understand what it is like to go through their day. Until you get this right, the next steps will not matter because you will get a faulty solution that does not solve the problem.

- **Choose the Right Algorithms**. Choosing the right algorithms is essential for building effective AI models. You need to have a good understanding of the strengths and weaknesses of different algorithms and be able to select the most appropriate ones for your specific use case. AI algorithms are used to take this data and turn it into something useful that can serve to automate processes, personalize experiences, and make complex predictions. Don't be afraid to use a commercial off the shelf solution (COTS). There is no need to reinvent the wheel when a solution already exists. Incorporating a hybrid approach also works well by taking a COTS solution and customizing it for your needs.

- **Don't Forget Infrastructure and Tools.** Building and training AI models requires significant computing power and specialized tools. You need to have a robust infrastructure in place, including high-performance computing resources and the right software tools. While there are many different types of software tools available for use, not all tools provide the same ease of use and accessibility. Tensorflow and Pytorch are two examples of very popular tools which have a plethora of online training resources available to support AI algorithm development.
- **Don't Be Afraid to Experiment and Iterate.** Developing AI capabilities is an iterative process that involves continuous experimentation and refinement. You need to have a culture of experimentation and be willing to try out different approaches, learn from your mistakes, and make improvements. Experimentation here means augmenting the insights from the data you have and planning business processes on a test and learn a basis to see how they respond. The process of experimentation can reap multiple rewards for businesses, considering how they will find themselves in a better position to continue with a given strategy if it proves to be successful.
- **Ensure You Have Domain Expertise.** To build effective AI models, you need to have a deep understanding of the domain you're working in. This includes not only technical knowledge of machine learning and data science, but also a strong understanding of the business context and the needs of your stakeholders.

Contracting Considerations to Ensure Successful AI Capability Development

The innovative and evolving nature of AI development requires an acquisition approach that is similarly innovative and evolving. The use of traditional contracting structures doesn't work well for AI development efforts for several reasons. First, traditional FAR-based acquisition approaches tend to encourage participation from traditional government contractors that specialize in the government over the technology. Second, traditional application of the FAR does not adequately address the need for agile contracting teams to instill fluidity and agility in the process. This kind of flexibility is essential for procuring and delivering emerging technology, and particularly for buying and adopting AI.

It is worth noting that "being traditional" is not equivalent to "using the FAR." For those with knowledge and skill, the FAR provides enough flexibility to engage in meaningful agile contracting. In the book and website *Agile Government Contracting,* the authors emphasize this point, and further show that *mature* agile teams will work within the regulatory parameters of federal procurement. Agile teams that ignore these parameters are just as ineffective as traditional contracting professionals that rely on outdated processes for rule compliance. There must be a balance to achieve true success and successful AI adoption (*Agile Government Contracting*, n.d.).

There are three major contracting areas that are unique to AI and that, in our experience, greatly increase the chances of successful AI adoption: (1) a meaningful Intellectual Property (IP) Strategy; (2) effective language on responsible use of AI (RAI); and (3) Agile contract structure and performance metrics centered on the Way of Working

(WoW) during contract performance and end-user value. This paper will cover these three areas in more detail in the following sections.

In some cases, it may make sense to consider the use of non-FAR-based acquisition authorities such as Other Transactions Authority (OTA). This approach offers a variety of methods to collaborate with innovative and emerging leaders in the AI arena. An example of this method is found in CDAO's Tradewind OTA Consortium vehicle. Tradewind is available for all DoD customers and the goal of the vehicle is two-fold: (1) provide a means to effectively procure and deliver AI from the best companies; and (2) help DoD customers learn the benefits of agile contracting so that they can start to practice this technique for future AI buys (whether they continue to use Tradewind or not). This second objective from CDAO emphasizes the realization that, right now, it is most beneficial for DoD agencies to help each other "learn" these new processes and take on a servant-type role of enabling the success of other agencies, rather than promoting oneself as the procurement expert organization for AI. More emerging tech-focused agencies should follow this example.

AI Validation (T&E)—Fingers Crossed, This Thing Actually Works!

Deploying AI capabilities requires rigorous testing and evaluation to ensure that they are performing as expected. Therefore, a comprehensive testing and evaluation plan must be in place to assess the effectiveness of the AI capabilities. The testing should cover a wide range of scenarios, including adverse scenarios, to identify any vulnerabilities or weaknesses in the system. Moreover, testing should be done continuously to identify any issues and address them promptly. The tests should focus on data and model quality, accuracy of predicted results, usability, and identify any future datasets that would improve the quality of the AI generated results.

Cultural Keys for Success in Validation of an AI Capability

"Field to Learn"—Don't Make Perfect the Enemy of the Good in AI/ML

The Government should not allow the perfect be the enemy of the good when it comes to development and fielding of AI/ML capabilities in the near-term. The culture must shift from one that puts speed to fielding first, even if the current iteration of a solution is less than ideal. In short, for AI and ML technologies to be adopted and improved, they must get into the hands of users as quickly as possible with the understanding that there will be a pipeline in place to push feedback for real-time or near-real-time refinements to improve functional capabilities and usability as additional data is collected. While on one hand, AI has shown that it can translate speech, diagnose cancer, and beat humans at poker. On the other hand, there have been missteps along the way that imply the technology may still be a long way off from full maturity. "For example, image recognition algorithms can now distinguish dog breeds better than you can, yet they sometimes mistake a chihuahua for a blueberry muffin. AIs can play classic Atari video games such as *Space Invaders* with superhuman skill, but when you remove all the aliens but one, the AI falters inexplicably" (Hutson, 2018). Such mistakes are indeed inevitable as nothing can fully replicate the fielding of a solution in a real-world environment. The important factor here is to ensure that the early fielding is done in a safe and responsible manner to ensure there are no serious impacts to the mission.

Technical Keys for Success in Validation of an AI Capability

As AI becomes more sophisticated and ubiquitous, it is critical that we ensure that it is used ethically, securely, and with trust. In this section, we will explore the technical keys for success in validating an AI capability that incorporates security, ethics, and trust. Below are four key technical considerations for the validation of an AI capability.

Understand the Data

The first technical key to success in validating an AI capability is to understand the data that will be used to train the AI algorithm. Data is the foundation of any AI system, and it is essential to ensure that the data is accurate, relevant, and representative of the real-world scenarios that the AI system will be deployed in.

In addition, it is crucial to understand the biases that may exist in the data. Biases in the data can lead to biased AI algorithms, which can have serious consequences. Therefore, it is essential to analyze the data for any biases and take steps to mitigate them. One example highlighting this problem is facial recognition technology. Facial recognition has been shown to have discrepancies in accuracy with females and minorities (SITNFlash, 2020). One of the problems is that early facial recognition programs were trained on friends and family members of the founders, and the dataset was mostly faces of white males. Fixing the training data by using more diverse groups of people to train the model, goes a long way to solving this problem, but it remains to be seen as to whether this action by itself resolves the problem. If a company or organization uses facial recognition for security, it is imperative to keep in mind the flaws and that any action taken as a result of a facial recognition process should be done with the utmost professionalism and care and should rely on other analytic methods.

Understand the Algorithm

The second technical key to success is to choose the right algorithm for the AI system. There are numerous AI algorithms available, and each has its strengths and weaknesses. Some algorithms may be better suited for certain tasks than others. It is also essential to understand the limitations of the chosen algorithm. No AI algorithm is perfect, and it is important to understand what the algorithm is capable of and what its limitations are. Understanding the limitations of the algorithm will help to manage expectations and ensure that the AI system is deployed in a manner that is safe, ethical, and trustworthy. This kind of understanding is also important for making sure your models are relevant. The world is constantly changing. If you understand the capabilities and limitations of your model, you are quicker to react and modify the model accordingly if a new dynamic occurs forcing you to change. As you validate the AI model, you should have a team separate from the development team to validate the model.

Ensure Security

The third technical key to success is to ensure the security of the AI system. Security is critical in any system, but it is especially important in an AI system that is handling sensitive data. Ensuring the security of the AI system involves taking steps to prevent unauthorized access, safeguarding against cyber-attacks, and ensuring that the data is stored securely.

Incorporate Ethical Considerations

The fourth technical key to success is to incorporate ethical considerations into the design and development of the AI system. Ethical considerations are critical because AI systems can have far-reaching consequences, both positive and negative. Incorporating ethical considerations involves ensuring that the AI system is designed to promote fairness, transparency, and accountability. AI development also requires an awareness of ethical considerations, such as privacy, bias, and fairness. You need to design and develop AI models that are ethical and responsible, and that respect the rights and interests of all stakeholders. Organizational leaders should constantly assess the following criteria:

1. Safe and secure

2. Private
3. Responsible
4. Robust and reliable
5. Transparent and explainable
6. Accountable
7. Fair and impartial

By focusing on these technical factors, you can build strong AI capabilities that deliver value to your organization and stakeholders.

Build Trust

The final technical key to success is to build trust in the AI system. Trust is critical because it determines how users perceive and interact with the AI system. Building trust involves designing the AI system to be transparent, explainable, and accountable. It also involves ensuring that the AI system is used in a responsible and ethical manner. Education is another key aspect to building trust.

Validating an AI capability that incorporates security, ethics, and trust requires technical expertise and a deep understanding of the data, algorithms, and ethical considerations involved. Ensuring the security of the AI system, choosing the right algorithm, incorporating ethical considerations, and building trust are all critical technical keys to success. By incorporating these principals, we can ensure that AI is used in a responsible, ethical, and trustworthy manner, ultimately benefiting society as a whole. Finally, you must always assess everything from your data, modeling, use cases, and even ensuring your workforce is cognizant of not just how the AI process works, but understand the ethics and trust issues which often lag behind technical development.

Contracting Considerations to Ensure Successful Validation of an AI Capability

The Importance of Third Party Neutrality to Establish "Trust"

In many cases, the developer of the AI model (or the large prime contractor of the project if the Government set up their contract to rely on a prime integrator) will offer services to test the reliability of their own models. In some cases, such as automated testing, this will be the most logical option. However, in most cases it will be essential for the Government to arrange a separate contract for third party testing. This establishes neutrality which furthers overall trust in the model. In such cases, it may be beneficial to arrange for a small multiple award ordering vehicle among a selected pool of trusted third-party AI testers. The vehicle will not only allow for faster repetitive orders but establish the basic parameters of trustworthy AI at the base contract level. If performed with skill, the CO can include terms and conditions in the base contracts which establish predictability in performance in all vendors. This will, in turn, begin to solidify a reliable "way of work" among the agile teams as they bring the testing companies into the overall process.

Testing for "Trust" in Responsible Use of AI (RAI)

There are two primary areas of "trust" needed in order for end users to become early adopters of AI technology for the benefit of government missions: (1) Trust in the working functionality of the technology to enhance the user's job and mission; and (2) Trust in the responsible use of the technology to prevent harm to innocent life and bias in outcomes. Although the first area of trust has been the primary focus of Test and Evaluation (T&E) activities, testers must address RAI with the same level of scrutiny. In this sense, AI provides a unique challenge, and COs must be cognizant of the need to imbed RAI considerations in the performance metrics. As with almost every element in AI acquisition, the contract is the mechanism in which the parties mutually agree on how RAI is addressed, and this places importance on the role of the CO. The two most challenging but equally impactful areas to address RAI in the contracting process are (1) at the source selection stage as a discriminator for award selection; and (2) at the T&E stage as a metric for contractor performance. In both areas, the CO must navigate through the dangers of ambiguity in defining what "responsible" and "trustworthy" look like. Challenging as it may be, it is essential for the success of the end users' AI adoption. The Defense Innovation Unit (DIU), the Air Force MIT Accelerator, and CDAO all provide guidance that can help the acquisition team select the appropriate contract language that allows for testing AI trustworthiness.

Deployment, Adoption, and Refinement—All Aboard the AI Bullet Train

Cultural Keys for Success in Deployment, Adoption, and Refinement of an AI Capability Across the Government

IT systems have made it possible to give senior commanders instantaneous access to information across the globe. While that can provide a strategic advantage, it also leads to micromanagement and tighter measures of control. When it comes to AI, having tools at the command center is crucial, but there must be a deliberate effort to push technology to the edge. Simply put, giving each individual rifleman the AI tools needed to plan and execute missions, anticipate the enemy, and provide force protection is essential to success on future battlefields. It is also critical not to overlook critical support functions such as predicting maintenance issues, assisting with logistics, or using AI to assess the wellbeing of our military personnel.

Build a Sense of Urgency

As noted in many articles over the last few years, the Government has to take concrete steps to improve the acquisition process so that military personnel have the best resources at their disposal. The entire process from requirement identification to signing the contract must move with urgency. Far too often, companies that try to help the government end up shutting their doors because they have run out of cash and their solutions were so unique that there was not a private sector counterpart. Without fixing this key aspect, many companies may shy away from working with the government. Contrast that with the war in Ukraine and how the Ukrainians have developed unique technical solutions at scale. After all, as noted by former Google CEO Eric Schmidt innovation power is the decisive form of power for world dominance. If the government cannot speed up acquisition, it will not be able to innovate effectively, causing the United States to fall behind as an innovative power (Schmidt, 2023).

Ensure Effective Change Management

Deploying AI capabilities across the Department of Defense requires effective change management processes to ensure that all stakeholders are on board with the deployment plan. This includes communicating the benefits of AI capabilities, training personnel, and addressing any concerns or objections that may arise. Additionally, it is essential to have a clear plan for managing the transition to AI capabilities, including the necessary infrastructure changes and modifications to existing processes.

Technical Keys for Success in Deployment, Adoption, and Refinement of an AI Capability Across the Government

AI is transforming the Government by improving decision-making, increasing efficiency, and enhancing operational effectiveness. However, deploying, adopting, and refining an AI capability across the Government requires a unique set of technical skills and expertise.

Develop a Comprehensive Plan

The first technical key to success is to develop a comprehensive plan for the deployment, adoption, and refinement of the AI capability based on mission need. This plan should include a clear and concise description of the AI capability, the benefits it provides, and how it will be deployed and adopted across the Government. It is essential to identify key tasks and the person assigned to those tasks. The plan should also include a roadmap for the refinement and improvement of the AI capability over time. This roadmap should identify the technical challenges and risks associated with the deployment and adoption of the AI capability, as well as the strategies that will be used to mitigate these risks. Once implemented, the Government will have to constantly assess and modify technology and resources to adapt to new trends. For example, the arrival of ChatGPT already threatens to place previous AI solutions into obsolescence. ChatGPT is so powerful that recently, several tech insiders have written a letter calling for a pause of the development of such models (Blake, 2023).

Robust Data Management

The quality of data is a critical factor in the development of AI capabilities. Therefore, it is essential to have a robust data management system in place. The system should be able to store, manage, and protect sensitive data from unauthorized access. Additionally, it should be able to handle large volumes of data and provide easy access to relevant data for analysis. A robust data management system ensures that AI capabilities are developed based on accurate and relevant data, leading to better outcomes.

Addressing Technical Challenges

The second technical key to success is to address the technical challenges associated with the deployment and adoption of the AI capability. The deployment and adoption of AI across the Government involves a complex set of technical challenges, including data integration, algorithm development, and system interoperability. It is important to identify and address these technical challenges early and ensure that you not only have the necessary technical infrastructure and capabilities, but also the key technical experts across the entire enterprise. Military personnel, ranging from the most senior general to the lowest ranking private have a role. After all, they make the decisions and execute military orders. They need to articulate what they need, address any modifications that need to be made to any AI solution, and validate that the solutions do indeed make their job easier and that they are rapidly deployable.

Strong AI Infrastructure

Deploying and operating AI capabilities requires a robust infrastructure that includes hardware, software, and networks. This infrastructure must be scalable, reliable, and secure. Furthermore, it must be designed to handle the complex computations required for AI applications. Therefore, investing in modern hardware and software technologies is critical to ensuring a successful deployment, adoption, and refinement of AI capabilities. The infrastructure must allow data to flow up and down the chain of command to not only provide the best AI modeling, but to allow full spectrum analysis of the situation in order for leaders to make the best battlefield. decisions.

Strong Cybersecurity Measures

Deploying AI capabilities across the Department of Defense requires robust cybersecurity measures to protect sensitive data and systems from cyber threats. This includes implementing strong access controls, encryption, and network segmentation to prevent unauthorized access. Additionally, it is essential to conduct regular security audits and implement continuous monitoring to detect and respond to any potential security threats.

Documentation is Key!

With a constant turnover, documentation is key. Oftentimes, this is one of the most overlooked aspects of an AI program, and indeed, just about any IT program. One of the reasons data storage and model building is somewhat disjointed is because of turnover and the lack of documentation.

In conclusion, deploying, adopting, and refining AI capabilities across the Department of Defense requires a robust technical foundation that includes robust data management, strong AI infrastructure, robust testing and evaluation, strong cybersecurity measures, and effective change management. With these key technical factors in place, the Department of Defense can develop and deploy AI capabilities that are effective, efficient, and secure.

Contracting Considerations to Ensure Successful Deployment, Adoption, and Refinement of AI Capabilities Across the Government

There is much to address in contracting for successful AI adoption, and this paper is not able to delve into all of these concerns in detail. As a foundational statement, it should be noted that successful deployment, adoption, and refinement are the most neglected areas in AI procurement. Consequently, prototypes die in the "valley of death," end users never experience or enjoy the impact that AI can have in their jobs, and the technology adoption by foreign adversaries continues to be a very real and disconcerting threat. The acquisition professionals hold the key to changing this reality, and contracting officers must adjust their practices in order to reverse the circumstances. The good news is that such changes are realistic and achievable, they just need to be accepted and practiced. It should also be noted that this is not a "top-down" problem, and real change can and should occur at the operational and tactical grassroots level (a.k.a., the acquisition team).

Strategizing Intellectual Property to Maximize Market Participation

An area in contracting that directly impacts the deployment and sustainment of an AI model is the topic of intellectual property rights. When it comes to AI, IP strategies take a slightly more complex approach. At the very least, proper strategies on IP require an adequate level of understanding and knowledge of the underlying technology. For example, the rights to the data, the model, the platform and the infrastructure may all have separate strategies to ensure the appropriate government ownership or use rights. When it comes to the model itself, the government should work to accept commercial terms and customary rights to leverage more industry participants. The infrastructure and platforms, however, may need more government control and ownership as any vendor-lock on large platforms may inhibit the government's ability to compete among various models that may connect to the platform via API. Finally, data rights offer unique considerations and will typically be case by case. The IP Cadre, set up by OUSD A&S, provides very good guidance for acquisition professionals, particularly on setting up innovative IP strategies for the procurement of emerging technologies.

Agile Contracting for Value-Added End User Adoption

While the term "agile" is more commonly associated with the development and deployment of software, there is a need for contracting teams to engage in flexible contracting that is iterative and nimble. It is also worth mentioning that agile contracting has always been a method that the FAR has recommended for large IT procurements. FAR 39.103 describes the process of modular contracting, which provide the necessary agility to pivot as circumstances change throughout the development and delivery phases of AI acquisition.

Incentives for the AI Ecosystem—Carrots and Sticks for Successful AI Development and Adoption

In this final section, this paper will address the very relevant and oft neglected area of meaningful incentives that bring about true AI adoption success. The importance of this subject area warrants a special attention and therefore a separate section. The incentive principles discussed in this section should be applied in all stages of the AI life cycle discussed above. Incentives need to be designed to help understand the dynamic and uncertain goals and objectives of the Government use cases that embed AI technologies as part of the solution. The real explainability challenging the Government may be less about the internal technology and more about of inherent unsureness in the problem statement, challenge, or statement of objectives. Solving successfully for the wrong objective is a major challenge for AI systems which must be addressed by iterative feedback, testing, and evaluation to ensure fidelity with the intended objectives. If pivots or adjustments are identified then changing the system to address the new direction should be encouraged, not discouraged. This, again, emphasizes a common theme exhibited throughout this paper: the core challenges of explainability, trust, and successful AI adoption are primarily centered on the way the Government executes an AI acquisition through diligent contracting and product management.

As always, the behavior of people as they respond to their incentives is critical to achieving these acquisition improvements. The non-financial and financial incentives that may be applied in a contract setting will be important determinants of overall project success. Furthermore, thoughtful incentives for AI projects will help bridge the much publicized “gap” between Government missions and private industry by providing real and meaningful benefits for high tech companies. Financial and non-financial rewards for the contractor project team can be tied to model and mission outcomes. Reliability, robustness, efficiency, and value for money metrics in best value procurements can be factored in the project team incentives. Criteria should be designed to be easy to measure and be one of the outputs of doing the work, not requiring separate effort.

Type	***Organization***	***Individual***
Financial	Incentive fee, SLA based, quantitative award fee or withhold based on subjective evaluation Award term additional period of performance	Bonus Promotion
Non- financial	Team Awards & Recognition CPARS, Past performance Intellectual property Customer Experience Mission impact & Reputation	Teamwork & Partnership Recognition & Reputation Learning new skills Management Excellence Flexible work hours & location

Figure 2. Traditional Performance Incentives for AI Solution Contractors

The performance incentives should include the following: a) clear and measurable performance objectives; b) financial and non-financial performance incentives and penalties;

c) regular monitoring and evaluation of contractor performance; and d) flexibility for contractors to adapt their approach based on performance feedback. In addition, rewards for individual functional specialists should be based in part on the team's overall performance to ensure alignment of effort.

As in any third-party effort or contract, the design of incentives should consider the Principal-Agent relationship between the Government, the Principal, and the performing contractor, the Agent. A divergence between their goals and objectives creates the potential for inefficiency and rent-seeking behaviors.

Non-Monetary Incentives

Managers and employees of solution delivery firms are expected by their company to behave in ways that increase the value of the enterprise. Significant determinants of company value include top-line revenue growth and bottom-line earnings. The successful companies in this market are the IT and professional services firms that have invested in the knowledge of how to work with the Government to overcome the many barriers to entry and business model requirements to be successful. However, critical mission success is dependent on diversifying the market participants, and therefore it is necessary to discuss how the Government can first incentivize new technology players in the acquisition processes before describing incentives for successful contract performance.

To incentivize new entrants, the Government should engage in selective cost-sharing. This will assist in building industry capability to meet government specific requirements like FedRamp. Defraying the costs of the Government-specific regulations would encourage more businesses to be willing to forego other business opportunities as the Government accommodates the business needs of industry for things like timely cash flow and reduced costs surrounding regulation compliance. For example, Other Transaction Agreements (OTAs) are, by design, a contractual mechanism to reduce barriers to entry because they are not subject to specific regulations of the FAR. The Government's new Office of Strategic Capital should make this their primary mission and goal, but any acquisition professionals can execute these incentives through thoughtful structuring of the contracts and agreements.

Traditional Government suppliers and their employees often share many of the attributes of their government clients, most importantly a dedication to the mission and its success. Such firms would be particularly sensitive to reputation-based incentives as follows:

- Public recognition: The Government publicly acknowledges the achievements of high-performing contractors, increasing their visibility and credibility in the market.
- Preferred contractor status: The Government grants preferred status to contractors that have demonstrated exceptional performance, making it easier for them to secure future contracts.

A company's excellent reputation can lead to more business opportunities and higher financial returns.

Government Incentives

Since the purpose of examining incentives in the Government AI acquisition is to ensure mission success, it is necessary to consider the incentives of all team members within an AI project, to include government professionals. To neglect the personal motivations of such key members is to ignore the impact that a high-morale government workforce has on an office's successful technology adoption. Government program managers are the first line of accountability for the performance of AI systems. They respond to the objectives, constraints, and incentives of their organization and in their careers. Financial incentives such as bonuses for government officials are limited by law, and not usually major incentives, either in value or influence.

Instead, the non-financial incentive of government contracts mission success is often the dominant incentive. Government managers have the same kind of devotion to the mission. Government buying teams have the desire to excel, but only if management fosters this desire and provides the rewarding environment. Team members should be measured on common program goals, not the goals of their specialist silos. They all need to transparently see measurable improvements in mission performance, new mission capabilities, and improved service levels, and to be recognized for those improvements. Program performance dashboards should be made easily accessible to all members of the Acquisition team. Team cohesion ensures mission focus, which will consequently transfer to cohesion with the contractor, who will merely be brought into the well-functioning team.

Monetary Incentives

Having addressed various non-monetary incentives necessary for overall program success, it is important to examine the alignment of contract incentives with meaningful performance metrics based on actual end user value. This will, in turn, ensure that monetary awards are properly aligned with progressive delivery and adoption of the AI technology.

Milestone-Based Payments

The Government releases funds to the contractor based on the successful completion of predefined milestones. This approach ensures that the contractor is financially incentivized to meet key project objectives and deliverables. It reduces the Government's exposure to financial risk while accounting for the cash flow needs of suppliers. As long as the Government buyers are satisfied with the performance of the contractor and has an associated exit strategy, milestone payments create powerful alignment between the goals of the Government buying organization and the contractor. Such milestone payments tie to performance with an exit strategy also serve to prevent lock-in effects where the Government develops such an integrated relationship with a provider that the switching costs effectively turn competition into a negotiation in which the service provider wields significant market power. When highly integrated teams engage in iterative development and delivery, these milestones may take on a different nature. Instead of large looming milestones, for example, it is possible for mature organizations to create "foot pebbles"—or shorter rewards based on successful completion of "done" for each sprint. It will still be essential to keep the team focused on the larger goals within a project by marking large distances with landmarks (a.k.a., a "milestone"), but perhaps it is equally as important to mark and reward progress based on some notable pebbles within the path itself. This form of iterative incentive awards could be another step closer to providing a realistic means for the Government teams to shift their thinking to agile development.

Technical Metrics for Performance-Based Contracts

While incentives should be tied to performance metrics, metrics for successful performance are not synonymous with incentives. Performance metrics are based on deployment, adoption, and refinement are essential measuring tools for successful performance regardless of whether an AI contract utilizes monetary incentives.

Technical implementation metrics are vital for tracking deployment, adoption, and refinement of AI systems:

Deployment Metrics (Guest Contributor, 2019)
Deployment Frequency—How long the AI takes to deploy

Failed Deployments—Deployments that cause issues or outages
Code Committed—The number of Commits the team makes to the software before it can be deployed into production
Lead Time—Measuring the amount of time passing between inception and the actual production and deployment, the team's ability to adapt to change
Error Rate—A function of the transactions that result in an error during a particular time window
Mean Time to Detection (MTTD)—The amount of time that passes between the beginning of the issue and the time when the issue gets detected and some remedial action is taken
Mean Time to Recovery (MTTR)—The average time taken by the team to repair a failure in the system

Adoption Metrics (Dilmegani, 2023)
Total Users—The total number of people using the AI tool
Active Users—The number of people who access the AL tool
Engaged Users—The number of people who interact with AI tool
New Users—The increase in users after initial implementation
Retention Rate—The percentage of users that continue use of the AI tool

Refinement (Dilnegani, 2023)
Goal Completion Rate—Captures the percentage of a successful engagement
Goal Completion Time—The time to complete a successful engagement
Failure Rate—Captures the percentage of a non-successful engagement
User Satisfaction—Defined through exit surveys
Change Fail Percentage—Captures the percentage of non-successful changes/updates

IPTs should work closely enough to know how things are going, thereby negating the need for a monthly report. Performance metrics centered on deployment are more fitting for metrics to measure acceptable contract performance. Performance metrics centered on adoption and refinement are more challenging as such goals may not be attained despite acceptable contractor performance. As such, these metrics could be more fitting as milestone incentives. Foot-pebble incentives can be based on individual sprint success, tracked iteratively and simply, and calculated and paid by the month/quarter/etc.

Conclusion and Final Thoughts

Artificial intelligence, machine learning, and deep learning represent the future of disruptive information technology innovations. While the promise of AI solutions is great, they are not one-size-fits-all and require varied types of domain knowledge, flexible processes, and capable technologies to effectively develop and implement. In some cases, the value proposition of a proposed AI solution may not outweigh the resource costs of its ultimate development and implementation because of the sheer complexity of the AI development pipeline. Acquisition of a successful AI capability thus requires a combination of cultural changes, technical capacity, contracting flexibility, and effective incentives. Because of these myriad factors, the Government must develop and execute a highly efficient yet carefully curated process that is tailored for the specific needs of the AI acquisition life cycle.

References

Agile Government Contracting. (n.d.). https://www.agilegovernmentcontracting.com/

Blake, A. (2023, March 29). Tech leaders call for development pause for GPT-4.5, GPT-5. *Digital Trends*. https://www.digitaltrends.com/computing/pause-ai-development-open-letter-warning/

Dilmegani, C. (2023, January 19). Top 22 metrics for chatbot analytics in 2023. *AIMultiple*. https://blog.aimultiple.com/chatbot-analytics/

Engstrom, D. F, Ho, D. E., Sharkey, C. M., & Mariano-Florentino, C. (2020, February). *Government by algorithm: Artificial intelligence in federal administrative agencies*. Stanford Law School, Thomson Reuters. https://law.stanford.edu/education/only-at-sls/law-policy-lab/practicums-2018-2019/administering-by-algorithm-artificial-intelligence-in-the-regulatory-state/acus-report-for-administering-by-algorithm-artificial-intelligence-in-the-regulatory-state/

Fountaine, T., McCarthy, B., & Saleh, T. (2020, June 1). Building the AI-powered organization. *Harvard Business Review*,. https://hbr.org/2019/07/building-the-ai-powered-organization

Guest Contributor. (2019, August 20). 7 crucial DevOps metrics that you need to track. *Packt Hub*. https://hub.packtpub.com/7-crucial-devops-metrics-that-you-need-to-track/

Hosanagar, K. (2017, April 13). The democratization of machine learning: What it means for tech innovation. *Knowledge at Wharton*. https://knowledge.wharton.upenn.edu/article/democratization-ai-means-tech-innovation/

Hutson, M. (2018, May 24). How researchers are teaching AI to learn like a child. *Science*. https://www.science.org/content/article/how-researchers-are-teaching-ai-learn-child.

Petrocelli, T. (2018, September 20). Democratization of AI development is beginning. *CMSWire.com.* https://www.cmswire.com/digital-workplace/democratization-of-ai-development-is-beginning/

Pisano, E. D. (2020, January 1). AI shows promise for breast cancer screening. *Nature News*, Nature Publishing Group. https://www.nature.com/articles/d41586-019-03822-8

Rahulbot et al.(2017, December 9). You don't need a data scientist, you need a data culture. *Data Therapy*. https://datatherapy.org/2017/12/06/building-a-data-culture/

Schmidt, E. (2023, March 14). Innovation power. *Foreign Affairs*. https://www.foreignaffairs.com/united-states/eric-schmidt-innovation-power-technology-geopolitics.

SITNFlash. (2020, October 26). Racial discrimination in face recognition technology. Science in the News. https://sitn.hms.harvard.edu/flash/2020/racial-discrimination-in-face-recognition-technology/

Leveraging Machine Learning and AI to Identify Novel Additive Manufacturing Technological Capabilities to Improve Fleet Readiness

Rebecca Decrescenzo—is a Business Analyst with over 6 years of experience across multiple industries, including national security, health policy, marketing, and small goods commerce. Her analysis at Govini has focused on critical technologies across the U.S. government as well as fleet readiness and support initiatives. She holds a Master of Science in Business Analytics from Bentley University.

Mihiri Rajapaksa—is an Engagement Manager at Govini. Prior to joining Govini, she spent over 5 years working as a civilian for the U.S. Navy. She started at NSWC Philadelphia as a HM&E ancillary equipment SME and then transitioned to PEO IWS 3.0. Within IWS 3, she worked in IWS 3L, the Vertical Launching Systems Program Office, for over 4 years overseeing new construction and fleet support as well as various tech refreshes and engineering development efforts. She holds a Master of Science in Robotics from the University of Pennsylvania.

Abstract

As competition between the United States and adversarial nations intensifies, the U.S. Navy faces a challenge to maintain advantages in the maritime domain. While the outcome of this competition will depend on many factors, one critical factor will be the speed and agility of the U.S. Navy to sustain the Navy's operational availability (Ao). However, current logistics, supply chain, and manufacturing capabilities seem unable to meet the current demands of the fleet. One technology that could support this is additive manufacturing (AM). Leveraging AM technologies to manufacture long lead time and high demand parts will enhance readiness and reduce logistic burdens.

What seems certain is that the country that leverages AM technology the fastest can gain and maintain a technological lead.

AM technology can augment traditional manufacturing techniques. Since some commercial practices must be modified to meet military requirements, this study looks at the current investment landscape across the U.S. government (USG) in the AM technology space to see what AM USG contracts are available now across to explore potential contracting actions. This study identifies the organizations developing cutting-edge AM technology that can be used by the U.S. Navy today to improve overall fleet readiness.

Introduction

Traditionally, bureaucratic and contracting hurdles have limited the U.S. government's (USG) ability to acquire new, key technology quickly. Without the ability to adopt cutting-edge technology from the manufacturing sector into the fleet sustainment and readiness missions, the U.S. Navy risks diminished or loss of advantage in the maritime domain.

Govini developed a repeatable and scalable methodology to analyze the additive manufacturing (AM) market. The methodology examines investments across the USG and Navy to identify active contracts that could enable Navy organizations to access and test with AM technology. To accomplish this task, the study leveraged machine learning (ML) and artificial intelligence (AI) to identify AM related contracts, subcontracts, grants, OTAs, academic research articles, and patents. The resulting data sets were then tagged and aligned to specific technology areas creating a scoped list of key AM vendors. The AM vendors were further refined by isolating USG contracts with available periods of performance and contract ceiling. Our assumption is that existing, active contracting vehicles could speed access to innovative technologies and implementation within the fleet. This study highlights the contracts that might be leveraged to quickly access AM technologies.

The U.S. Navy has started down the right path by approving Huntington Ingalls Industries to utilize certain additively manufactured parts, but there is a further expanded use for this technology (Katz, 2023). The insights from the study can aid decision-makers in the Department of the Navy (DoN), Department of Defense, and broader USG as they grapple with the challenges of accelerating production and maintaining U.S. maritime superiority.

Key Findings

- **USG demand for AM technology is currently at its peak.** There are 210 active contracts for AM technology or services across the USG. The Air Force contracted roughly 5 times as much as the Navy on AM from Fiscal Year (FY) 2018 to FY2022.
- **The industrial base for AM is large but underutilized by the USG.** There are 7,800 vendors in this space, and 135 are currently being used by the USG—representing less than 2% of the entire vendor ecosystem. AM vendors span a spectrum from small, start-up private companies to large, publicly traded, and well-known defense companies.
- **$1.3 billion of contract ceiling is currently available on active AM contracts across the USG.** Available contract ceiling means that the USG has available contract vehicles to potentially leverage to quickly access this innovative technology.

Methodology

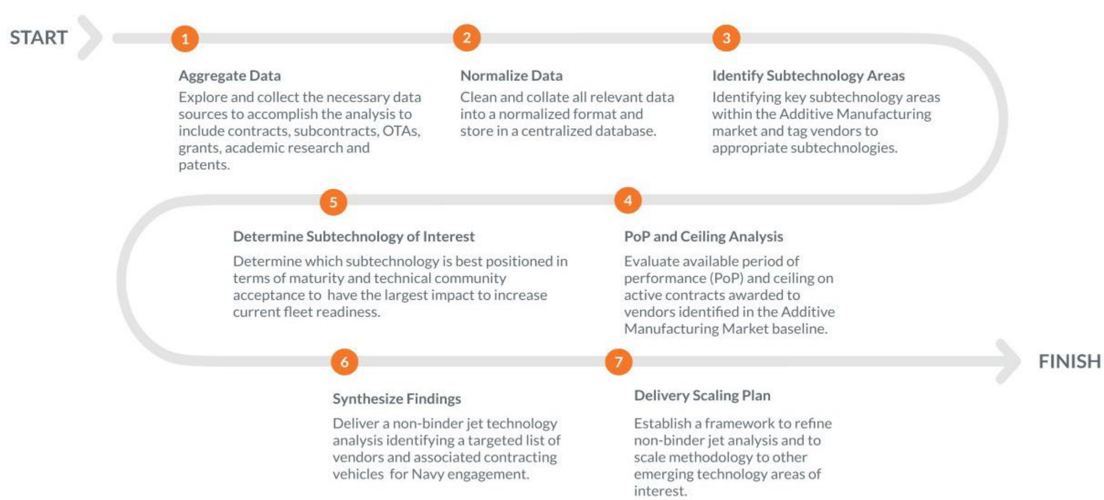


Figure 1: Analytical Methodology Utilized for This Report

Through an iterative process, a robust set of keywords were generated to query Govini's National Security Knowledge Graph (NSKG) for relevant contract awards in the AM market. The NSKG is driven by Govini's patent-pending Object Fusion data engine that continuously ingests, normalizes, and integrates new data sources with existing data catalogs. Govini analysts leveraged the information in the NSKG to construct the associated vendor landscape views across the AM market through the use of ML algorithms. This comprised the baseline data set for analysis.

The first phase of this study analyzed historical and current USG award data, academic research, and patents to create a baseline of vendors operating in the AM market. Supervised ML and natural language processing (NLP) was applied to parse, analyze, and categorize large volumes of federal contracts and grants data. The use of AI and supervised ML models enables analysis of the large volumes of irregular data contained in federal contracts and grants—data that is often inaccessible through regular government reporting processes or required human-intensive analytical approaches. Moreover, beyond simply making usable an expansive body of data sources, the mathematical principles that underlie Govini's AI and ML technologies also increase confidence in the fidelity with which the data are categorized and aggregated to produce a comprehensive and accurate depiction of federal spending over time. All vendors were tagged by capability into one of 27 different sub-technology areas within the AM market. The 27 sub-technology areas can be seen in Appendix Table 1.

In the second phase, the vendor baseline data set was evaluated to identify vendors who have USG prime contracts, subcontracts, OTAs, or grants with active periods of performance (PoP) and available ceiling. An active PoP was defined as a contract with a PoP that ended after September 2023, aligning with the start of a new fiscal year. The combination of an active PoP and available ceiling indicates that this could be an option for a potential contract vehicle to easily access the technology or service provided by that particular vendor.

Analysis

There are approximately 7,800 unique vendors who have historically operated in the U.S. commercial and government AM market from 2017 to 2022, identified through prime contracts, subcontracts, OTAs, grants, academic research publications, and/or patent awards. As seen in Figure 2, the count of vendors in this market has fluctuated over time with a peak in calendar year 2021. This means that there is a wide range of vendors and their associated capabilities and technologies for the Navy to evaluate to integrate into maintenance and production to enhance overall fleet readiness. The dip in FY2022 is a result of lower patent awards and academic research during that time period, which seems in line with an overall decrease in innovation in that time (Data Journalism Team, 2022).

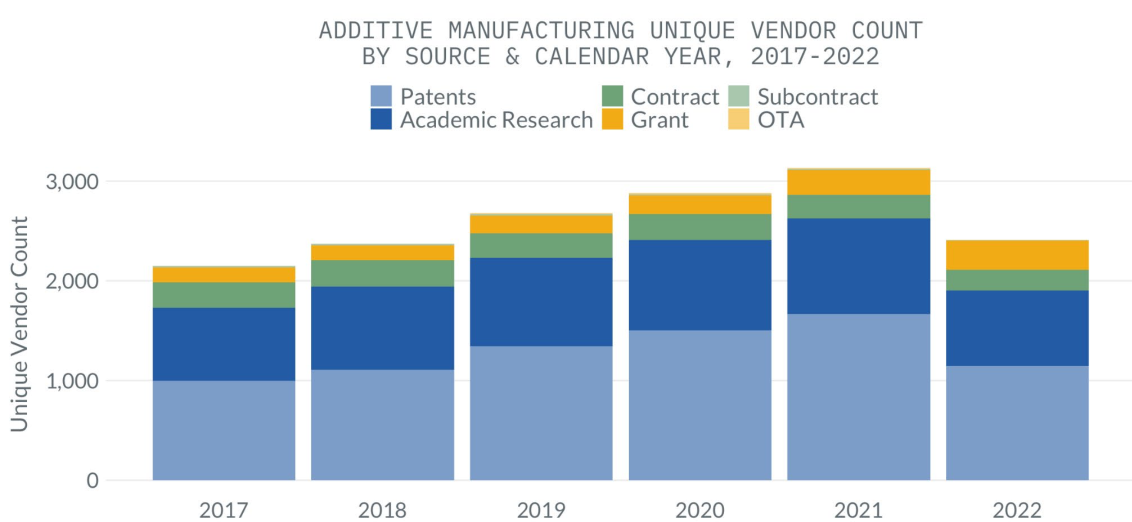


Figure 2: Unique Vendor Count by Source and Calendar Year

Analyzing the vendor location can be a methodology to assess vendors who are easy to partner with for future work. Figure 3 shows the physical location of all vendors in the AM market. Based on the AM technology application, it may be beneficial to work with vendors in geographical proximity to a naval base or laboratory location. There are high concentrations of AM vendors in Southern California, the Pacific Northwest, and Northeastern regions, which coincides with a number of fleet concentration areas, U.S. Navy bases, and naval surface, undersea, and aviation warfare centers.

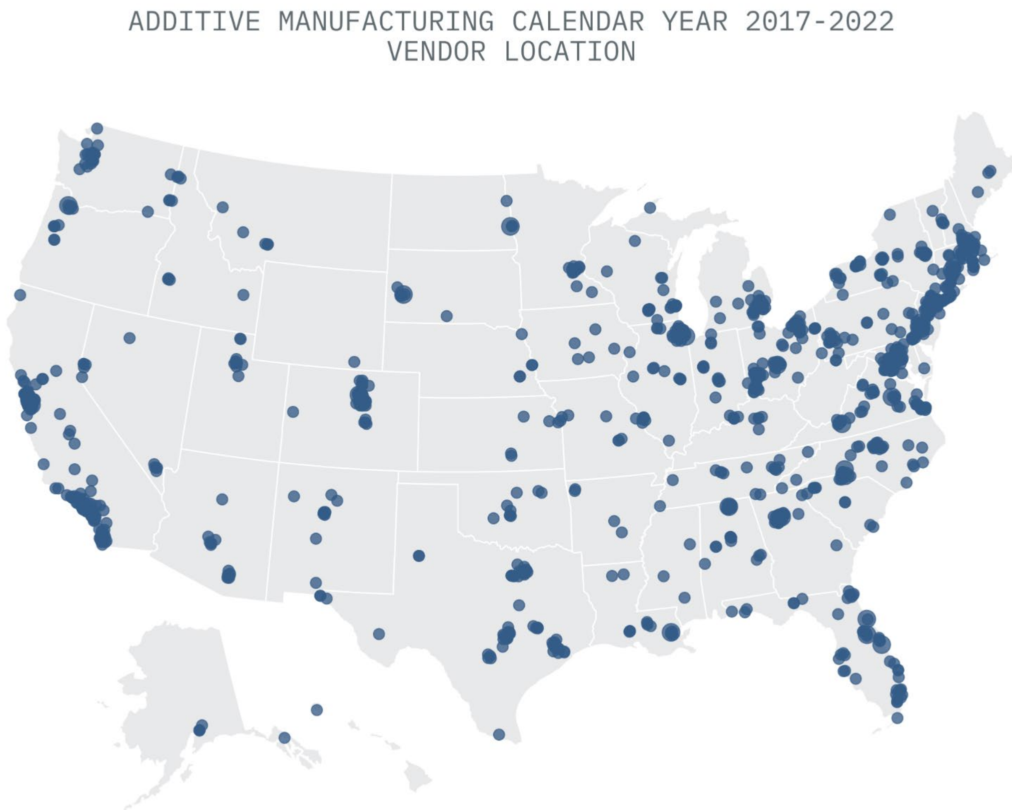
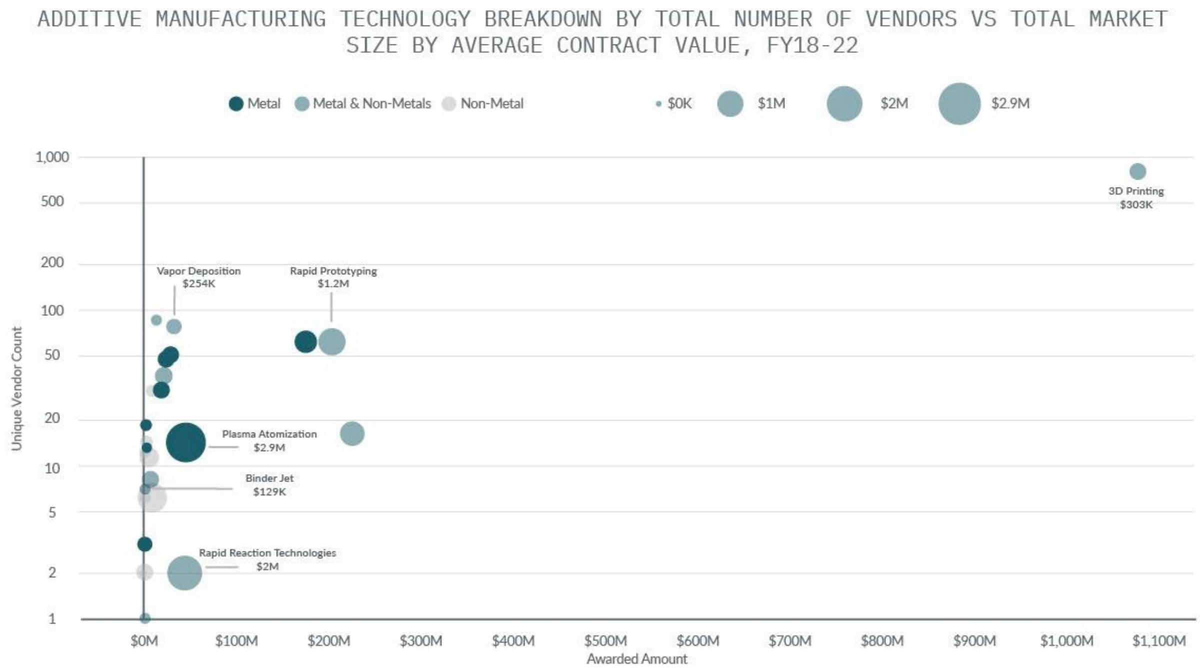


Figure 3: U.S. Map of All Additive Manufacturing Market Vendor Locations Sized by Number of Vendors Associated With Each Latitude and Longitude Grouping

Only 9.3% of the vendors in the entire AM market have been awarded USG contracts since 2018. As seen in Figure 4, the subset of vendors in the USG market provide a variety of AM technologies, including Powder Bed, Plasma Atomization, and standard 3D printing. For 3D printing, there are almost 1,000 vendors who have received a total award amount of approximately $1.1 million. The average award amount for 3D printing is $303,000, which means that there are a lot of small contract awards in this technology market. Govini found that contract award amounts related to Plasma Atomization, which works in metal AM, tend to be larger than those for standard 3D printing, which could be a variety of metal and nonmetal (e.g., plastics, etc.) applications. Broader AM technology groups such as rapid prototyping and 3D printing could allow for more flexibility in the utilization of applicable contracts.



Note. *Size of the bubble represents the total average contract size. Color of the bubble represents the material types associated with the additive manufacturing technology area.*

Figure 4: Subsegment Technology Areas With the Total Associated Additive Manufacturing Market Size Measured Against the Total Number of Vendors

Currently, a number of these technologies are being evaluated for technical feasibility across the DoN, including laser metal deposition and binder jet technologies. Specifically, the binder jet technology market has a lower on average award amount ($129,500), which places it at 19 out of the 27 defined AM technology areas and material types included in the active AM USG contracts as ranked by average award amount. The binder jet technology market also has a lower total awarded amount, with $1.8 million awarded from FY2018 to FY2022. As this technology becomes more mature, there may be an increase in awards for binder jet technology products and services, which will result in higher total award amounts.

According to subject matter experts in the field, non–binder jet technology for metal material AM appears more promising on producing parts to sustain and repair the fleet than binder jet technologies. Therefore, binder jet technology contract awards were removed from the AM market for the remaining portion of this analysis. Looking at the remaining 26 technology areas (binder jet excluded), there are 134 vendors currently working with the USG and approximately 1,050 vendors that have taken USG investment for work and/or research from FY2018 to FY2022. Figure 5 shows the top contracting agencies across the USG by award amount and the top four vendors each contracting office awarded contracts to—with the vendors ranging from large systems integrators who work in many fields, including AM, to smaller, AM-specific vendors.

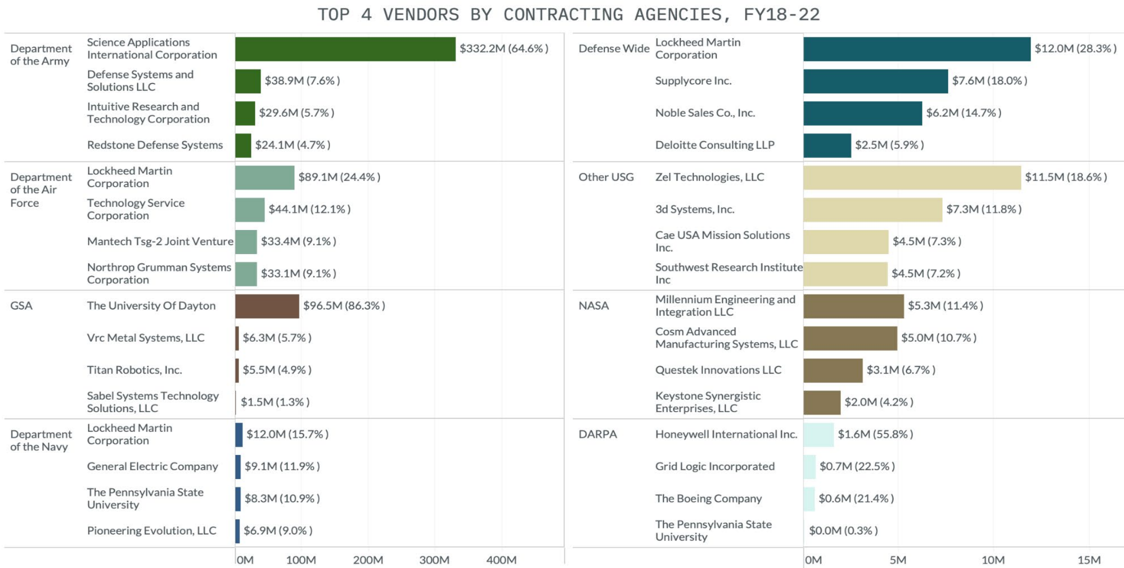
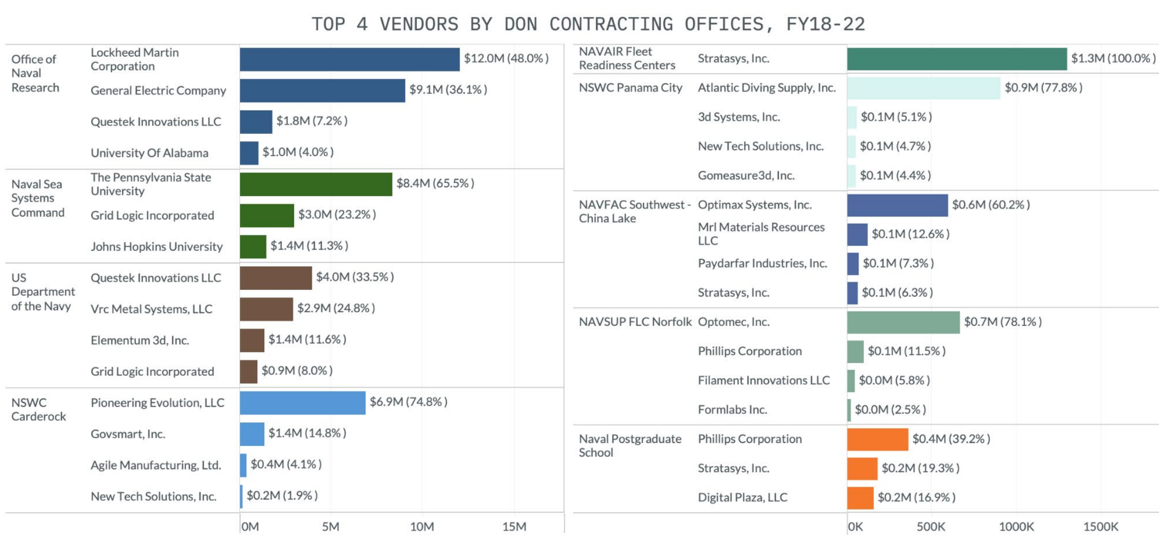


Figure 5: Top 4 Vendors by Sum Awarded Amount and Percentage of Contracting Agency Awarded Amount

Most illuminating, perhaps, is the apparent lack of investment in AM and contracting paths currently available inside the DoN agencies. Figure 5 shows the percent of contract awards the vendor has received from that contracting office for AM-related work. For example, Lockheed Martin has received 15.7% of all AM contract awards from the DoN from FY2018 to FY2022, while they have received 24.4% of all AM contract awards from the Department of the Air Force. The agencies shown in Figure 5 have a high utilization of certain vendors and represent the subset of contracting agencies who it may be ideal to partner with to get quick access to AM technology. Figure 6 shows specific contracting offices within the DoN for a more granular view at U.S. Navy the contracting activity level.



Note: Contracting offices with less than four vendors displayed awarded contracts to less than four vendors in the Additive Manufacturing market from FY2018 to FY2022.

Figure 6: Top 4 Vendors by Sum Awarded Amount from DoN Contracting Office and Percentage of DoN Contracting Office Awarded Amount

Analyzing the investments within the DoN, Figure 6 shows the top four DoN contracting offices by total contract award amount during the time period analyzed for work in the AM market. The offices within the U.S. Navy, Office of Naval Research ($25.1 million), Naval Sea Systems Command ($12.8 million), and NSWC Carderock ($9.2 million) are most likely the best initial starting point for partnering discussions once the specific vendor and technology of interest has been identified because they have the highest cumulative award amount within the AM market. The top vendors utilized by these three program offices are Lockheed Martin Corporation, Pennsylvania State University, and Pioneering Evolution.

As seen in Figure 7, a majority of active contracts across the USG pertain to broader technology areas such as 3D printing and rapid prototyping that can be suited for both metal and nonmetal applications. The largest of these contracts are awarded by the U.S. Department of the Air Force for rapid prototyping technologies. Rapid prototyping and 3D printing contracts may allow a higher degree of flexibility in the type of AM products or services procured when leveraging existing contracts with available ceiling and period of performance.

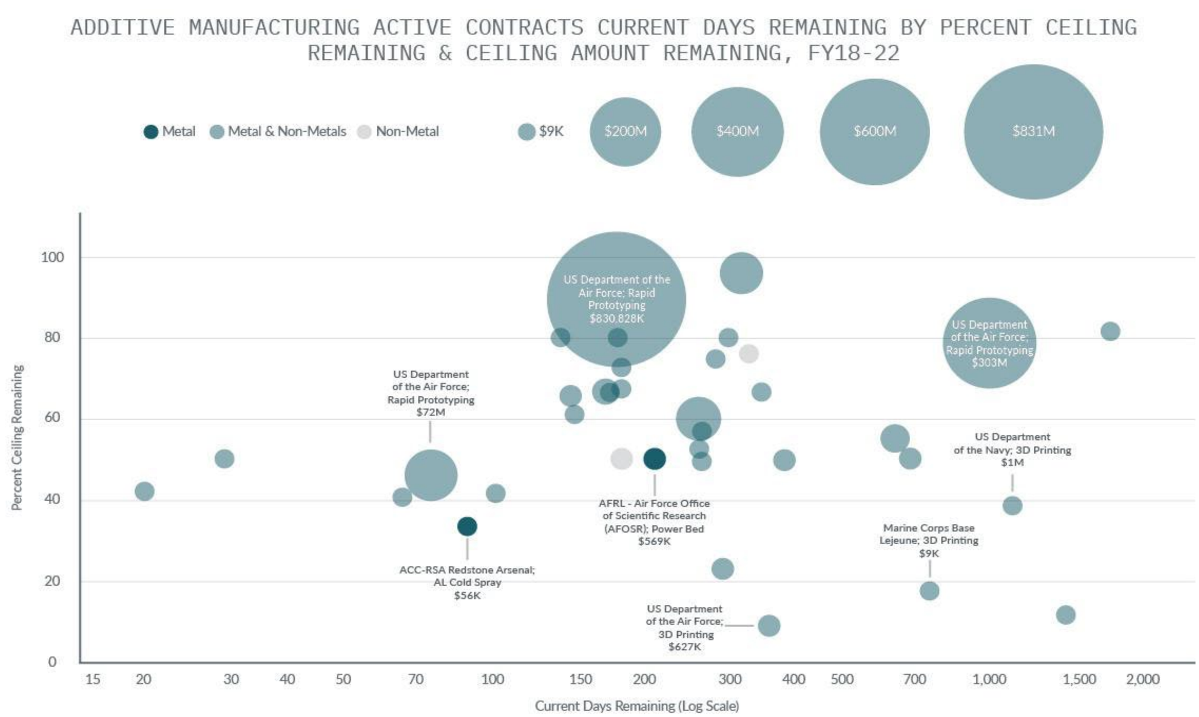


Figure 7: Active Contracts Across the USG by Current Days Remaining, Percent Ceiling Remaining, and Ceiling Amount Remaining

Looking at the available contract ceiling in isolation, which is the maximum amount of money that the USG can fund on a specific contract, is not a good indicator because the contract might have recently been awarded and that could be the reason for the large available ceiling. Figure 7 combines three key metrics—current days remaining, percent ceiling remaining, and ceiling amount remaining—to allow for quicker visibility into potential contracting opportunities with the ideal available ceiling and period of performance. For example, given the time to move money and for the vendor to provide their goods and services, an ideal contract may be those in the top center of Figure 7.

More specifically, for the procurement of a hardware capability, such as the machines needed for non–binder jet manufacturing, the ideal contract to leverage would be a contract with a shorter period of performance and a large available ceiling. Those hardware contracts could potentially be leveraged by other funding offices because of the short duration of the PoP and large contract ceiling. However, for services-oriented contracts, a longer period of performance may be required to ensure the required services can be performed in the remaining time on the contract. This analytical process surfaced 28 target contracts in the AM market. By evaluating this contract subset and associated 22 vendors, U.S. Navy program offices can identify the required capability set to incorporate into ship production and maintenance. These 28 target contracts, 22 vendors, and the associated contracting offices can be seen in Appendix Table 5.

Implications for the Navy

The Navy needs the ability to use AM to produce parts quickly and at the point of need both at sea and ashore in order to keep the fleet ready and sustained. Identifying contracting paths to access key technologies is vital to maintaining fleet readiness and therefore maritime superiority over adversarial nations. Additionally, the data to surface the right vendor with that key technology of interest and the data required for cross-USG analysis to identify those existing contracting vehicles is not easily accessible to Navy analysts. Figure 7 provides a starting point to identify contracting offices across the USG with active contracts for specific key capabilities and can be used by the U.S. Navy to move faster to get the requisite parts manufactured, tested, approved, and installed in the fleet. Automating this discovery and qualification process should allow for quick outreach to the government points of contacts to start the initial process of leveraging the current contracting vehicle. In the future, the U.S. Navy can strengthen those relationships with other offices within the USG to come up with joint contracting strategies to reduce government contracting workload and increase government buying power. The combined demand signal to the vendor can result in lower prices for the technology/service. This could also result in joint investments into key vendors to increase capability needed to support fleet readiness.

Next Steps

In order to further refine the results from this study, the team would conduct initial discussions with U.S. Navy leadership and technical subject matter experts to better understand immediate production and sustainment needs and what technology and applicable use cases have currently been approved by the appropriate technical communities for shipboard usage. This will allow for further refinement of key AM technologies that can be utilized to address those needs. Discussions could also surface the need for quick access to other emerging technologies areas. The methodology used in this study could be applied to another technology area of interest such as unmanned vehicles, materials informatics, or biomanufacturing as well.

Appendix I - Additive Manufacturing Technology Areas

Table 1: Subsegment Technology Areas With the Total Associated Additive Manufacturing Market Size, Associated Material Type, Total Additive Manufacturing Market Size, Total Average Contract Size, and Total Number of Vendors

Rank	Additive Manufacturing Technology Group	Material Type	Total Awarded Amount (FY2018–FY2022)	Average Contract Awarded Amount (FY2018–FY2022)	Unique Vendor Count
1	Plasma Atomization	Metal	$46,904,250	$2,931,516	14
2	Rapid Reaction Technologies	Metal & Nonmetal	$44,465,915	$2,021,178	2
3	Thermoset Manufacturing	Nonmetal	$9,582,114	$1,368,873	6
4	Rapid Prototyping	Metal & Nonmetal	$204,130,732	$1,222,340	63
5	Prototype Integration Facility (PIF)	Metal & Nonmetal	$225,607,965	$964,137	16
6	Cold Spray	Metal	$176,370,955	$683,608	64
7	Photopolymerization	Nonmetal	$6,112,151	$555,650	11
8	Material Jetting	Nonmetal	$2,108,233	$421,647	2
9	Open Manufacturing	Metal & Nonmetal	$7,463,226	$414,624	8
10	Atomic Layer Deposition	Metal	$29,975,864	$389,297	52
11	Powder Bed	Metal	$19,075,809	$381,516	30
12	Nanophotonic	Metal & Nonmetal	$22,953,190	$376,282	38
13	Metal Additive Manufacturing & Printing	Metal	$25,610,036	$346,082	48
14	3D Printing	Metal & Nonmetal	$1,073,783,490	$303,414	804
15	3D Printing	Metal	$849,781	$283,260	3
16	Vapor Deposition	Metal & Nonmetal	$32,479,809	$253,749	78
17	Laser Sintering	Nonmetal	$3,850,277	$167,403	14
18	Stereolithography	Nonmetal	$2,478,892	$137,716	12
19	Binder Jet	Metal & Nonmetal	$1,812,870	$129,491	7
20	Selective Laser Melting	Metal	$3,609,206	$124,455	18
21	Fused Deposition Modeling	Nonmetal	$9,591,697	$112,843	30
22	3D Printing	Nonmetal	$1,182,376	$90,952	6
23	3D Scanning	Metal & Nonmetal	$14,152,701	$80,413	88
24	Electron Beam Melting	Metal	$3,797,163	$79,108	13
25	Adv. Concept Tech Prototyping	Metal & Nonmetal	$434,843	$36,237	1
26	Laser Cutting	Nonmetal	$57,025	$28,513	2
27	Digital Light Processing	Nonmetal	$0	$0	3

Appendix II – Additional Additive Manufacturing Market Details

This section provides more detailed information on the Additive Manufacturing market landscape.

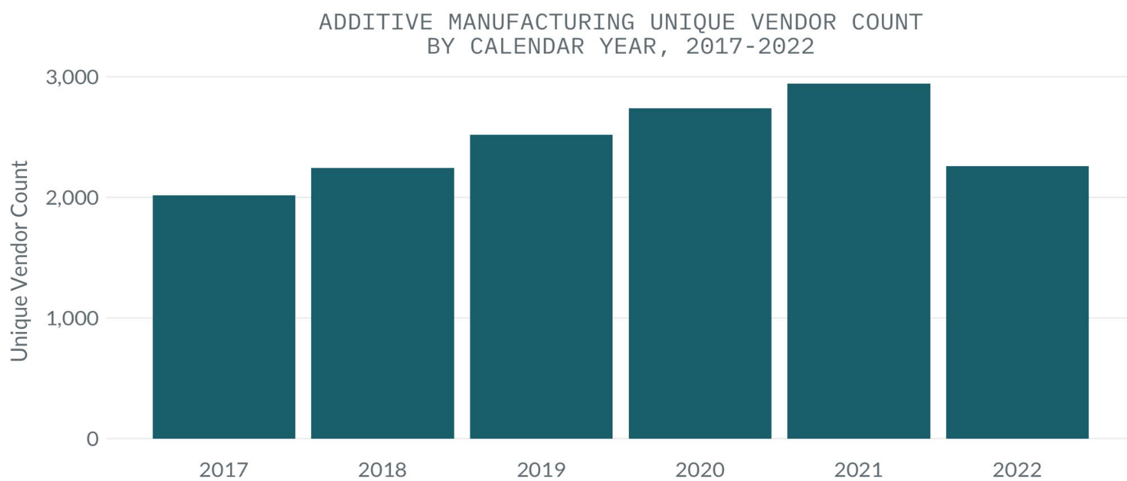


Figure 8: Additive Manufacturing Market Vendor Trend Over Time

Table 2: Top 10 Vendors Based on Award Amount in the Additive Manufacturing Market

Vendor Name	Additive Manufacturing Technology Group	Contracting Office	Total Awarded Amount (FY2018–FY2022)
Lockheed Martin Corporation	Rapid Prototyping	U.S. Department of the Air Force	$98,042,290
Northrop Grumman Systems Corporation	Rapid Prototyping	U.S. Department of the Air Force	$84,747,890
The Boeing Company	Rapid Prototyping	U.S. Department of the Air Force	$80,555,168
Southwest Research Institute	Cold Spray	U.S. Air Force Academy (10 CONS)	$45,745,277
Johns Hopkins University	3D Printing	U.S. Department of the Air Force	$27,180,577
Integrated Solutions for Systems	3D Printing	AFRL RWK - Eglin AFB	$11,714,035
General Electric Company	3D Printing	DLA Aviation (formerly Defense Supply Center Richmond)	$10,000,000
Questek Innovations	3D Printing	DCMA Chicago–Arlington Heights; U.S. Department of the Army	$8,279,027
Titan Robotics	3D Printing	GSA Federal Acquisition Service	$5,500,000
Concurrent Technologies Corporation	Powder Bed	U.S. Department of the Air Force	$5,265,000

Table 3: Top 10 Vendors Based on Available Ceiling Amount on Individual Additive Manufacturing Prime Contract

Vendor Name	Additive Manufacturing Technology Group	Contracting Office	Available Ceiling
Lockheed Martin Corporation	Rapid Prototyping	U.S. Department of the Air Force	$830,827,627
The Boeing Company	Rapid Prototyping	U.S. Department of the Air Force	$302,817,377
Northrop Grumman Systems Corporation	Rapid Prototyping	U.S. Department of the Air Force	$71,994,999
Johns Hopkins University	3D Printing	U.S. Department of the Air Force	$41,067,217
Advanced Technology & Research Corporation	3D Printing	FAS Office of Assisted Acquisition Services–FEDSIM	$33,634,425
Titan Robotics	3D Printing	GSA Federal Acquisition Service	$6,700,000
Mrl Materials Resources	3D Printing	DLA Contracting Services Office–Philadelphia	$3,194,542
Integrated Solutions for Systems	3D Printing	AFRL RWK–Eglin AFB	$1,121,327
Elementum 3d	3D Printing	U.S. Department of the Navy	$999,845
Questek Innovations	3D Printing	U.S. Department of the Navy	$996,599

Table 4: Top 10 Vendors Based on Available Ceiling Percentage on Individual Additive Manufacturing Prime Contract

Vendor Name	Additive Manufacturing Technology Group	Contracting Office	Percent Available Ceiling Remaining	Available Ceiling
Advanced Technology & Research Corporation	3D Printing	FAS Office of Assisted Acquisition Services–FEDSIM	96.1%	$33,634,425
Lockheed Martin Corporation	Rapid Prototyping	U.S. Department of the Air Force	89.4%	$830,827,627
Stratasys	3D Printing	ACC–APG Natick, MA	81.5%	$125,400
Cenmed Enterprises	3D Printing	U.S. Department of the Air Force	80.0%	$83,520
Stratasys	3D Printing	U.S. Department of the Air Force	80.0%	$80,000
Simbionix USA Corporation	3D Printing	National Institute on Drug Abuse	80.0%	$58,000
The Boeing Company	Rapid Prototyping	U.S. Department of the Air Force	79.0%	$302,817,377
Nano Dimension USA	3D Printing	DITCO–Scott: IT Contracting (PL83)	76.1%	$165,549
3d Systems	3D Printing	U.S. Department of Veterans Affairs	75.0%	$59,940
Sun Nuclear Corp.	3D Scanning	U.S. Department of Veterans Affairs	75.0%	$55,152

Table 5: All Vendors Based on Available Ceiling Percentage on Individual Additive Manufacturing Prime Contract for Contracts With More Than $50,000 Available Ceiling and Greater Than 30 Days Remaining in the Period of Performance

Vendor Name	Additive Manufacturing Technology Group	Contracting Office	Days Remaining on PoP	Total Available Ceiling	Percent Available Ceiling Remaining
Questek Innovations	3D Printing	U.S. Department of the Navy	66	$99,925	40.6%
Northrop Grumman Systems Corporation	Rapid Prototyping	U.S. Department of the Air Force	75	$71,994,999	45.9%
Luna Innovations Incorporated	Cold Spray	DCMA Eastern Region; ACC–RSA Redstone Arsenal, AL	89	$55,997	33.4%
Elementum 3d	3D Printing	U.S. Department of the Navy	101	$99,644	41.6%
Cenmed Enterprises	3D Printing	U.S. Department of the Air Force	136	$83,520	80.0%
Mrl Materials Resources	3D Printing	DLA Contracting Services Office–Philadelphia	168	$3,194,542	66.7%
Lockheed Martin Corporation	Rapid Prototyping	U.S. Department of the Air Force	176	$830,827,627	89.4%
Stratasys	3D Printing	U.S. Department of the Air Force	177	$80,000	80.0%
Rpm Innovations	3D Printing	U.S. Department of the Army	181	$86,800	67.4%
Storagenergy Technologies	Stereolithography	ACC–APG Research Triangle Park, NC	181	$549,982	50.0%
Mrl Materials Resources	Powder Bed	AFRL–Air Force Office of Scientific Research	211	$568,820	50.0%
Johns Hopkins University	3D Printing	U.S. Department of the Air Force	258	$41,067,217	60.2%
Goengineer	3D Printing	OL H PZI PZIM–Hill AFB	259	$75,580	52.7%
Stratasys	3D Printing	ACC–RSA Corpus Christi, TX	261	$52,643	56.7%
3d Systems	3D Printing	U.S. Department of Veterans Affairs	279	$59,940	75.0%
Engineering and Software System Solutions	3D Printing	U.S. Department of the Air Force	289	$627,383	23.1%
Simbionix USA Corporation	3D Printing	National Institute on Drug Abuse	296	$58,000	80.0%
Advanced Technology & Research Corporation	3D Printing	FAS Office of Assisted Acquisition Services–FEDSIM	314	$33,634,425	96.1%
Nano Dimension USA	3D Printing	DITCO–Scott: IT Contracting (PL83)	324	$165,549	76.1%
Integrated Solutions For Systems	3D Printing	AFRL RWK–Eglin AFB	357	$1,121,327	8.7%
Sun Nuclear Corp.	3D Scanning	U.S. Department of Veterans Affairs	364	$55,152	75.0%
Questek Innovations	3D Printing	U.S. Department of the Navy	384	$996,599	49.9%
Titan Robotics	3D Printing	GSA Federal Acquisition Service	639	$6,700,000	54.9%
Elementum 3d	3D Printing	U.S. Department of the Navy	684	$999,845	50.0%
The Boeing Company	Rapid Prototyping	U.S. Department of the Air Force	988	$302,817,377	79.0%
Georgia Tech Research Corporation	3D Printing	Federal Highway Administration	1093	$171,618	38.4%
Stratasys	3D Printing	IBC Acquisition Services Directorate	1400	$64,000	11.5%
Stratasys	3D Printing	ACC–APG Natick, MA	1723	$125,400	81.5%

Table 6: Top 10 Vendors Based on Available Ceiling Percentage on Individual Additive Manufacturing Prime Contract for Contracts With More Than $50,000 Available Ceiling and Greater Than 30 days Remaining in the Period of Performance

Vendor Name	Additive Manufacturing Technology Group	Contracting Office	Days Remaining on PoP	Total Available Ceiling	Percent Available Ceiling Remaining
Questek Innovations	3D Printing	U.S. Department of the Navy	66	$99,925	40.6%
Northrop Grumman Systems Corporation	Rapid Prototyping	U.S. Department of the Air Force	75	$71,994,999	45.9%
Luna Innovations Incorporated	Cold Spray	DCMA Eastern Region; ACC–RSA Redstone Arsenal, AL	89	$55,997	33.4%
Elementum 3d	3D Printing	U.S. Department of the Navy	101	$99,644	41.6%
Cenmed Enterprises	3D Printing	U.S. Department of the Air Force	136	$83,520	80.0%
Mrl Materials Resources	3D Printing	DLA Contracting Services Office–Philadelphia, PA	168	$3,194,542	66.7%
Lockheed Martin Corporation	Rapid Prototyping	U.S. Department of the Air Force	176	$830,827,627	89.4%
Stratasys	3D Printing	U.S. Department of the Air Force	177	$80,000	80.0%
Rpm Innovations	3D Printing	U.S. Department of the Army	181	$86,800	67.4%
Storagenergy Technologies	Stereolithography	ACC–APG Research Triangle Park, NC	181	$549,982	50.0%

References

Data Journalism Team. (2022, August 28). *Big data innovation among military industry companies has dropped off in the last year*. Army Technology. https://www.army-technology.com/dashboards/patents/big-data-innovation-among-military-industry-companies-has-dropped-off-in-the-last-year/

Katz, J. (2023, April 5). HII gets Navy's green light to expand use of 3D printed parts in shipyards. Breaking Defense. https://breakingdefense.com/2023/04/hii-gets-navys-green-light-to-expand-use-of-3d-printed-parts-in-shipyards/

PANEL 11. ASSESSING CONTRACTING OUTCOMES

Wednesday, May 10, 2023	
3:45 p.m. – 5:00 p.m.	**Chair: John G. (Jerry) McGinn,** Executive Director, Center for Government Contracting, George Mason University ***Antecedents and Consequences of Sourcing Strategy Appropriateness in Public Procurement*** Tim Hawkins, University of North Texas Sean McConville, University of North Texas Jamie Porchia, University of North Texas Suman Niranjan, University of North Texas Lt Col Daniel Finkenstadt, USAF, Naval Postgraduate School ***Analyzing Noise in Contracting Officer Decision-Making*** James Rich, University of Virginia Richard Wahidi, Naval Postgraduate School Rene Rendon, Naval Postgraduate School ***DoD Bid Protests*** David Drabkin, Acquisition Innovation Research Center Chris Yukins, George Washington University

John G. (Jerry) McGinn, Ph.D.— is the Executive Director of the Greg and Camille Baroni Center for Government Contracting in the School of Business at George Mason University. In this role, he has established and is leading the first-of-its-kind university center for research, education and training, and collaboration on issues facing the $500B+ government contracting community. The Center has published over 70 influential reports, white papers, and commentaries on issues such as defense innovation, government contracting, intellectual property, budget reform, industrial resilience, collaboration with allies and partners, and COVID-19. The impact of the Center's work led to recent $7 million naming gift, the largest-ever cash donation to the School of Business. The Center has also been awarded over $3 million in sponsored research and has had hundreds of interviews and media mentions with regional and national print, video, and audio outlets to date.

Dr. Mcginn is also a trusted strategic advisor and board member sought after for his expertise in U.S. industrial policy, security cooperation, supply chain, industrial security, export control, foreign military sales, and industrial base policies. Prior to joining GMU, he served as the senior career official in the Office of Manufacturing and Industrial Base Policy in the Department of Defense, leading efforts to analyze the capabilities and overall health of the defense industrial base, including the 2017-2018 interagency review of the manufacturing and defense industrial base. He also directed hundreds of reviews of high-profile mergers and acquisitions as well as transactions before the Committee on Foreign Investment in the United States.

Previous to DoD, he spent a decade in senior defense industry roles at McGinn Defense Consulting LLC, Deloitte Consulting LLP, QinetiQ North America, and Northrop Grumman. Before industry, he served in DoD as Special Assistant to the Principal Deputy Undersecretary (Policy) and as a political scientist at RAND.

Dr. McGinn is also a widely acclaimed thought leader and sought-after speaker. He has published influential George Mason reports and white papers, RAND monographs, and articles in The Hill, Business Insider, Defense News, Defense One, and other outlets. He has also testified before the U.S. Congress and the UK House of Commons and he has participated in advisory studies for the Homeland Security Advisory Council, the NATO Industrial Advisory Group, the Defense Science Board, and the Professional Services Council. He was the only university recipient of the prestigious Wash100 award in 2021 and 2022.

Dr. McGinn was commissioned into the U.S. Army and served with distinction as an infantry officer and is a graduate of Ranger and Airborne Schools. He has received numerous civilian and military awards and has earned a Ph.D., M.S., and M.A. from Georgetown University as well as a B.S. from the United States Military Academy.

Antecedents and Consequences of Sourcing Strategy Appropriateness in Public Procurement

Timothy G. Hawkins, Ph.D. —is an Associate Professor of Logistics at G. Brint Ryan College of Business. [timothy.hawkins@unt.edu]

Sean McConville—is a Ph.D. Candidate at the G. Brint Ryan College of Business. He is a graduate of the USAF Weapons School and holds a MS in Operations Management from the Air Force Institute of Technology. His research interests include goal and incentive alignment in distribution channels. [sean.mcconville@unt.edu]

Jamie Porchia—is a doctoral student in the Department of Logistics and Operations Management at the University of North Texas. She is also a Federal contracting professional. Her research interests include government procurement, supply chain mapping, supply chain transparency, and technology impacts on the supply chain. [jamie.porchia@unt.edu]

Suman Niranjan, Ph.D. —is an Assistant Professor of Logistics at G. Brint Ryan College of Business. Dr. Niranjan's research interests lie in multi-echelon inventory optimization, additive manufacturing's role in supply chain, supply chain collaboration, process improvement, peer-2-peer asset sharing, distracted driving, and field services. [suman.niranjan@unt.edu]

Lieutenant Colonel Daniel Finkenstadt, USAF—is an active duty contracting officer with over 20 years' experience in federal contracting. He graduated from the University of North Carolina at Chapel Hill with a PhD in marketing and has been an Assistant Professor in the Graduate School of Defense Management at the Naval Postgraduate School since 2020**.** [daniel.finkenstadt@nps.edu]

Abstract

Based on a sample of 350 sourcing professionals, this study examines the antecedents and consequences of sourcing strategy appropriateness in public procurement using structural equation modeling. Requirement criticality, the severity of a bid protest, sufficiency of procurement administrative lead time, and contracting officer authority affect sourcing strategy appropriateness, which, in turn, affects supplier performance and compromised technical evaluation of an offeror's proposal. This research is the first to explore the appropriateness of sourcing strategy and its impact on public management objectives such as value for money. Based on the findings, theoretical and managerial implications are offered.

Keywords: sourcing strategy; public procurement; bid protest

Introduction

Public procurement is growing in importance, practically and theoretically (Flynn & Davis, 2014; Patrucco et al., 2017). Yet, despite being such a large portion of government expenditure (OECD, 2021) with enormous economic importance (Boland & Godsell, 2021; Patrucco et al., 2021), public procurement remains an understudied sector of spending (Josephson et al., 2019). Research attention is needed to understand "the effect of features of the procurement officers' operating environment on contracting outcomes" (Boland & Godsell, 2021).

The sourcing strategy is a means of connecting the operating environment to contracting outcomes (Patrucco et al., 2021). The concept of sourcing strategy is synonymous to acquisition planning (Nash et al., 2021), which is "the process by which the efforts of all personnel responsible for an acquisition are coordinated and integrated through a comprehensive plan for fulfilling the agency need in a timely manner and at a reasonable cost" (Nash et al., 2021, p. 8). Sourcing strategies include objectives, constraints, plans, and goals; they align supply market opportunities and resources with organizational objectives (Trent, 2007).

Sourcing strategy decisions are numerous and complex. They can include: sourcing goals, single versus multiple sourcing (competition), number of suppliers, type of contract, duration of contract, negotiation techniques, source selection method (e.g., trade-off versus lowest price), price or cost analysis, evaluation criteria, financial and term incentives, intellectual property rights, inspection and acceptance methods, supplier performance management methods, payment terms, global versus local sourcing, socio-economic goals, procurement milestones, and source selection team size and composition, to name a few. Given this complexity, sometimes sourcing strategies do not result in the intended outcome (Trent, 2007). For example, the U.S. Air Force's procurement to replace its aging tanker fleet exemplifies a misaligned sourcing strategy. This acquisition suffered numerous errors including: an attempted lease (versus buy), the mis-categorization of the tanker as a "commercial product," the failure to obtain cost and pricing data, and awarding the highly uncertain development work as a firm-fixed price contract as opposed to a fixed-price incentive, or cost-based contract (DoD IG, 2004).

Despite failed sourcing strategies, the issue of sourcing strategy appropriateness has not been empirically examined. Thus, we don't know which factors render a strategy more or less appropriate to the buying situation (Bunn, 1993), and thus, more or less likely to attain desired sourcing outcomes. In the public purchasing setting, we do not know how sourcing teams, through strategy decisions, are able to satisfy objectives such as value for money, fairness and accountability, and efficiency and effectiveness, nor do we know the factors that facilitate or hinder those desired outcomes.

The purpose of this research, therefore, is to explore the antecedents and consequences of sourcing strategy appropriateness pertaining to public procurement. The following research questions are investigated:

1. What factors peculiar to public procurement affect the perceived appropriateness of the sourcing strategy?
2. What are the consequences of sourcing strategy appropriateness?

This research contributes to public procurement literature by offering an empirical investigation of sourcing strategy appropriateness. In doing so, it addresses three strategic objectives of public management: achieving value for money (Wang & Li, 2014), providing accountability and integrity (Bauhr et al., 2020), and contracting efficiently and effectively (Alonso et al., 2015). Often these are competing goals (Wang & Li, 2014), and this research explores factors that can balance this tension while attaining desired sourcing outcomes. From a practical perspective, this research provides public buyers with a framework for understanding the effects of protests and rushed source selections on sourcing strategy appropriateness, and more fully understanding the consequences of sourcing strategies.

The remainder of this research is organized as follows: First, building on agency theory, the relevant literature is reviewed and synthesized into a conceptual model. Secondly, the research design and methodology are explained. Finally, we discuss these research implications and provide suggestions for future research.

Literature Review and Hypothesis Development

Sourcing Strategy Appropriateness

Sourcing strategy appropriateness represents the extent to which a sourcing strategy matches the objectives of the source selection and the buying situation. The FAR asserts that the best-value sourcing strategy "exists on a continuum between cost and non-cost factors" (Part 15-1). Two types of source selection methods, lowest-price technically acceptable (LPTA) and full tradeoff, correspond to the cost and non-cost portions of this continuum, respectively. An LPTA source selection requires the contract be awarded to the offeror that meets minimum technical specifications stated in the request for proposal (RFP) while offering the lowest reasonable price. LPTA selections are appropriate when the procurement is simple and its requirements are well defined (Rumbaugh, 2010). The tradeoff approach allows the buyer to assign value to non-price factors such as specifications and past performance which surpass the minimum requirements and thus, award a contract to an offeror that did not submit the lowest price. The tradeoff method is appropriate when the buyer's requirements have low repeatability, are difficult to define, are complex, or when the services required demand a high level of skill (Rumbaugh, 2010).

In addition to generally being cheaper and faster than a full-tradeoff source selection (Cibinic et al., 2011), LPTA selections are less likely to invite a bid protest (Hawkins et al., 2022). (A bid protest is an objection to the source selection process, which results in the interruption of the sourcing process). There are two reasons for this. First, the complexity of the full tradeoff source selection—and the tedious documentation which accompanies it—leaves more opportunity for error (Hawkins et al., 2016). Secondly, the transparency of the LPTA process facilitates defending against an offeror's protest. These aspects of LPTA, when coupled with the monetary and non-monetary costs associated with bid protests, create incentives for its misuse (Arena et al., 2018; Hawkins et al., 2016).

Manipulating the source selection method isn't the only way that agencies might select a suboptimal sourcing strategy to mitigate the possibility of a bid protest. Awarding a task order only to a firm with an existing contract, leveraging a small business set aside program to award a sole-source contract to a small business, or modifying an existing contract are all avenues for an agency to circumvent a "full and open competition" while obliging the letter of the law, but not its intent. Limiting or avoiding a competition expedites the acquisition but decreases the number of parties involved in it. Since each additional seller represents an opportunity for a misstep (and thus, a protestable error), by limiting or avoiding a competition, the buyer decreases its process risk. It pays a price for doing this, however, as such decisions can render a sourcing strategy less appropriate—that is, less able to connect the buying situation to the sourcing objectives.

Another way in which sourcing strategies may be inappropriate concerns the type of contract selected. Contract type essentially is the means to allocate risk between buyer and seller. For example, The U.S. Air Force awarded a firm-fixed price (FFP) contract for its KC-46 refueling tanker aircraft—a platform that while based on an existing, mature Boeing 767, required a significant amount of development and modification to add a refueling capability. Although a FFP contract helps the buyer mitigate cost growth, the risk associated with the uncertain developmental work was absorbed by Boeing, who substantially underestimated the additional development and testing. Consequently, Boeing lost money on the contract and the Air Force has a tanker that does not meet mission requirements (CRS, 2020).

With sourcing strategy appropriateness as the centerpiece of this research, we present the following conceptual model (Figure 1). We next present an in-depth discussion on the antecedents and consequences of sourcing strategy appropriateness, as well as hypotheses regarding the relationships between these constructs.

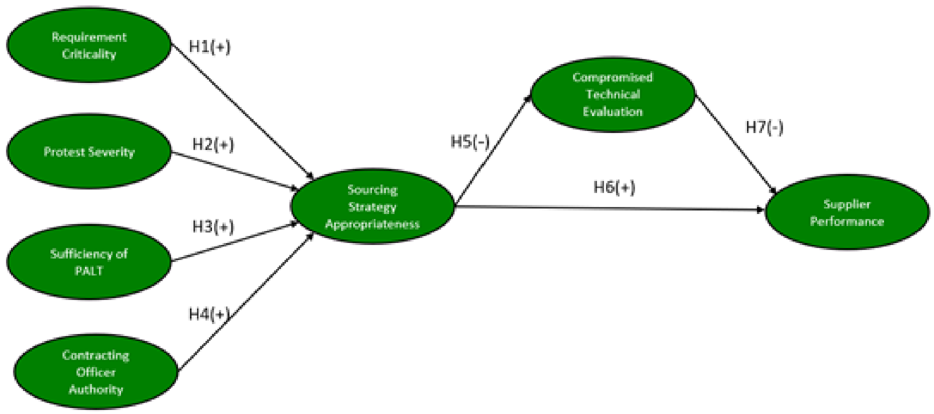


Figure 1. Conceptual Model

Requirement Criticality (RCL)

Kraljic's (1983) seminal purchasing taxonomy evaluates the strategic importance of a purchase along with the market position of the buyer and supplier. It prescribes a decision authority and purchasing strategy as a function of these factors. This framework relegates purchasing decisions pertaining to strategic items (i.e., those items and services critical to function or profitability) to the highest level of an organization. Item availability, substitutability, and the risk of non-delivery are other factors that contribute to the strategic importance of a purchase (Kraljic, 1983). Hence, an item or service that would not otherwise be "critical" takes on a strategic importance when its lack of on-time availability impedes organizational function (e.g., medical gowns during a pandemic, etc.).

While Kraljic (1983) recommends using defensive measures such as in-house investments in R&D to protect the supply of strategic purchases, such measures are not often viable in the public sector. However, the buyer may still protect itself by using an appropriate source selection strategy. Additional defensive measures such as oral presentations, more procurement administrative lead time (PALT), larger and more experienced contracting teams, considerations to the seller's past performance, and full tradeoff vs. LPTA selections may be implemented as part of this strategy.

Rigorous defensive measures are not necessary for non-critical acquisitions. For these items "a defensive posture would be overconservative and costly" (Kraljic, 1983, p. 114). Furthermore, given that the acquisition workforce is strained from decades of underinvestment, inadequate training, and inadequate staffing (Arena et al., 2018; GAO, 2018; Wong et al., 2022), it is unlikely that it will invest its limited resources in acquisitions that do not represent as much of a strategic risk. This yields:

H1: There is a positive relationship between requirement criticality and sourcing strategy appropriateness.

Protest Severity

If the FAR represents a set of behavioral controls designed to promote fairness and transparency in the public purchasing domain, then the bid protest mechanism is the primary means of enforcing these controls. This enforcement mechanism serves several purposes. First, it signals to potential sellers that the government is willing to acknowledge its powerful role in the economy and conduct business as an equitable partner. Additionally, it stands as tacit acknowledgment while the incentives for government purchasing officials are different than they are for purchasing officials in the private sector, the government is willing to ensure that its agents adhere to a process that maximizes the public's interests (Arena et al., 2018; Gordon, 2013; Kovacic, 1995).

Bid protests are costly to the government. If a protest is sustained, an agency may be forced to stop work, reevaluate the proposal, resolicit the contract, and/or reimburse the protestor's legal fees (Rumbaugh, 2010). Between FY 2017 and FY 2021, more than 2,200 protests were filed annually. While only 15% of these protests were sustained, more than 40% of the cases resulted in a corrective action or settlement prior to a formal decision on the claim. This "effectiveness rate" grew as high as 51% in 2020 (Perez, 2021).

A protest need not be filed to result in costs to the buyer. The mere fear of a bid protest increases transaction costs. To guard against potential missteps that might invite a bid protest, agencies assemble larger acquisition teams comprised of more cost analysts, technical evaluators, legal counsel, and consultants. Yet, they do so at the expense of the resource costs associated with these individuals (Hawkins et al., 2022). Organizations establish entire centers of excellence for managing source selections to—in part- reduce protest risks. This corresponds with the agent theoretic view of behavioral control; while monitoring a low-programmable task is expensive (Eisenhardt, 1985; Mitnick, 1975), by installing a monitoring apparatus on the agent (in this case, the larger and more specialized acquisition team) the buyer gains additional information about its agent's activities and can more deftly exercise its control.

Previous research has examined the relationship between the perceived risk of a protest and sourcing strategy from the perspective of Protection Motivation Theory (PMT; Hawkins et al., 2022). PMT postulates that an individual's motivation to respond to a threat is, in part, a function of the probability of the threat taking place and its severity (Floyd et al., 2000). In this framework, the risk of a protest represents the product of the probability of a protest taking place and the severity of that protest. The study did not find a significant relationship between protest risk and source selection method appropriateness (Hawkins et al., 2022).

In streams of research spanning health and behavior (Weinstein, 2000), information technology (Johnston & Warkentin, 2010; Sommestad et al., 2016), and supply chain management (Bode et al., 2022), more modern conceptualizations of PMT either completely discount the role that the probability of a threat plays in driving a behavioral response (Johnston & Warkentin, 2010), or acknowledge a complex interaction between threat probability and threat severity (Bode et al., 2022; Sommestad et al., 2016; Weinstein, 2000). In studying motivation to respond to health hazards, Weinstein (2000) found that a model comprised of only the severity of a threat closely approximated a much more complex, stepwise function that considered additive and multiplicative components of each variable. For this reason, we consider *only the severity of a potential protest* as a motivating factor for an adjustment to the sourcing strategy.

Not all procurements are subject to the same potential protest severity; a delay to a $5 billion, decade-long acquisition of a major weapon system will not bring equal consequence as a delay to a $200,000 facility services contract. From this standpoint, a bid protest represents an interruption to supply, and the perceived severity of that protest is proportional to the strategic impact of that interruption. Furthermore, public purchasing agents must contend with a resource constrained environment. The increasing complexity of acquisitions, coupled with training, recruiting, and staffing shortfalls have resulted in a significant strain on the acquisitions workforce (Arena et al., 2018; GAO, 2018). Consequently, we expect savvy purchasing agents to prioritize the allocation of their limited resources against supply interruptions that represent a greater threat to their principal's interests (Kraljic, 1983). Thus, we propose:

H2: There is a positive relationship between protest severity and sourcing strategy appropriateness.

Procurement Administrative Lead Time (PALT)

Public procurement is wrought with idiosyncrasies that impact the planning timelines for acquisitions. Purchases are planned on an annual budget cycle, but urgent operational needs, delayed budgets, and expiring funds necessitate obtaining financial resources outside of this cycle. Since Congress controls organizational budgets, doing this is difficult (Anton et al., 2020). Additionally, leaders are pressured to show results toward public objectives. Together, these peculiarities often result in an inordinate emphasis on PALT.

Contracting officers need sufficient PALT to properly define and communicate requirements, conduct market research, document evaluation criteria, estimate costs, formulate the sourcing strategy, conduct negotiations, evaluate proposals, and determine tradeoffs among price and non-price factors (Hawkins & Muir, 2014; Hawkins et al., 2016). In the absence of this time, buyers might resort to less appropriate, albeit more expedient sourcing strategies (e.g., LPTA). From an agency-theory perspective, this is akin to the buyer relaxing its behavioral control on the buyer's agent to meet a perceived need for urgency in the acquisition. Notably, while the buyer may have relaxed its behavioral controls on the agent, offerors who seek equity in the sourcing process likely have not. They may, therefore, choose to hold the buyer accountable. This in line with extant research which links decreased sufficiency of planned PALT to an increased fear of bid protests (Hawkins et al., 2016). Thus, we propose:

H3: There is a positive relationship between sufficiency of planned PALT and source selection method appropriateness.

Contracting Officer Authority

Agency theory offers conflicting perspectives on agent autonomy and performance. On one hand, we might expect the performance of an organization to increase as a function of the agent autonomy; more autonomy enables the agent to better act in its principal's interests. Alternatively, since agents are self-interested utility-maximizers, more agent autonomy should coincide with more comprehensive control mechanisms to ensure that agents use their increased autonomy to the principal's benefit. Previous research into agent autonomy and performance yields mixed results that are heavily dependent on the agents and their setting (Yu, 2021).

In the context of this research, "autonomy" represents the ability of the buyer's agent to work towards maximizing the buyer's value, while obliging the FAR's constraints for fairness and transparency. Empowering the contracting officer to conduct negotiations, evaluate proposals, make tradeoff decisions, and frame requirements fosters competition between offerors. However, as other acquisition team members get involved, they exert influence on the process and weaken the authority of the contracting officer. For instance, previous research has anecdotally suggested that legal teams prefer LPTA type source selections (Arena et al., 2018; Hawkins et al., 2016), presumably due to the perception that they are less likely to result in a bid protest and that they are easier to defend should one take place. Institutional pressures to meet timelines might also result in a contracting officer compromising his or her decisions to placate high-level advisors.

Contracting officers' knowledge of the FAR, the market, and the seller provides them with a unique vantage point from which they can leverage the needs of the user with the market environment to determine the most appropriate sourcing strategy. Therefore, we posit that:

H4: There is a positive relationship between contracting officer authority and sourcing strategy appropriateness.

Compromised Technical Evaluation

If the source selection is a means of aligning the buyer's goals with those of the offeror, the technical evaluation is how the buyer judges that fit. Evaluation factors represent key areas of importance to be considered in the source selection decision and must support a meaningful comparison between competing proposals (FAR Part 15-304; Rumbaugh, 2010). Examples include quality, delivery lead time, technical approach, performance risk, key personnel qualifications, and past performance. Evaluators' ability to distinguish between proposals is legally constrained by the evaluation criteria. However, the evaluators that assess a proposal are not always the ones who defined the factors upon which that proposal is being evaluated (Hawkins et al., 2016). Ambiguity in the evaluation criteria leaves room for these evaluators to bring their own interpretation or agenda. For this reason, contracting officers, attorneys, and advisors try to be as meticulous as possible in spelling out that criteria. Frequently, this requires numerous changes to the wording of RFPs, and the need for revision is not apparent until proposals are evaluated. If the buyer is not willing to delay the source selection process to revise the evaluation criteria, then the proposal is advanced with the sub-optimal criteria (Hawkins et al., 2016). Essentially, the technical evaluators are not allowed to appropriately discriminate between proposals; rather, they are constrained by the (sometimes faulty) definitions of evaluation factors in the RFP. Therefore, we posit that:

H5: There is a negative relationship between sourcing strategy appropriateness and compromised technical evaluation.

Supplier Performance

The FAR defines "best value" as "the expected outcome of an acquisition that, in the Government's estimation, provides the greatest overall benefit in response to the requirement" (Part 2-101), while emphasizing that best value "is achieved by balancing the many competing interests in the system. The result is a system which works better and costs less" (Part 1-102). Returning to the conceptualization of the sourcing strategy as the mechanism for connecting the buying environment to contracting outcomes (Patrucco et al., 2021), we recognize the sourcing strategy as the primary means for balancing the competing interests in the public purchasing environment (i.e., the seller's interest in maximizing its utility, the need for fairness, transparency, and judicious use of the public's resources) with the buyer's best value outcomes. More appropriate sourcing strategies will maintain equity in the public purchasing system while allowing the buyer's agent to identify the most competitive sellers. Therefore, we expect to see more appropriate sourcing strategies associated with higher supplier performance:

H6: There is a positive relationship between sourcing strategy appropriateness and supplier performance.

The technical evaluation is an important part of the value creation process. With it, the buyer assesses how well the seller understands the buyer's desired objectives (Rumbaugh, 2010). It allows the buyer to identify the strengths, weaknesses, and deficiencies of each offer. The sourcing strategy could, hypothetically, motivate supplier performance on its own. However, the buyer's inability to make meaningful distinctions between proposals would leave it to the mercy of the operating environment. Therefore, we propose:

H7: There is a negative relationship between compromised technical evaluation and supplier performance.

Methodology

Survey Design

Structural equation modeling was used in conjunction with cross-sectional survey data to test the hypotheses. Data was reused from that of a prior study (Calandruccio et al., 2014; Hawkins et al., 2016). Existing scales were used exclusively. All scales which measured latent constructs were 7-point Likert-type scales, except for protest severity. The items for this scale were scored between -5 (completely undesirable) and +5 (completely desirable) and converted to an 11-point Likert-type scale. Scales for sourcing strategy appropriateness, requirement criticality, protest severity, contracting officer authority, compromised technical evaluation, and supplier performance were taken from Hawkins et al. (2016). Scales for sufficiency of planned PALT were taken from Hawkins and Muir (2014).

Sourcing strategy appropriateness measured the extent to which the survey respondents perceived that the sourcing strategy matched the objectives of the source selection and the contracting environment. Protest severity measured the perceived impact that would accompany a (pre or post-award) bid protest, in terms of time, cost, and workload. Compromised technical evaluation measured the degree to which technical evaluators felt inhibited by the language of their own technical evaluation. Supplier performance measured the level to which a purchased good or service matched the contractual requirements. Sufficiency of planned PALT was a 3-measure scale which assessed whether a contracting officer felt that he or she had sufficient time to conduct the source selection.

Sample

Data was collected via an online survey. The unit of analysis was a government source selection. We maximized response rate by using Dillman’s (2000) internet survey design methodology. The population for this study was 3,882 U.S. civilian and military contracting officers who had executed a FAR Part 15–based formal source selection for one military department. A military sourcing context offers a large pool of potential respondents, a large quantity of contracts covering a variety of goods and services, and a wide range of contract scope (e.g., dollars). Participation was solicited via email. There were 661 responses received. Yet, 311 of these contained missing or invalid data and were deleted. This left 350 usable responses, with a total response rate of 17% and final complete response rate of 9%. While this complete response rate is low, it is consistent with other supply chain and public procurement research (Finkenstadt, 2020; Gimenez & Sierra, 2013). Additionally, given the difficulties of accessing the public procurement population (Finkenstadt, 2020; Saastamoinen et al., 2017) a low response rate is not surprising. Usable responses covered contracts over 113 product and service codes, and spanned a breadth of contracting experience, qualification, and contract type, lending evidence of generalizability.

Control Variables

Two control variables were used to account for expected significant effects on source selection method appropriateness: contract value and the contracting officer’s source selection experience. Documentation, team size, and evaluation rigor increases with dollar value, which should help to fit an appropriate sourcing strategy (Hawkins et al., 2016). The more experience a contracting officer has, the less of a concern there should be for an inappropriate source selection method due to a lack of knowledge; this individual has accumulated more formal techniques for managing and mitigating bid protests, and thus, should be less inclined to adjust the appropriateness of the sourcing strategy to do so. Furthermore, contracting officer experience is shown to have an empirical, positive relationship with compliance to contracting policy (Hawkins & Muir, 2014).

Reliability and Validity

We used Armstrong and Overton’s (1977) approach to test for non-response bias. First, we categorized surveys into three groups, based on their time of receipt. We tested for differences in means of three of the latent constructs and two of the demographic variables. These tests failed to yield any statistically significant differences, thereby indicating a lack of response bias. To mitigate selection bias, respondents were instructed to answer the survey with respect to their most recently completed formal source selection. ProMax Kaiser rotation was used during exploratory factor analysis to reduce 38 survey items to 30 items on seven latent factors. Composite reliabilities were used to assess the reliability of these constructs (Fornell & Larcker, 1981). These values may be observed in Table 1. All scales exceeded Nunnally’s (1994) prescribed threshold of 0.7. Construct validity was assessed using average variance extracted (AVE). All constructs exceeded the 0.50 threshold, demonstrating convergent validity (Hair et al., 2010). No covariance approached the square root of AVE for any construct, indicating discriminant validity (Fornell & Larcker, 1981).

Table 1. Construct Validity

Items	Mean	SD	Factor Loadings	AVE	CR	Items	Mean	SD	Factor Loadings	AVE	CR
RCL2	5.903	1.191	0.912			COATH1	5.274	2.382	0.891		
RCL3	5.791	1.285	0.901	0.777	.913	COATH2	5.431	2.102	0.942		
RCL4	5.766	1.299	0.829			COATH3	5.6	1.794	0.848	0.624	0.889
PSEV1	8.56	8.155	0.789			COATH4	3.843	2.892	0.587		
PSEV2	9.466	5.249	0.832	0.627	0.834	COATH6	4.897	3.087	0.611		
PSEV4	8.491	8.216	0.752			QEF1	5.334	2.503	0.534		
PALT1	3.623	2.03	0.809			QEF2	3.497	2.93	0.843	0.539	0.819
PALT2	3.357	1.79	0.831	0.706	0.878	QEF3	3.366	2.643	0.85		
PALT3	3.831	1.99	0.879			QEF6	3.474	3.032	0.661		
SSA1	5.509	1.724	0.861			SP1	4.686	1.878	0.909		
SSA2	5.606	1.542	0.828			SP2	4.737	1.737	0.926		
SSA3	5.169	2.34	0.781	0.667	0.923	SP3	4.737	1.737	0.925		
SSA4	5.757	1.664	0.789			SP4	4.757	1.692	0.88	0.822	0.970
SSA5	5.517	1.787	0.803			SP5	4.574	1.585	0.929		
SSA6	5.506	1.941	0.836			SP6	4.529	1.466	0.833		

	RCL	PSEV	PALT	SSA	COATH	QEF	SP
RCL	**0.88**						
PSEV	0.20**	**0.79**					
PALT	-0.04	-0.18**	**0.84**				
SSA	0.28***	0.14*	0.26***	**0.82**			
COATH	0.23***	0.06	0.24***	0.40***	**0.79**		
QEF	-0.03	-0.06	-0.31***	-0.20***	-0.27***	**0.73**	
SP	0.18**	-0.02	0.2***	0.28***	0.21†***	-0.23***	**0.91**

Notes: RCL= requirement criticality, PSEV=protest severity, PALT= procurement administrative lead time, SSA=sourcing strategy appropriateness, COATH=contracting officer authority, QEF=compromised technical evaluation, SP=supplier performance

(1) Diagonal entries represent the square root of average variance extracted (AVE). (2) Off-diagonal entries represent correlations. (3) ***Significant at p< 0.001; **Significant at p< 0.01; *Significant at p<0.05,

We performed confirmatory factor analysis in MPlus, version 8.8. All latent factors were allowed to covary freely. In the measurement model, all loadings were significant at ($p \leq 0.05$). No Heywood cases were observed. No standardized loadings exceeded 1.0. The measurement model demonstrated acceptable fit (Table 2).

Table 2. Measurement and Structural Models

Model	χ^2 (dof)	TLI	CFI	RMSEA	SRMR
Measurement	829.7 (414)	0.933	0.941	0.054	0.075
Structural	959.0 (483)	0.926	0.932	0.053	0.067

Path	β	Supported? (Y/N)
H1(+) RCL → SSA	0.284**	Y
H2(+) PSEV → SSA	0.086*	Y
H3(+) PALT → SSA	0.221**	Y
H4(+) COAUTH → SSA	0.289**	Y
H5(-) SSA → QEF	-0.089*	Y
H6(+) SSA → SP	0.264**	Y
H7(-) QEF → SP	-0.483*	Y

Notes: RCL= requirement criticality, PSEV=protest severity, PALT= procurement administrative lead time, SSA=sourcing strategy appropriateness, COATH=contracting officer authority, QEF=compromised technical evaluation, SP=supplier performance
* significant at $p < 0.05$
** significant at $p < 0.01$

Results

A structural equation model (SEM) was fit to the data (Table 2). Our model shows reasonable fit. CFI and TLI are well above the recommended standard of 0.90 (Bagozzi & Yi, 1988), RMSEA meets the target cutoff value of less than 0.06, and SRMR is well below the recommended maximum threshold of 0.09 (Hu & Bentler, 1999). Table 2 shows the results of the hypotheses tested from the structural model. All seven hypotheses tested significant at $p < 0.05$.

Discussion

Public procurement is a rapidly expanding, albeit understudied field (Flynn & Davis, 2014; Josephson et al., 2019; Patrucco et al., 2017). The scope of its magnitude, complexity, stakeholders, and its prevalence of relatively recent high-profile shortcomings emphasize the importance of understanding how aspects of this domain coalesce into desired outcomes. The objective of this research was to explore how factors peculiar to public procurement affect the appropriateness of the sourcing strategy, and to examine the consequences of sourcing strategy appropriateness. Agency theory was a useful theoretical lens for exploring these issues. To examine sourcing strategy more closely, we developed a structural equation model of environmental factors, antecedents, and consequences pertinent to public procurement. This model was tested and found to exhibit good fit. Our findings have several theoretical and managerial implications.

Managerial Implications

Acquisition teams need sufficient authority, time, and risk acceptance from their organizations to develop an appropriate sourcing strategy. These teams must understand the importance of well-defined evaluation criteria and best-value determination criteria prior to the buying decision. Once a source selection decision is made, the strengths and shortcomings in these antecedents are manifest in the delivered product or service and the buyer must bear the consequences.

An obvious implication is that buying teams should not assume that their chosen sourcing strategies are entirely appropriate. They could document limitations, accepted risks, and assumptions in the acquisition plans and source selection plans, and document the reasons. Then, document the potential effects on key outcomes such as the mission, efficiency, supplier performance (public value), and transparency and fairness. This would yield data on sourcing strategies that could be analyzed over time to improve the buying organization's performance.

Of the four antecedents to sourcing strategy appropriateness, contracting officer authority was the strongest predictor. While this is comparable to the influence of requirement criticality, it is important to recognize that the buyer has little say in whether it needs to purchase strategically important requirements, but it does have the option of empowering the contracting officer in its doctrinal role as the lead of its purchasing teams. While this individual should entertain inputs from advisors, the contracting officer's judgement should not be subservient to this counsel. One means to increase contracting officer authority is to raise the dollar thresholds that invoke additional oversight.

As the sufficiency of PALT is a strong predictor of sourcing strategy appropriateness, sourcing teams should avoid rushing source selection timelines. Doing so may not only adversely affect fairness and transparency in the source selection process but could diminish public value by hindering supplier performance. Realistic milestones should be set and procurements should commence far enough in advance to allow adequate time.

Requirement criticality is more than three times as strong of a predictor than protest severity is on sourcing strategy appropriateness. This implies that, to obtain the "best value" contract, the buyer should focus more resources on appropriately sourcing critical requirements than it should on defending against bid protests.

While sourcing strategy appropriateness had a strong positive effect on supplier performance, this effect was eclipsed by the negative effect of a compromised technical evaluation. Since appropriate sourcing strategies are negatively associated with compromised technical evaluations, the effect of an inappropriate sourcing strategy is twofold; not only does it preclude the buyer from obtaining the best performance level, but it inhibits the buyer from being able to assess the value of the offer.

Limitations and Future Research

While this study provided several unique insights, it is not without limitations. Given that this sample came solely from one military department, additional research is needed to assess the generalizability of our findings. Additionally, the response rate for this survey was low. It is nevertheless consistent with extant trends in business literature (Melnyk et al., 2010) and may be attributable to the survey length. For the sake of parsimony, this research examined only two key outcome of sourcing strategy appropriateness—public value and contracting effectively (as indicated by supplier performance). We incorporated another key aspect—fairness and transparency—but only indirectly via the bid protest mechanism. Future research should expand on this by measuring procedural and distributive justice constructs from the perspectives of the buyer's and the offeror's agents. This would enable researchers to examine the alignment between statutory mechanisms for fairness in public purchasing strategy setting, and ex-post perceptions of the efficacy of that strategy.

Critics of agency theory assail its foundational assumption that agents are self-interested utility maximizers (Davis et al., 1997; Hernandez, 2012; Jensen & Meckling, 1994; Shapiro, 2005). Specifically, they point to its inability to explain circumstances in which the goals of the agent and principal are inherently aligned (Davis et al., 1997). Stewardship theory is a natural counterpoint to agency theory, as a steward's interests are inherently aligned with those of its principal (Davis et al., 1997; Hernandez, 2012). Recent research into agent-principal relationships presents agency and stewardship as opposing ends across a spectrum of behaviors (Bjurstrøm, 2021; Caers et al., 2006; Grøn et al., 2022; Mills et al., 2021; Schillemans, 2013; Schillemans & Bjurstrøm, 2020; Van Puyvelde et al., 2016; Yu, 2021). An interesting avenue for further study would be examining stewardship behaviors in contracting officers as a transposable mechanism for the (costly) behavior-based controls in public contracting system. For instance, could prospective contracting officers be screened in advance for stewardship behaviors? What would this cost? Might we expect these agents to use more appropriate sourcing strategies than their low stewardship counterparts? Would it be reasonable to expect these agents to use more appropriate sourcing strategies in resource constrained environments?

Declaration of Interest Statement

This material is based upon work supported by the Acquisition Research Program under Grant No. HQ00341810007. The views expressed in written materials or publications, and/or made by speakers, moderators, and presenters, do not necessarily reflect the official policies of the Department of Defense nor does mention of trade names, commercial practices, or organizations imply endorsement by the U.S. Government.

References

Adams, J. (1996). Principals and agents, colonialists and company men: The decay of colonial control in the Dutch East Indies. *Source, 61*(1) 12–28.

Alonso, J. M., Clifton, J., & Díaz-Fuentes, D. (2015). Did new public management matter? An empirical analysis of the outsourcing and decentralization effects on public sector size. *Public Management Review*, *17*(5), 643–660. https://doi.org/10.1080/14719037.2013.822532

Anton, P. S., Tannehill, B., McKeon, J., Goirigolzarri, B., Holliday, M. A., Lorell, M. A., & Younossi, O. (2020). *Strategies for acquisition agility: Approaches for speeding delivery of defense capabilities* (pp. 1–148). RAND. Research and Development Corporation.

Arena, M. V., Persons, B., Blickstein, I., Chenoweth, M. E., Lee, G. T., Luckey, D., & Schendt, A. (2018). *Assessing bid protests of U.S. Department of Defense procurements: Identifying issues, trends, and drivers* (pp. 1–92). RAND Corporation.

Armstrong, J. S., & Overton, T. S. (1977). Estimating nonresponsive bias. *Journal of Marketing Research*, *XIV*, 396–402.

Bagozzi, R. P., & Yi, Y. (1988). On the evaluation of structural equation models. *Journal of the Academy of Marketing Science*, *16*(1), 74–94.

Bauhr, M., Czibik, Á., Fine Licht, J., & Fazekas, M. (2020). Lights on the shadows of public procurement: Transparency as an antidote to corruption. *Governance*, *33*(3), 495–523. https://doi.org/10.1111/gove.12432

Bjurstrøm, K. H. (2021). How interagency coordination is affected by agency policy autonomy. *Public Management Review*, *23*(3), 397–421. https://doi.org/10.1080/14719037.2019.1679236

Bode, C., Macdonald, J. R., & Merath, M. (2022). Supply disruptions and protection motivation: Why some managers act proactively (and others don't). *Journal of Business Logistics*, *43*(1), 92–115. https://doi.org/10.1111/jbl.12293

Boland, M., & Godsell, D. (2021). Bureaucratic discretion and contracting outcomes. *Accounting, Organizations and Society*, *88*. https://doi.org/10.1016/j.aos.2020.101173

Caers, R., Du Bois, C., Jegers, M., De Gieter, S., Schepers, C., & Pepermans, R. (2006). Principal-agent relationships on the stewardship-agency axis. *Nonprofit Management and Leadership*, *17*(1), 25–47. https://doi.org/10.1002/nml.129
Calandruccio, J., Combs, B., & Colbert, S., (2014). *What are the effects of protest fear?* [NPS-CM-14-019]. Acquisition Research Program, Naval Postgraduate School.
Carlson, D. S., & Kacmar, K. M. (2000). *Work-family conflict in the organization: Do life role values make a difference?*
Cibinic, J., Nash, R. C., & Yukins, C. R. (2011). *Contract administration and personnel. Formation of government contracts.* George Washington University School of Law, Government Contracts Program.
CRS. (2020). *Air Force KC-46A Pegasus tanker aircraft program* (pp. 1–18).
Davis, J. H., David Schoorman, F., & Donaldson, L. (1997). Toward a stewardship theory of management. *Source: The Academy of Management Review*, *22*(1), 20–47.
Dillman, D. A. (2000). *Mail and internet surveys: The tailored design method.* John Wiley and Sons, Inc.
DoD IG. (2004). *Acquisition of the Boeing KC-767A* (D-2004-064; pp. i–144). US Department of Defense.
Eisenhardt, K. M. (1985). *Control: Organizational and economic approaches* (Vol. 31, Issue 2, pp. 134–149). https://about.jstor.org/terms
Eisenhardt, K. M. (1989). *Agency theory: An assessment and review* (Vol. 14, Issue 1, pp. 57–74). Academy of Management Review.
Fayezi, S., O'Loughlin, A., & Zutshi, A. (2012). Agency theory and supply chain management: A structured literature review. *Supply Chain Management*, *17*(5), 556–570. https://doi.org/10.1108/13598541211258618
FAR, Ch. 1 (2022).
Finkenstadt, D. J. (2020). *Essays on perceived service quality and perceived value in business-to-government knowledge-based services*. https://doi.org/10.17615/50cn-4579
Floyd, D. L., Prentice-Dunn, S., & Rogers, R. W. (2000). A meta-analysis of research on protection motivation theory. *Journal of Applied Psychology*, *30*(2), 407–429.
Flynn, A., & Davis, P. (2014). Theory in public procurement research. *Journal of Public Procurement*, *14*(2), 139–180.
Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, *XVIII*, 39–50.
GAO. (2018). *Federal acquisitions: Congress and the executive branch have taken steps to address key issues, but challenges endure* (pp. 1–57) [GAO-18-627].
Gimenez, C., & Sierra, V. (2013). Sustainable supply chains: Governance mechanisms to greening suppliers. *Journal of Business Ethics*, *116*(1), 189–203. https://doi.org/10.1007/s10551-012-1458-4
Gordon, D. I. (2013). *Bid protests: The costs are real, but the benefits outweigh them*.
Grøn, C. H., Opstrup, N., Salomonsen, H. H., & Villadsen, A. R. (2022). Managing in all the right directions? The relationship between public managers' perceived autonomy and leading upwards, sidewards, outwards, and downwards. *Public Management Review*, 1–23. https://doi.org/10.1080/14719037.2022.2126882
Hair, J. F. Jr., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis*. Prentice Hall.
Hawkins & Muir. (2014). An cxploration of knowledge-based factors affecting procurement compliance. *Journal of Public Procurement*, *14*(1), 1–32.
Hawkins, T. G., Gravier, M. J., & Niranjan, S. (2022). Predicting bid protests: What should sourcing teams (not) do? *Journal of Business and Industrial Marketing*, *37*(4), 859–873. https://doi.org/10.1108/JBIM-06-2021-0284
Hawkins, T., Gravier, M., & Yoder, E.C. (2016). Federal bid protests: Is the tail wagging the dog? *Journal of Public Procurement*, *16*(2), 152–190. https://doi.org/10.1108/jopp-16-02-2016-b001
Hernandez, M. (2012). Toward an understanding of the psychology of stewardship. *Academy of Management Review*, *37*(2), 172–193. https://doi.org/10.5465/amr.2010.0363
Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria verses new alternatives. *Structural Equation Modelling*, *6*(1), 1–55.
Jensen, M. C., & Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, *3*(4), 305–360.
Jensen, M. C., & Meckling, W. H. (1994). The nature of man. *Journal of Applied Corporate Finance*, *7*(2), 4–19.
Johnston, A. C., & Warkentin, M. (2010). Fear appeals and information security behaviors: An empirical study. *MIS Quarterly*, *34*(3), 549–566.
Josephson, B. W., Lee, J. Y., Mariadoss, B. J., & Johnson, J. L. (2019). Uncle Sam rising: Performance implications of business-to-government relationships. *Journal of Marketing*, *83*(1), 51–72. https://doi.org/10.1177/0022242918814254
Kovacic, W. E. (1995). Procurement reform and the choice of forum in bid protest disputes. *The Administrative Law Journal*, *9*, 461–513.
Kraljic, P. (1983). Purchasing must become supply management. *Harvard Business Review*, *September*, 109–117.

Liff, R., & Andersson, T. (2021). Experts' contribution to strategy when strategy is absent. A case study of quality experts in hospitals. *Public Management Review*, *23*(9), 1377–1397. https://doi.org/10.1080/14719037.2020.1751256

MacKenzie, S. B., Podsakoff, P. M., & Jarvis, C. B. (2005). The problem of measurement model misspecification in behavioral and organizational research and some recommended solutions. *Journal of Applied Psychology*, *90*(4), 710–730. https://doi.org/10.1037/0021-9010.90.4.710

Melnyk, S. A., Davis, E. W., Spekman, R. E., & Sandor, J. (2010). Outcome-driven supply chains. *MIT Sloan Management Review*, *51221*.

Mills, D. E., Bradley, L., & Keast, R. (2021). NPG and stewardship theory: Remedies for NPM privatization prescriptions. *Public Management Review*, *23*(4), 501–522. https://doi.org/10.1080/14719037.2019.1695883

Mitnick, B. M. (1975). The theory of agency: The policing "paradox" and regulatory behavior. *Public Choice*, *24*(winter), 27–42.

Nash, R. C., O'Brien-DeBakey, Schooner, S. L., & Edwards, V. J. (2021). *The government contracts reference book: A comprehensive guide to the language of procurement*. Wolters Kluwer.

Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric theory*. MGraw-Hill.

Pashev, K. V. (2011). Corruption and accession: Evidence from public procurement in Bulgaria. *Public Management Review*, *13*(3), 409–432. https://doi.org/10.1080/14719037.2011.553270

Patrucco, A. S., Agasisti, T., & Glas, A. H. (2021). Structuring public Procurement in local governments: The effect of centralization, standardization and digitalization on performance. *Public Performance and Management Review*, *44*(3), 630–656. https://doi.org/10.1080/15309576.2020.1851267

Patrucco, A. S., Luzzini, D., & Ronchi, S. (2017). Research perspectives on public procurement: content analysis of 14 years of publications in the Journal of Public Procurement. *Journal of Public Procurement*, *17*(2), 229–269.

Perez, E. E. (2021). *Bid protest statistics for fiscal years 2017–2021* (Vol. 1, Issue 1, p. 6). GAO.

Rumbaugh, M. G. (2010). *Understanding government contract source selection*. Management Concepts.

Saastamoinen, J., Reijonen, H., & Tammi, T. (2017). The role of training in dismantling barriers to SME participation in public procurement. *Journal of Public Procurement*, *17*(1), 1–30.

Schillemans, T. (2013). Moving beyond the clash of interests: On stewardship theory and the relationships between central government departments and public agencies. *Public Management Review*, *15*(4), 541–562. https://doi.org/10.1080/14719037.2012.691008

Schillemans, T., & Bjurstrøm, K. H. (2020). Trust and verification: Balancing agency and stewardship theory in the governance of agencies. *International Public Management Journal*, *23*(5), 650–676. https://doi.org/10.1080/10967494.2018.1553807

Shapiro, S. P. (2005). Agency theory. *Annual Review of Sociology*, *31*, 263–284. https://doi.org/10.1146/annurev.soc.31.041304.122159

Sommestad, T., Karlzén, H., Nilsson, P., & Hallberg, J. (2016). An empirical test of the perceived relationship between risk and the constituents severity and probability. *Information and Computer Security*, *24*(2), 194–204. https://doi.org/10.1108/ICS-01-2016-0004

Trent, R. J. (2007). *Strategic supply management: Creating the next source of competitive advantage*. J. Ross Publishing.

Van Puyvelde, S., Caers, R., Du Bois, C., & Jegers, M. (2016). Managerial objectives and the governance of public and non-profit organizations. *Public Management Review*, *18*(2), 221–237. https://doi.org/10.1080/14719037.2014.969760

Voorn, B., van Genugten, M., & van Thiel, S. (2019). Multiple principals, multiple problems: Implications for effective governance and a research agenda for joint service delivery. *Public Administration*, *97*(3), 671–685. https://doi.org/10.1111/padm.12587

Wang, C., & Li, X. (2014). Centralizing public procurement in China: Task environment and organizational structure. *Public Management Review*, *16*(6), 900–921. https://doi.org/10.1080/14719037.2013.770056

Weinstein, N. D. (2000). Perceived probability, perceived severity, and health-protective behavior. *Health Psychology*, *19*(1), 65–74. https://doi.org/10.1037/0278-6133.19.1.65

Williams, L. J., Cote, J. A., & Buckley, M. R. (1989). Lack of method variance in self-reported affect and perceptions at work: Reality or artifact? *American Psychological Association*, *74*(3), 462–468.

Wong, J. P., Younossi, O., LaCoste, C. K., Antón, P. S., Vick, A., Weichenberg, G., Whitmore, T. C., United States. Department of the Air Force, Project Air Force (U.S.). Resource Management Program, & Rand Corporation. (2022). *Improving defense acquisition insights from three decades of RAND research* (pp. 1–119). The RAND Corporation.

Yu, J. (2021). Agency autonomy, public service motivation, and organizational performance. *Public Management Review*. https://doi.org/10.1080/14719037.2021.1980290

Zsidisin, G. A., & Smith, M. E. (2005). Managing supply risk with early supplier involvement: A case study and research propositions. *Journal of Supply Chain Management*, *41*(4), 44–57. https://doi.org/10.1111/j.1745-493X.2005.04104005.x

Appendix A: Measurement Scales

Label	Item
Contracting Officer Authority	
CoAUTH 1	I was empowered to make required decisions throughout the source selection.
CoAUTH 2	I was trusted that the decisions I made throughout the source selection would be appropriate
CoAUTH 3	My management supported me on the decisions that I made during the source selection
CoAUTH 4	If I disagreed to an aspect of a legal opinion/review, I had the latitude to deviate from it
CoAUTH 5*#	I had to change documents generated during the source selection to correspond with reviewers
CoAUTH 6*	I might as well not have a warrant since my decisions were overridden by reviewers
Sufficiency of PALT	
PALT 1*	The milestones for awarding this contract were too aggressive
PALT 2	I was not rushed to award this contract
PALT 3	I had sufficient time to get this contract awarded
Compromised Technical Evaluation	
QEF 1	At least once, a technical evaluator was required to change the wording of his or her technical evaluations
QEF 2	At least one technical evaluator expressed concern about not being able to say what needs to be said during a technical evaluation
QEF 3	At least one technical evaluator was concerned that the constraints imposed on his or her evaluations impeded the evaluator’s ability to write a meaningful evaluation
QEF 4#	The technical evaluators believed that the quality of their evaluations could not have been better
QEF 5#	If there were no federal acquisition regulations, no source selection policy, and no threat of a bid protest, the quality of the technical evaluations would have been the same
QEF 6	Upon evaluation of proposals, at least one technical evaluation expressed a need to change at least one evaluation criterion or its definition
Supplier Performance	
CP 1	Product/service quality per specifications
CP 2	Delivery performance per specifications
CP 3	Product/service consistently meets customer expectations
CP 4	Responsiveness to requests for changes
CP 5	Required service and/or technical support
CP 6	Non-conformance rate
CP 7	Overall performance
Protest Severity†	

PR 1	Increased costs to settle a terminated contract(s)
PR 2	Time delay to the mission
PR 3#	Embarrassment/shame
PR 4	Increase in workload to resolve the protest
PR 5#	Career repercussions for making a mistake or omission that caused a bid protest
Sourcing Strategy Appropriateness	
SSA 1	Our acquisition strategy was the best means to source our requirement
SSA 2	Our acquisition strategy was the best means to achieve our acquisition objectives
SSA 3	It would have been difficult to achieve our goals without the use of our acquisition strategy
SSA 4	The selection method we used (e. g., LPTA, full-tradeoff, or PPT) was the most appropriate for this requirement
SSA 5	Our acquisition strategy ensured we selected the best offeror
SSA 6	Our acquisition strategy provided the best fit to the buying situation (e.g., complexity, dollar value, acquisition objectives, contract length, performance risk, criticality to the mission, availability of supply, time available to award a contract, etc.).
Requirement Criticality	
RCl 1#	This requirement was important for the good operation of our customer's organization
RCl 2	This requirement supported a core competency of our customer's organization
RCl 3	Compared to other purchases from our customer, this requirement was important
RCl 4*	An unsuccessful outcome of the RFP would have had only minor consequences to our customer
RCl 5#	As a portion of the customer's total annual spending amount, the dollar value of this requirement was high.

All scales 7 point Likert except where noted
#item was discarded during Exploratory Factor analysis
*item was reverse coded
† Initially coded -5 (completely undesirable) to +5 (completely desirable). Recoded to 12 point Likert

Analyzing Noise in Contracting Officer Decision-Making

James Rich (MPA/PhD)—is the Program Coordinator for the Procurement and Contract Management graduate certificate at the University of Virginia and a Senior Advisor at Dawson & Associates. He is a retired federal employee with 35 years of contract management experience to include serving as the contracting officer for the Pentagon Renovation, Army Residential Communities Initiative and enterprise level A-76 studies. Rich is active in the NCMA, serving as a mentor for the Contract Management Leadership Development Program and a member of the Board of Advisors. [Jjr7j@virginia.edu]

Captain Richard Wahidi—is an active-duty U.S. Air Force Contracting Officer assigned to Wright-Patterson Air Force Base, OH, where he currently serves as an Executive Officer to the Air Force Installation Contracting Center senior contracting official. Wahidi has 9 years of contracting experience, having executed installation and mission support requirements unique to the National Capital Region as well as systems engineering requirements in support of the F-15 Eagle and various airborne electronic warfare sub-systems. He is a 2022 Naval Postgraduate School graduate and a 2021 graduate of the National Contract Management Association's Contract Management Leadership Development Program. [richard.wahidi@nps.edu]

Dr. Rene G. Rendon—is an Associate Professor at the Naval Postgraduate School, where he teaches graduate defense acquisition and contract management courses. He completed a career as an Acquisition Contracting Officer in the USAF, serving as a contracting officer for weapon systems such as the Peacekeeper ICBM, Maverick Missile, and the F-22 Raptor. He also served as a Contracting Squadron Commander, Director of Contracting for the Space Based Infrared Satellite program and the Evolved Expendable Launch Vehicle program. Rendon has published in the Journal of Public Procurement, the Journal of Contract Management, and the Journal of Purchasing and Supply Management. [rgrendon@nps.edu]

Abstract

The Federal Acquisition Regulation (FAR) states that contracting officers have authority to enter into, administer, or terminate contracts and make related determinations and findings (FAR 1.602-1, 2023). In performing these duties, contracting officers make decisions necessary for effective contract management, ensuring compliance with the terms of the contract, and safeguarding the interests of the United States in its contractual relationships. These contracting decisions are based on contracting officers' knowledge and experience in contract management principles more so than by government rigid rules or checklists. In making these decisions, contracting officers are allowed wide latitude to exercise business judgment (FAR 1.602-2, 2023). This wide latitude may result in variability in these decisions, often referred to as "noise" (Kahneman et al., 2021). An agency does not expect individual contracting officer decisions to be entirely free of noise, but when aggregated, often noise is far above the level that agency leaders would consider acceptable. The problem in government contracting is that managers do not account for noise in contracting decision making. The purpose of this research is to investigate the level of noise in contracting officer decisions.

Introduction

The federal government obligates billions of dollars on contracts every year for the procurement of supplies and services (USAspending, 2023). These contracts are planned, awarded, and administered in accordance with statutory and regulatory requirements by formally designated contracting officers. The Federal Acquisition Regulation states that contracting officers have the authority to enter into, administer, or terminate contracts and make related determinations and findings (FAR 1.602-1, 2023). In the performance of these duties, contracting officers make decisions necessary for effective contract management, ensuring compliance with the terms of the contract (FAR 1.602-2, 2023) and safeguarding the public interests of the United States in its contractual relationships (Cohen & Eimicke, 2008). Although federal government contracts must comply with statutory and regulatory requirements, many contracting officer decisions are based on contracting officers' knowledge and experience in contract management more so than by government rigid rules or checklists (FAR 1.603-2, 2023). In making these decisions, contracting officers are allowed wide latitude to exercise sound business judgment (FAR 1.602-2, 2023). Contracting officers exercising business judgement in decision-making may result in variability in these decisions. That is, different contracting officers may arrive at different decisions when encountered with the identical situation. In addition, the same contracting officer may arrive at a different decision, given different situational factors (day of the week, time of day, mood, …). This inconsistency of judgment or variability in decisions is referred to as "noise" (Kahneman et al., 2021). Although an agency does not expect contracting officer decisions to be entirely free of noise, it should be concerned if the level of noise is above the level that organizational leaders would consider acceptable. Just as business managers are unreliable decision makers (Kahneman et al., 2016), the problem in government contracting is that contracting officers may also be unreliable decision makers.

Background

Although there has been past research on decision-making and variability in decisions (see, for example, Yoon et al., 2017), the concept of noise and bias in decision-making can be attributed to research conducted by Kahneman et al. in 2016. In their *Harvard Business Review* article, "Noise: How to Overcome the High, Hidden Cost of Inconsistent Decision Making," Kahneman et al. (2016) argue that although organizational leaders expect to see consistency in the decisions of their managers that require judgment, "judgments can vary a great deal from one individual to the next, even when people are in the same role and supposedly following the same guidelines." This variability in decision-making can be caused by irrelevant factors (e.g., mood, weather, disposition), which can change one person's decisions from one occasion to another occasion. Kahneman et al. (2016) state that this variability in decision-making is called noise, and it is surprisingly costly to companies, which are usually completely unaware of it. Their research states that variability in decision-making can result in "successful companies to lose substantial amounts of money without realizing it" (Kahneman et al., 2016). In follow-on research by Kahneman et al. published in *Noise: A Flaw in Human Judgement* in 2021, the researchers broached new ways of explaining why people make bad judgments. Their research examined decades of data on noise, and its profound impact on how we make decisions, and provided compelling reasons to identify and manage its effects. Most of all, their research revealed that organizational noise is more prevalent, persistent, and pernicious than we may think (Kahneman et al., 2021).

Research Purpose and Methodology

The purpose of this exploratory research is to investigate the level of variability (noise) in contracting officer decisions. Our primary research question is "To what extent does variability in decisions (noise) exist in the contracting officer/contract manager workforce?" The methodology for this research included the deployment of a Qualtrics-based survey to a small sample population of contract management professionals. The survey consisted of 11 short scenario questions requiring a contracting decision. Each scenario included multiple options, with one option to be selected by the respondents. The scenarios and questions are the type that there is no one correct answer. The survey was voluntary and anonymous. The survey also included demographic questions. An analysis was conducted of the respondents' selected options to the scenarios by determining the level of variability (noise) in the respondents' answers.

Population Demographics

The number of survey responses ranged from 40 to 43 responses. We intentionally did not target a specific demographic (e.g., buyer versus seller, government versus industry) and the assessment instrument was deployed in forums that are populated largely by members of the National Contract Management Association (NCMA; 2023). The NCMA (2023) is the premier professional association for the contract management profession and consists of members from both the buying and selling communities in all employment sectors.

In terms of experience, 50% of the survey population had 20 or more years of experience in the contract management field. Seven percent had 4–8 years of experience, and no respondent had fewer than 3 years of experience. Overall, the population had a substantial level of experience in the CM profession. Forty-two percent (42%) of respondents held a contracting officer warrant. That statistic likely understates the level of decision-making authority respondents had, as approximately 50% of the sample are currently working in the private sector and may never have worked for a public sector agency as a warranted contracting officer.

In terms of professional certifications, 70% of respondents held one or more NCMA certifications. That number appears high, but the sample, as mentioned, was weighted toward contract management professionals that were active in NCMA-related activities or forums. Over half of the population (53%) were Defense Acquisition Workforce Improvement Act (DAWIA) or Federal Acquisition Certification-Contracting (FAC-C) certified. We did not attempt to measure respondents who may be enrolled in the new DAU Back to Basics single entry-level certification program.

Findings

While the survey data generated in this study is not amenable to in-depth quantitative analysis, it does inform us about how decision makers differ when faced with a choice of solutions to common contracting scenarios. No one would expect a survey where all the respondents chose the same solutions. But most of us have a feel for how much variance in decision making is acceptable, particularly if we believe there is one correct answer. Below, we offer analysis of the responses to a few scenarios simply to offer an example of one way to interpret the data.

In Scenario 1, the respondent is asked to review the facts about a contractor claim related to a specification interpretation and decide to dismiss the claim, pay the contractor what they ask, or decide the claim has merit but would require a negotiated settlement. Almost 70% of the respondents said they would negotiate the claim with the contractor, but 28% said they would dismiss the claim outright. If you were a manager who felt strongly that the facts in the case warranted negotiation with the contractor, you may be somewhat surprised that 28% of the contracting professionals surveyed would summarily dismiss the claim. While there is no guarantee that a contractor will pursue further legal remedies when a claim is dismissed, the potential for a lengthy appeal process is a distinct possibility.

Scenario 3 posed a situation where the contract schedule was impacted by unusually severe weather. The severity of the weather is not in doubt as the amount of rainfall during a critical month on the schedule was three times greater than the historical average for that month. Respondents were asked if they would offer a no cost time extension or pay the contractor additional monies to accelerate the effort and complete the contract on schedule. Although there is no way to tell which alternative is correct (we don't have information on what a delay would cost the government), we do know that accelerating the contractor will cost $300,000. What is interesting in this finding is the distribution of responses which suggests that most respondents (58%) felt a no cost 60-day time extension was the best choice for the government. But a sizable minority of respondents (42%) valued maintaining the original schedule, even though it would cost the project an additional $300,000. One argument for the variability in decisions is that 58% of the respondents prioritized cost over time and 42% felt that saving schedule was more important than cost. Yet, the two groups had the same initial data. This is a noisy decision, but it is probably not occasion noise. When we are faced with a time–cost trade-off we all bring a conceptual framework to the decision process, and that framework likely reflects a bias toward either time or cost. (Note that in formal source selections, the trade-off may be between cost technical approach or past performance, but the argument for implicit bias would still remain.) This may be a simple case of professionals who disagree based on their interpretation of the facts.

In Scenario 10, an offeror submits a paper copy and an electronic copy of their proposal in accordance with the solicitation instructions to offerors. The paper copy of the proposal is timely, but the electronic submission is corrupted or otherwise unreadable. How should the government treat that offeror? Approximately 5% of respondents favored disqualification of the offer, thus the decision to either allow a corrected version to be submitted or simply evaluate the paper copy strongly suggests the contractor's proposal will be evaluated without penalty. But the breakdown of the proposed government reaction is revealing. While 57% of respondents would require that a corrected electronic version of the proposal be submitted, a significant number of respondents, 38%, would simply evaluate the paper copy. Given that the electronic copy of the offer is a requirement of the solicitation, a decision to simply dismiss the requirement is disconcerting. We have to assume that there was a reason an electronic version of the proposal was required and waiving the need for the electronic version raises questions about why the requirement was initially stated in the solicitation. If the offeror were to win the contract and the waiver become public knowledge, are there grounds for a post-award protest?

Implications of Findings

Although this was an exploratory investigation on noise in contracting officer/manager decision-making with a very limited population sample, our preliminary findings indicate that perhaps there is some variability (noise) in the decisions made by our respondents. Although most contracting professionals, especially government contracting officers, complete a structured and regulated contracts training program to be selected as warranted contracting officers or contract managers (FAR 1.603-2, 2023), there appears to still be some level of variability in contracting decisions. As previously stated, contracting officers/managers make decisions based on judgement and interpretation of contracting policies and statutes. Because many contracting decisions are based on judgment and policy interpretation, it would not be expected to have no noise or zero variability in contracting officer decisions. Some variability in decisions is expected in contracting officers' use of judgment and policy interpretation. The problem facing organizational leadership may be more of acknowledging that noise or variability in contracting decisions exists, having an appreciation for the potential causes of variability (e.g., types of biases), and determining how to limit the extent of unwarranted or unwanted noise in contracting decisions.

Conclusion

The purpose of this research was to investigate the level of noise in contracting officer decisions. Based on our research findings, the wide latitude given to contracting officers may be resulting in noise in contracting decisions. The importance of noise is only revealed when organizations take the necessary steps to isolate decisions and compare them objectively and, ideally, from a number of different perspectives. As we have observed, noise is not always obvious or observable on the surface of a contract management organization's day to day operations. But it is likely present, and it may have a significant, if silent, impact on the myriad of decisions that contracting professionals make in the performance of their duties. While you may not be able to identify and quantify noise across the organization, you could probably examine discreet decision processes for evidence of variability. If the variance is unwarranted and unwanted, you have a manageable problem to mediate, and you will have a new lens to view the decision-making mechanics of your organization.

References

Cohen & Eimicke. (2008). *The responsible contract manager: Protecting the public interest in an outsourced world*.

Federal Acquisition Regulation (2023). https://www.acquisition.gov/browse/index/far

Kahneman, D., Rosenfield, A. M., Gandhi, L., & Blaser, T. (2016). *Noise: How to overcome the high hidden cost of inconsistent decision making*. https://hbr.org/2016/10/noise

Kahneman, D., Sibony, O., & Sunstein, C. R. (2021). *Noise: A flaw in human judgment* (1st ed.). Little, Brown Spark.

National Contract Management Association. (2023). *Contract management body of knowledge* (7th ed.).

USAspending. (2023). https://www.usaspending.gov/

Yoon, S., Vo, K., & Venkatraman, V. (2017). Variability in decision strategies across description-based and experience-based decision making. *Journal of Behavioral Decision Making*, *30*(4), 951–963. https://doi.org/10.1002/bdm.2009

DoD Bid Protests

Dave Drabkin—is the Chair, Procurement Round Table. Formerly, Chair of the Advisory Panel on Streamlining and Codifying Acquisition Regulations (Section 809 Panel); Director, Government Contracts, Dixon Hughes Goodman, LLP (DHG); Director Corporate Contracts and Director Acquisition Policy, Northrop Grumman Corporation; Deputy Chief Acquisition Officer and Senior Procurement Executive, U.S. GSA; Deputy Program Manager Pentagon Renovation Office; Assistant Deputy Under Secretary of Defense (Acquisition Reform); Associate Counsel for Procurement, DLA; Chief Counsel DCMR-NY; and Army Judge Advocate. Member SARA Panel and GSA MAS Panel. [ddrabkin@stevens.edu]

Chris Yukins—is the Professor of Government Contracts Law and Co-Director, Government Procurement Law Program, The George Washington University Law School. Of counsel, Arnold & Porter LLP. Council Member, ABA Public Contract Law Section. Faculty Advisor, Public Contract Law Journal. Advisor, U.S. Delegation to Working Group, UNCITRAL Model Procurement Law. Former Trial Attorney, U.S. Department of Justice. [cyukins@law.gwu.edu]

Abstract

Improvements to the Agency Level Bid Protest Process in the DoD could lead to greater participation by companies in the marketplace, thus resulting in delivery of greater capability to the warfighter inside the turn of near peer competitors and nonstate actors. This paper addresses Congressional questions concerning the DoD Bid Protest process, in particular the Agency Level Bid Protest Process. It is based upon a report to Congress, DoD Bid Protests, September 2022 (n.d.). The Report to Congress was based on literature research, data analysis, and surveys and interviews of DoD, GAO, and U.S. Court of Federal Claims personnel.

Introduction

In the words of the Section 809 Panel, "*At the end of the day, it's all about delivering capability to the warfighter inside the turn of our Nation's near peer competitors and nonstate actors.*"

This paper is taken from the report to Congress, *DoD Bid Protests, September 2022* (Report; n.d.)). This paper, in addressing questions posed by Congress on the DoD's Bid Protest Process, offers eight suggestions for improving the DoD Bid Protest Process to improve the DoD's ability to deliver capability to the warfighter inside the turn of its near peer competitors and nonstate actors and to provide greater transparency into the bid protest process to allow Senior Procurement Executives greater visibility into issues impacting the procurement process.

Background

Section 886 of the conference report that accompanied the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2021 directed the Defense Department to launch a new study of bid protests. The conference report directed a study of bid protests to follow up on an earlier congressionally mandated 2018 RAND report, *Assessing Bid Protests of U.S. Department of Defense Procurements.* The conferees noted that they "continue to support efforts to improve the handling of bid protests," and directed the "Secretary of Defense to undertake a study through the . . . Acquisition Innovation Research [Center] . . . to examine elements . . . for which the RAND National Defense Research Institute was unable to obtain full and complete data during its analysis."

Section 885 of the conference report that accompanied the NDAA for FY2017 called for a study (undertaken by RAND) on "the extent and manner in which the bid protest system affects or is perceived to affect . . . the development of a procurement to avoid protests rather than improve acquisition" and for detailed statistical data on bid protests.

The 2017 RAND study concluded:

- Although there had been an increase in the number of bid protests filed, their numbers remained relatively small—less than .3% of contracts awarded.
- While DoD personnel "were concerned that the process incentivized protests, potentially preventing the timely award of contracts," the private sector "viewed bid protests as a way to hold the government accountable" and as a way to "provide information on how the contract award or source selection was made."
- The DoD should improve post-award debriefings to stem bid protests, should maintain the timelines for resolving normal protests, and should sustain its standards for task-and-delivery order (T&D) protests.
- There should be an expedited process to resolve protests regarding the smallest contracts and changes to reduce protests by small businesses.
- The DoD should consider additional data and recordkeeping of protests to facilitate future studies and improve procurement policy decision-making.

The RAND study did not conduct an analysis of data relating to protests' effects on procurement, protests' costs to the government, or of protest trends, in part because the DoD did not collect the data at the time, and RAND did not undertake to identify and collect the data.

Responding to perceived areas for inquiry identified from the RAND report, in a more recent conference report Congress called for a new study to address:

- The rate at which protesters are awarded the contract that was the subject of the bid protest;
- The time it takes the DoD to implement corrective actions after a ruling or decision, the percentage of those corrective actions that are subsequently protested, and the outcomes of those protests;
- Analysis of the time spent at each phase of the procurement process attempting to prevent a protest, addressing a protest, or taking corrective action in response to a protest, including the efficacy of any actions attempted to prevent the occurrence of a protest; and
- Analysis of the number and disposition of protests filed within the DoD.

The conferees also emphasized "the potential benefits of a robust agency-level bid protest process" and called for the study to evaluate the following for agency-level bid protests: "prevalence, timeliness, outcomes, availability, and reliability of data on protest activities; consistency of protest processes among the military Services; and any other challenges that affect the expediency of such [agency-level bid] protest processes." The conferees said that the study "should review existing law, the Federal Acquisition Regulation, and agency policies and procedures," and should "solicit input from across the DOD and industry stakeholders."

The conference report called attention to a recent academic study on agency-level bid protests led by Professor Christopher Yukins that the Administrative Conference of the United States (ACUS) commissioned as part of an initiative to reform agency-level protests. The conferees directed the Defense Department "to consider these recommendations" from the ACUS-sponsored study "among those it might make to improve the expediency, timeliness, transparency, and consistency of agency-level bid protests."

Bid Protests in the Federal Government

A bid protest is a formal objection to an acquisition decision. The Federal Acquisition Regulation (FAR) establishes a range of grounds under which vendors can file a protest:

1) A Solicitation or other request by an agency for offers for a contract for the procurement of property or services.
2) The cancellation of the solicitation or other request.
3) An award or proposed award of the contract.
4) A termination or cancellation of an award of the contract, if the written objection contains an allegation that the termination or cancellation is based in whole or in part on improprieties concerning the award of the contract.

There is no corollary to the bid protest process in the commercial market. Although bid protest systems are well-established in nations around the world, and are called for by the United Nations Convention Against Corruption, not all State or local governments have adopted a "protest" process. The American Bar Association (ABA) has developed a model procurement code that includes a "protest" process. The history of the federal bid protest system provides a backdrop for the federal procurement system generally and reflects Congress' intent to create an integrated acquisition system with oversight, accountability, and potential remedies for government contractors.

The federal government has in place many laws designed to "ensure that federal procurements are conducted fairly," including provisions which allow vendors to seek review of a contracting official's decision through a bid protest. "The right to seek independent review of award decisions is something that distinguishes federal contracting from the commercial sector." The Government Accounting Office (now the Government Accountability Office [GAO]) heard the first bid protest in the U.S. system roughly 60 years before Congress first explicitly granted any forum the statutory authority to do so. The current system is supposed to resolve protests quickly and fairly without disrupting the procurement process. Currently there are three jurisdictions where a protest against a procurement action may be filed: (1) the contracting agency, (2) the GAO, (3) the U.S. Court of Federal Claims (COFC).

A vendor in the U.S. federal procurement system has multiple options when it objects to a federal agency's procurement decision; it can:

1) Decide to take no action, and accept the decision of the agency;
2) Protest to the agency;
3) File a protest with the GAO; or
4) File a protest before COFC.

If an agency denies a protest, the contractor may seek relief at the GAO or COFC; if the GAO denies a protest, the protester may renew its protest at COFC. There is no administrative exhaustion requirement, but there are rules of preclusion limiting protests; for example, a vendor may not simultaneously protest the same matter at both COFC and the GAO. As Figure 1 reflects, protesters may appeal a decision by COFC in the U.S. Court of Appeals for the Federal Circuit (Federal Circuit), and from there to the U.S. Supreme Court.

Elements of an Effective Bid Protest System

The history of the U.S. bid protest system stretches over approximately 100 years. During that time, however, Congress has not defined the purpose of a bid protest. More specifically, Congress has not confirmed whether it intends that protests provide a remedy for a disappointed offeror or that protests serve as a management tool for government oversight of the federal procurement system. To address that gap, the Section 809 Panel proposed that Congress state the bid protest system's purpose in order to provide a standard against which to measure the system's effectiveness.

The precise measures of an "effective" system remain largely unaddressed, but the factors determining an effective bid protest system start with the goals of both the procurement system and the system's process for adjudicating bid protests.

General Goals of the Procurement System

Competition is the heart of the procurement system, and thus, Congress emphasized facilitating "full and open" competition in the Competition in Contracting Act (CICA), the same legislation which codified the GAO's authority to hear bid protests. When the government maximizes full and open competition, the government naturally receives the best value from the procurement, but efficiency is essential to *maximize* full and open competition. At the same time, public procurement, as a function of government, must accommodate a wide array of socioeconomic goals. Taken in sum, an efficient acquisition system is one that reduces costs and time to delivery while ensuring users' satisfaction, and an effective bid protest system is one that furthers those goals. Uniform regulations, such as the FAR, can improve efficiency by reducing costs for officials and competitors.

While "full and open" competition is indeed the heart of the procurement system, and bid protests advance competition by assuring bidders of a fair and lawful system, the bid protest system also functions as an anti-corruption tool. In this role, an effective system ensures that government procurements transcend bribery, favoritism, and unethical behavior. The government's notification system, where agencies post procurement opportunities, awards, and other activities, maintain the system's integrity and transparency. The same system, the System for Award Management (SAM), hosts contractor qualification information, including lists of suspended and debarred parties.

Thus, the goals of the government procurement system generally include: (1) competition; (2) integrity; (3) transparency; (4) efficiency; (5) customer satisfaction; (6) best value; (7) socioeconomic opportunity; (8) risk avoidance; and (9) uniformity. The systems that define the procurement process—including the bid protest system—are in place to promote and advance these goals.

Goals of the Protest System

The Section 809 Panel suggested that the goal of the protest regime is to ensure an efficient and transparent procurement system. In general, the protest process should balance "the desire to exhaustively investigate any complaint" and "the need to let the procurement process move forward." Moreover, the process must produce "fair and equitable decisions based on consideration of all parties' arguments on a fully developed record." In other words, if a key purpose of the protest system is to provide a remedy to an unsuccessful offeror, the protest system should strive to provide meaningful reviews and remedies to the protester, while moving the procurement forward with speed and fairness.

The standard of integrity for any system that uses public funding should be higher than mere fairness. As such, the government strives to ensure that a process allocating funds adheres to the highest degree of integrity and transparency, and the protest system, as an instrument of that process, should "deter and punish ineptitude, sloth, or corruption of public purchasing officials."

The elements discussed above, taken in sum, suggest that the efficacy of a bid protest system turns on the following elements:

Table 1. Elements of an Effective Bid Protest System

Element	Description
Integration	A simplified and integrated process is more efficient and requires fewer resources, saving protesters from expending resources determining which rules to follow or at which forums to present their claims. Without integrated rules and forums, effectiveness of review may suffer.
Meaningful Review	Meaningful review depends on an adequate scope of standing (i.e., who may protest) and an independent arbiter. Bid protester standing is not uniform across the U.S. system. Independent review ensures the integrity and strength of the bid protest system because, without an independent review, protesters could be hesitant to bring bid challenges.
Transparen cy	Vendors and other interested parties should be able to access and understand the processes and rules under which contracts are awarded. Governments can do this by publishing information such as decisions, regulations, and procedures in a readily accessible public place. Because the bid protest system is largely self-enforced, making the relevant documents used during each procurement decision public increases the effectiveness in the bid protest system.
Speed	Public procurement is a process that needs to move forward with speed. Resolution of protests, therefore, should also move quickly to avoid interruptions to fulfilling the requiring activities' needs.
Meaningful Remedies	The primary remedy of any bid protest is the correction of the government's error and the opportunity for the protester to form a contract with the government, but other meaningful relief also promotes overall effectiveness of bid protest system. Depending on the governing law, remedies may include damages and attorney's fees, as well as a "stay" provision and other necessary protections for the protesting bidder, to promote effectiveness of the overall procurement system.

History of Legislative Action on Federal Bid Protests

For an in-depth history of Federal Bid Protests, see the Report.

Opportunities to Improve Agency-Level Protests

Agency-level bid protests, which allow vendors and agencies to resolve their differences quickly and efficiently, are a lost opportunity for most agencies. Although agency-level bid protests are typically much less disruptive than protests brought at the other fora, vendors seldom resort to them because many perceive them as biased, opaque, and procedurally risky. But agency-level bid protests, when effective, afford protesters a quick and inexpensive forum where even the smallest business can challenge an agency's procurement errors. If well-administered, agency-level protests can dramatically reduce the time and attention agencies must devote to bid protests, for they allow agencies to handle procurement failures internally, quickly, and with minimum disruption. Making agency-level bid protests an effective alternative means of resolving vendor challenges would benefit federal agencies and bidders by reducing the costs and delays normally caused by bid protests.

The earlier ACUS study recommended that agencies initially hear all bid protests in an administrative forum independent of the agency conducting the procurement—a recommendation overtaken by President Clinton's executive order of that same year, which called for rules formalizing agency-level bid protests. The 1995 ACUS recommendations also suggested that the Federal Circuit be assigned all appeals from administrative bid protest decisions. The complementary ACUS recommendation that all administrative authority over bid protests be consolidated in one forum was included in an early version of the defense authorization act for fiscal year 1996, which would have consolidated that authority in the GAO. The final version of the defense authorization bill, however, dropped that reform. Finally, the earlier ACUS recommendation urged Congress to mandate empirical assessments of the effects of the bid protest process, for example, between agencies. An ACUS study from 2019–2020 revisited the potential role that agency-level protests can play in the procurement system and provided an updated overview of the current agency-level bid protest systems.

The Protest Forum

The 2019–2020 ACUS study relied heavily upon an analytical structure for bid protests put forward by Daniel Gordon in 2006. The first element of Gordon's analytical structure goes to where in the government (or here, where in the agency) the bid protest function is located. Agency-level protests' origins lie in the contracting officials' inherent authority to review and correct their own procurement decisions. In fact, the model law developed through the United Nations (and relied upon internationally) explicitly treats these types of protests as a form of self-correction by contracting agencies. FAR 33.103 allows vendors to seek that type of review by the contracting officer herself, but also allows for a higher-level review. This section focuses on the latter question—the higher-level review—and draws on emerging agency practices to assess how that might best be structured.

Current Practices Regarding Placement of Agency Protests

Currently agencies have significant discretion to decide where the agency-level protest function is located and how it should be structured. FAR 33.103 states that: (1) agency-level protests will be resolved by the contracting officer or an official designated to receive protests; (2) interested parties may request an independent review of their protests at a level above the contracting officer, by officials designated by the agency; and (3) if practicable, an official who conducts an independent review should not have had previous personal involvement in the procurement. Agencies' varying approaches show that these basic requirements can be met in a number of ways.

When an agency allows the protester to choose between filing a protest with the contracting officer or an independent review authority, the two choices generally are treated as alternatives and protesters are prohibited from appealing internally from the agency decision. An exception is the Department of Veterans Affairs, which allows for the appeal of a contracting officer's decision within the agency. Additionally, when an agency allows a choice of agency forum, generally if the protest is silent on the protester's choice of forum, then by default the contracting officer will decide the protest.

Vendors will sometimes choose to protest directly to the contracting officer rather than a higher agency authority in order to avoid embarrassing the contracting officer (vendors often have long-standing relationships with the contracting officers, as agency customers), or to encourage the contracting officer to focus on and resolve a recurring issue in the procurements she oversees (again, because both the contracting officer and the vendor are repeat players in a cyclical procurement process).

Another potential reason *not* to file an agency-level protest with a contracting officer is that if the contracting officer denies the protest, an appeal for higher-level review within the agency (if available) will not suspend the GAO's timeliness requirements. Any protest to the GAO must be filed within 10 days of knowledge of initial adverse agency action, and an adverse decision by a contracting officer is an initial adverse agency action. Once the contracting officer's decision is issued, the vendor may be forced to choose between appealing to a higher level in the agency or preserving a timely protest at the GAO. Worse yet, it may be unclear whether the agency has taken adverse action, for (as discussed below) under the GAO's bid protest regulations, any vendor knowledge of adverse agency action, actual or constructive, may trigger the GAO filing deadline. Because protesting to the contracting officer may put the vendor into this uncertain tactical "box," many vendors will simply forgo an agency-level protest.

Scope of Agency-Level Bid Protest Jurisdiction

The next element in Gordon's analysis looked at the question of subject matter jurisdiction, and specifically at how broadly that jurisdiction swept for a bid protest function. As the discussion below reflects, agencies have taken divergent and ad hoc approaches to defining the scope of jurisdiction in their agency-level bid protest functions. Because most limits on jurisdiction are at the margins of the procurement system (one agency, for example, bars agency-level protests regarding subcontracts), this might not seem a critical issue for reform. But because new methods of procurement are emerging which may fall outside the authority of the traditional bid protest venues (the GAO and COFC), agencies may wish to take an expansive approach to agency-level bid protest jurisdiction to ensure oversight and accountability (and thus contain agencies' risks) regarding new procurement methods.

Current Practices Regarding Jurisdiction

The FAR is silent on the limits of the jurisdiction of agency-level protests, and some agencies (discussed below) have exercised their discretion to set their own limits on jurisdiction. When asked in interviews for the ACUS report whether the jurisdiction of agency-level bid protests should be limited, some agency counsel said no because they considered agency-level protests as tools to resolve problems which logically could emerge in any aspect of an agency's procurement functions.

Agencies' ad hoc approaches to jurisdiction in agency-level protests have created a patchwork of rules, for example regarding task-and delivery-order protests under IDIQ contracts. That patchwork of rules undercuts the effectiveness of agency-level bid protests for agencies, for the sometimes conflicting jurisdictional rules create risks and uncertainties for vendors, who are less likely to turn to agency-level bid protests as a result.

Some agencies, such as the United States Agency for International Development (USAID) and the VA, bar agency-level protests on issues of contract administration, small business status, and responsibility determinations. The Marine Corps has argued that only the GAO has jurisdiction over task or delivery order protests, and the Army Materiel Command (AMC) refuses to hear agency-level protests under "the GAO's $25 million jurisdictional threshold to protests of task and delivery orders issued under [DOD] procurements." In contrast, at least one other agency has decided an agency-level protest on a task or delivery order where the GAO apparently lacked bid protest jurisdiction.

Standing to Protest

The FAR requires that the protester in an agency-level protest be an interested party in the procurement. The FAR defines an interested party as "an actual or prospective offeror whose direct economic interest would be affected by the award of a contract or by the failure to award a contract." Agencies generally adopt this definition to define standing to bring agency-level bid protests, with a few agencies incorporating language from the definition into the agencies' FAR supplements. Some agencies also explicitly prohibit subcontractors from filing protests.

Time Limits at the Forum

As Daniel Gordon explained, there are actually two separate time constraints to be considered in ordering a bid protest system: how soon a vendor must file its protest, and how long the deciding forum has to decide the protest. Both time limits relate back to a core concern for any bid protest system: how to minimize the disruption to the procurement cycle—here, the time required to complete that cycle—caused by a protest system. Both issues of time are acutely important to agency-level bid protests, which must accommodate users' demands that the services and goods they need be purchased as rapidly as possible.

Uniform Deadlines for Filing, Varying Deadlines for Concluding Protest Review

The FAR's most basic time limit on vendors—the deadline for filing an agency-level bid protest—has not been altered by the agencies in implementing the basic rule. In important ways, FAR 33.103 follows the same timeliness requirements as apply at the GAO: agency-level protests must be filed at the agency within 10 days after contract award or within 5 days after a debriefing date offered to the protester under a timely debriefing request, whichever is later. After the agency initially decides the protest, if an internal "appeal" is available, the vendor must decide if it will appeal the agency-level protest within the agency, which the protester generally must do within 10 days. Alternatively, the protester may file a protest anew with the GAO, which the vendor also must do within 10 days.

Unlike the deadlines for filing protests (which have been borrowed largely intact from the GAO process), the timelines for deciding agency-level protests have been reworked by many agencies over the years. Under the FAR, the basic rule is that agencies must make their best efforts to resolve agency-level protests within 35 days after a party files a protest. Different agencies have adopted different deadlines for resolving agency-level bid protests, ranging from the basic rule's maximum 35 days to as few as 20 days. Some agencies also require the deciding official to meet other milestones, such as conducting a scheduling conference with the parties within 5 days after the protest is filed.

Sufficiency of Evidence to Reach Its Decision

The next issue in the analysis, regarding the record in the protest, breaks into two parts. The first part looks at the standards for compiling the administrative record for the agency's consideration when deciding an agency-level protest. The second part considers what access a protester should have to that record.

Agency Record for Protest

The current FAR rule provides almost no guidance on what record is to be compiled by the contracting agency in order to resolve an agency-level protest. FAR 4.803 includes an extensive list of the materials to be included in a contract file, but those materials stretch beyond the documents relevant to contract award and include many documents that would be irrelevant to a bid protest. GAO Bid Protest Regulation 21.3 calls for the following documents to be included with the agency's report to the GAO on a bid protest: "all relevant documents . . . including, as appropriate: the bid or proposal submitted by the protester; the bid or proposal of the firm which is being considered for award, or whose bid or proposal is being protested; all evaluation documents; the solicitation, including the specifications; the abstract of bids or offers; and any other relevant documents." A more detailed list of documents potentially relevant to a bid protest is included in Appendix C to the Rules of the U.S. Court of Federal Claims (RCFC), which, in paragraph 22, list nearly two dozen categories of documents that, if relevant to a bid protest before the court, should be compiled by the agency. Those documents range from the source selection plan to records of prior proceedings. The court's detailed list of the documents that might be considered in a bid protest highlight the gaps in the FAR provision governing agency-level protests—specifically, the failure of FAR 33.103 to specify the documents that should be before the agency in deciding an agency-level protest.

Access to the Agency Record

Even if a complete record is compiled for review during the agency-level bid protest, there is no current mechanism for sharing that record with the protester—which is a major reason cited by vendors' counsel for not using agency-level bid protests. In a protest before the GAO or COFC, protesters' counsel normally will gain access to a substantial administrative record, usually under a protective order. A protester typically will use that administrative record to support and explain its protest grounds, and a protester often will identify additional protest grounds in the record. Not having access to that record is a severe disadvantage in an agency-level protest, but it may not be practically possible, absent very significant changes to the agency-level bid protest process or other advances in open government initiatives, to afford protesters access to sensitive materials in the agency procurement record.

Remedies to Define the Record and Grant Protesters Access

The current FAR rule leaves agencies wide discretion in deciding what to include in the administrative record that will be considered by the deciding official. FAR 33.103(d) calls for the protester to submit "relevant documents" with the protest itself, but beyond that, the rule says nothing about what documents (or other evidence) the deciding official should consider.

Some agencies have developed their own procedures for gathering and considering the record during an agency-level protest. The agency-level protest rule does not allow the protester discovery from the administrative record, and some agencies call for the deciding official to rule upon the protest based upon the documents provided by the protester and the agency. Other agencies, such as the Department of Labor, encourage scheduling conferences to establish plans for creating an appropriate record for the agency-level protest. Still other agencies, such as the Department of Energy (DOE), require the contracting officer to create a protest report to be used by an official at a level above the contracting officer.

Although FAR 33.103 says that to the "extent permitted by law and regulation, the parties may exchange relevant information," nothing in the rule mandates that the agency provide the protester with relevant record information. In fact, as agency counsel explained in interviews, agencies generally do not provide protesters with any documents or other evidence in an agency-level protest. None of the agency counsel interviewed said that agency documents are regularly provided to protesters in the agency-level protest process. That leaves vendors with very few ready sources for documentation to support agency-level protests. Probably the most important documentation that a vendor will receive, then, is the debriefing that offerors (both successful and not) are entitled to request from the awarding agency.

An ideal reviewing official doesn't need to supervise the contract officer; in fact, it is better if the independent reviewer does not have a connection to the protested procurement. At a debriefing, the agency will tell the offeror of the weaknesses in the offeror's proposal and answer relevant questions as to whether the source selection procedure conformed to the solicitation and applicable law. Debriefings may be done in writing, orally, or by any other acceptable method.

In recent years, the scope of debriefings has expanded for larger procurements. Section 818 of the NDAA for FY2018 provided for enhanced debriefings at the DoD. Section 818 required the DoD to respond to additional questions from disappointed offerors, and the DoD has implemented that requirement by a change to the Defense Federal Acquisition Regulation Supplement (DFARS). Section 818 also called for Defense agencies to produce a redacted version of the source selection determination in awards worth over $100 million and to make the same disclosure in smaller procurements ($10–100 million) if asked to do so by a small business or a nontraditional contractor.

In principle, information from the administrative record should also be available to a disappointed offeror through the Freedom of Information Act (FOIA) and under expanding requirements regarding "open government" (i.e., ready public access to and use of government data). In practical terms, however, it is unlikely an agency will respond to a FOIA request from a vendor in time to support a protest, and federal implementation of open government obligations remains in its infancy.

Putting the Procurement on Hold

The next element of Gordon's analysis looks at whether the procurement is "put on hold" pending the agency-level protest. While this seems an administrative nicety, it is at the heart of a healthy protest system in the U.S. government. Unlike bid challenge procedures in some other countries, the U.S. federal bid protest system generally does not award expectancy damages (i.e., lost profits) to protesters. Although successful protesters may be able to recover some or all of their bid-and-proposal costs and attorney fees from the agency, the prospect of those damages typically does not drive the protest decision—vendors instead protest in order to have an opportunity to compete fairly for the contract. Keeping that contract award available as a "bounty" for protesters by staying award or contract performance during the protest is thus essential to the health of the federal protest system. Agencies, for their part, have a collateral but important shared interest in the stay: If award or performance proceeds during the protest and ultimately the protest succeeds in reopening the competition, an agency may bear damages and transaction costs in undoing the original award and performance. Making the stay effective is, therefore, in the interests of both agencies and vendors.

Current Practices: An Uncertain Stay

Currently, FAR 33.103 requires that if an agency-level protest is timely filed, the contract will not be awarded (if the protest is before award) or performance will be stayed (if post- award). To preserve agencies' operational flexibility, the agency may "override" the stay; most agencies require the head of the contracting activity to make the determination when urgent and compelling reasons justify such a decision.

Even if the agency will not override it, the stay of award can present a tactically difficult question for the vendor. If the vendor is considering a pre-award agency-level protest (typically to the terms of the solicitation), the stay presents a less acute problem because even if the agency-level protest is denied, if due to the protest the bidding deadline (and thus the protest deadline) has been extended by the agency (which is often the case), the vendor can file anew at the GAO before that extended deadline to maintain the stay on the procurement. An agency-level bid protest thus may allow a vendor to preserve the status quo (to stay the contract performance) by bringing a new GAO protest before the newly extended bidding deadline.

The same is not true for post-award protests, however, for after award, the statutory deadline for obtaining a stay at the GAO runs from the award decision or the debriefing which follows award. An agency-level protest does not affect the deadline for filing at the GAO to trigger an automatic statutory stay. If an agency denies an agency-level protest brought after award, by that time the statutory deadline for filing a GAO protest to trigger an automatic stay almost certainly will have passed. The agency may agree informally to a temporary suspension, but that raises substantial uncertainty and risk for the vendor. The vendor's only recourse–if the contract is to be preserved with some legal certainty—will be to file suit in COFC and seek an injunction during the pendency of the protest. The court, however, may refuse to enjoin the agency.

According to vendors' counsel, the lack of a durable stay makes agency-level protests far less appealing. Vendors may not want to risk losing a possible stay at the GAO (viewed as a more robust forum) by filing an agency-level protest first, even if the agency-level protest is a quicker and more efficient option. As a result, vendors often will file directly with the GAO to avoid losing the stay of the procurement while the GAO considers the protest.

Difficulty for the Protester to Win

The last element in Gordon's analysis asks how difficult it is for a protester to prevail in a given protest system. This statistic, as noted, is vitally important to stakeholders — the likelihood of success informs protesters' willingness to use the protest system. Under current practice, because almost no data are available on agency-level protest outcomes, the process is a "black box," which discourages vendors from using agency-level protests. From both vendor and agency vantage points, therefore, improved transparency regarding the agency-level protests is important.

Hidden Outcomes

FAR 33.103 currently requires that an agency protest decision be well-reasoned and explain the agency's position. The FAR also requires that the protest decision be provided to the protester using a method that provides evidence of receipt. If the agency-level protest is sustained by the agency deciding official, some agencies define the following available remedies: (1) terminating the contract; (2) recompeting the requirement; (3) amending the solicitation; (4) refraining from exercising contract options; (5) award of contract consistent with statute, regulation, and terms of solicitation; or (6) other action that the deciding official determines is appropriate.

Because almost no statistics on outcomes in agency-level bid protests are captured or published, in interviews, this simple question was put to agency counsel: How often do agency-level bid protests succeed at your agency? The responses highlighted the fact that "success" in agency-level bid protests can take many forms, because the vendor and the agency typically seek a constructive outcome—not a mere "win" in the administrative process. One government counsel said agency-level protests are almost never sustained at his agency, but he hastened to explain that, because an agency-level protest is a management tool–an opportunity for the agency to identify and correct its own error—a meritorious agency protest is typically resolved through corrective action rather than a formal decision. The government counsel stressed that because the agency prefers to resolve these issues itself, informally and quickly and through corrective action, if necessary, his agency prefers that vendors pursue agency-level bid protests, rather than more cumbersome GAO and COFC protests. As experienced agency counsel acknowledged, agencies have a stake in an improved agency-level bid protest system, as agencies and vendors share an interest in an effective system.

To keep the agency-level bid protest system vital, it is important that prospective protesters know that they have a reasonable chance of success. Almost inevitably, that requires published statistics on protest outcomes. Publication means resolving the following questions, building on the current rule and agency best practices:

1. What is the essential data to be used for assessing agencies' internal bid protest systems?
2. What information should the agency publish—agency protest decisions, for example, or simply statistics on protests and outcomes?
3. How will agencies and regulators measure outcomes? Will only decisions sustaining a protest "count" as protest victories, or will agencies also tally corrective actions as "wins"?
4. Who in the agency should gather and publish information and statistics on agency bid protests, and how can the public confirm those reports?

These questions are reviewed below, in an assessment of how FAR 33.103 might be improved to reflect agency best practices in gathering and publishing information on protest outcomes.

Agency Protest Requirements

In 1995, President Clinton issued Executive Order No. 12,979 which required executive agencies to create alternative dispute resolution (ADR) systems for bid protests. The Executive Order also requires that agency heads make a system that is "inexpensive, informal, procedurally simple and expeditious" for bid protest resolution. FAR 33.103(d) states that the goal of an effective agency protest must: (1) resolve agency protests effectively, (2) increase confidence in the federal procurement system, and (3) reduce protests in the GAO and COFC spheres.

FAR 33.103(g) requires that an agency make "their best efforts" to resolve a protest within 35 days after the protest has been filed. During the resolution of the protest, the agency and protester may provide information regarding the protest. It is also required that the agency decision is "well-reasoned" and "provide sufficient factual detail explaining the agency position." The agency must submit a copy of the decision to the protester in any manner of which the agency can verify receipt.

The chief practical issue presented by this study is how to accomplish Congress' goals—how to leverage bid protests in Defense Department procurement to reduce systemic risk, while minimizing the disruption that bid protests can bring to delivering capability to the warfighter inside the turn of near peer competitors and nonstate actors. One ready answer is to encourage the use of agency-level bid protests. As a recent study published by ACUS noted, agency-level bid protests offer a more efficient, less disruptive alternative to GAO protests or protests brought before COFC.

The question, then, is how agency-level bid protests might be structured in order to make them more effective. The recent ACUS study cited a number of problems in the current agency-level bid protest rules structure, including a lack of an administrative record and transparency—problems which have impeded widespread use of agency-level bid protests. The report recommended a number of reforms to make agency-level bid protests more effective. Relatively modest reforms proposed by the ACUS report—most drawn directly from agency best practices that have evolved since the rule was first published a quarter-century ago—could substantially improve the transparency and validity of the agency-level bid protest process. These reforms would allow vendors to rely more on agency-level bid protests, a step forward that would improve procurement processes for agencies, which generally prefer to resolve bid challenges internally, quickly, and efficiently. For a greater discussion of the ACUS report recommendations, see Report to Congress.

As the discussion below reflects, the proposed reforms put forward in the ACUS report generally would be well within best practices already used in the DoD, as the AMC already uses many of these strategies in its agency-level bid protest system. Implementing these reforms, as the AMC's example below shows, could be done within the existing legislative and regulatory structure, though the more forward-looking reforms (such as gathering and publishing data on agency-level protests) could require changes to regulations and guidance within the Defense Department.

Army Materiel Command: A Model Agency-Level Bid Protest System

As noted, a potential model for reform already exists in the Defense Department: the Army Materiel Command agency-level bid protest system. As LT COL Bruce L. Mayeaux pointed out in a research paper recently published in the *Military Law Review*, the AMC agency-level bid protest system could provide a model for other components of the Defense Department that seek to use agency-level bid protests as a risk management tool. From a historical perspective, this is not surprising because the AMC agency-level bid protest system was itself the model for President Clinton's government-wide executive order which endorsed agency-level protests in 1995.

Mayeaux suggests that the DoD should model the DoD agency-level bid protest system after AMC's current program. Mayeaux outlines that the AMC agency-level bid protest system incorporates many crucial elements:

1) AMC has an established, independent APO.
2) AMC's system can accommodate agency-level bid protests relating to all possible procurements.
3) AMC's system aligns with the GAO's legal "standing" rules.
4) AMC has a formalized process similar to that used for disputes under the Contract Disputes Act of 1978.
5) AMC's system generates administrative reports similar to the GAO's merits decisions.
6) AMC's system facilitates sharing the report with protesters.
7) AMC employs a consistent regulatory stay of award or performance.
8) AMC compiles agency-level bid protest data to analyze and manage risk.

As LT COL Mayeaux explains, the AMC agency-level bid protest system already reflects many of the reforms that the ACUS report recommended to advance the agency-level bid protest system as an effective risk management tool and as an alternative to the more cumbersome and expensive bid protests systems at the GAO and in the courts. See the Report for a more in-depth discussion of the AMC process.

Analysis of Bid Protest Data

For a discussion on analysis of DoD data on bid protests, see the Report.

Findings: Answers to Congress

Congress identified four issues for the study that resulted in the Report.

Issue 1: The Rate Protesters Win the Contract

The first question Congress presented asks for the rate at which protesters ultimately win the contested contract. This study showed that the majority of responding agencies within the Defense Department do not actively track the rate at which protesters are awarded the contract that was the subject of a bid protest. The agencies that do not track this information stated as justifications for not doing so: the lack of protests, the ease of manually retrieving protest information from the relevant files when necessary, and the burden of adding an additional task to the contracting process.

If implemented, the data extraction processes set forth in the 2021 article, *Data Scarcity in Bid Protests*, would make determining the rate at which protesters are awarded the protested contracts relatively simple. The awardee's information presumably would be in the final contract which would be on file, and the protester's information would be in their protest filing. The program could extract that information and output it, for example to a single row in a spreadsheet or a report.

One of the data points that such a program would record is the protester and ultimate contract awardee's Unique Entity Identifier (UEI). These could then be cross-referenced and answer in a binary "yes" or "no" as to whether the original awardee ultimately retained the contract (by matching UEIs). Assuming that the UEIs could be reliably identified programmatically (which would depend, in turn, on the fidelity of the submitted data), automatically collecting the protester's UEI should be straightforward. An alternative, though suboptimal, approach, as discussed above, is that the protester's UEI is copy-pasted manually from the relevant documentation.

The data referenced in this Report illustrate both the costs and benefits of *not* integrating bid protests into a broader automated acquisition system. Data scientists collected the data for this study by programmatically extracting solicitation PIIDs from GAO merits decisions and some GAO docket information, spanning 2008 to 2022, from GAO.gov. The data scientists then paired the PIIDs to USASpending.gov contract data by matching the "solicitation_identifier" field in the USASpending data. The data scientists paired the bid protest information and USASpending contract data and then analyzed it to render the referenced data. Using this methodology, data scientists were able to gather data on 2,015 protests from 2008 to July 2022. These data, and the results, did *not* reflect all GAO cases from this period, nor do they include agency-level or court bid protest decisions.

Amongst other insights, the available data showed that the protester was eventually awarded the contract 5.56% of the time. (Because this finding is based on GAO merits decisions, it does not capture cases where, for example, a protester was able to negotiate an alternative solution with the agency, or where a protest resulted in early corrective action by the agency resolving the problems raised by the protest.) Where the protest was sustained, the protester was awarded the contract 10.92% of the time, and where the protest was not sustained (encompassing withdrawals, denials, and dismissals), the protester was awarded the contract 5.05% of the time. This quasi-manual process was computationally intensive (the net time for a personal computer to run the processing programs was approximately 30 hours) and required substantial effort to clean, process, and initially analyze the data. This makes it far less efficient than the proposed automated process would be.

Barring the adoption of the recommendations in this paper, one simple but critical improvement to the system would be to make the entry of the solicitation identifier mandatory in the Federal Procurement Data System (FPDS; which is then mirrored into USASpending data), thus allowing this process to capture data on all of the bid protests. It is unclear at this time why the FPDS fields captured in the PDS XML data are not all automatically uploaded to FPDS, as it would not take additional time and would greatly improve data collection. The XML data would, definitionally, be reflective of the information written into the contract, so validation should not be a concern.

Issue 2: Corrective Action Relative to Protests

Congress next asked for information on agencies' responses to corrective action, which typically results in dismissal of a protest. None of the agencies surveyed within the DoD tracks the time that it takes to implement corrective action after a decision, nor do most agencies track the percentage of protests where corrective action is taken that the corrective action is protested. While all of the agencies track the final outcomes of protests, the agencies' records of the final outcome do not generally show any affiliation with corrective action.

The Defense Department's automated acquisition systems are evolving very rapidly, and it is only possible to speculate on what information may be specifically available to study corrective actions and how to leverage what is currently being recorded to gain more insights. The only data point on corrective actions currently available was derived from protest awardee data discussed above, which showed that protesters whose protests were not sustained still ended up being awarded the contract roughly 5% of the time, indicating that agencies took voluntary corrective actions at least that frequently. Given that the same data analysis suggested that sustained protests resulted in the protester being awarded the contract only roughly 11% of the time, it is likely that corrective actions occur far more frequently, given that corrective actions do not automatically result in the protester being awarded a contract. In an improved data reporting system, a range of fields could be implemented to aggregate data on corrective actions, depending on what specific aspects of the corrective action were of most interest.

How to determine the time it takes the DoD to implement corrective actions after a ruling or decision?

Congress also asked for information on the time required for DoD agencies to implement corrective actions after a ruling (by the GAO for example) or an internal agency decision to correct an apparent mistake. The survey of DoD agencies showed that this data is not broadly available from the agencies. If the only datapoint being sought when tracking corrective actions is the gap in time between the rendering of a decision in response to a protest and the solicitation or contract becoming active again, the time it takes could be calculated by comparing the two relevant dates. Where the GAO renders a written merits decision, and the solicitation is reissued, or otherwise formally restarted, the dates could be extracted from those two documents. As discussed above, where there is a protest decision not formatted for programmatic processing, it needs some manual data entry. If more benchmarks are required, more information would be required, but it would be equally straightforward to accommodate them.

As demonstrated by the gaps in USASpending Data and the DoD's Protest Tracker data (an internal compendium of partial bid protest data), requiring personnel to enter data invariably results in incomplete datasets. Reducing the amount to be manually entered to 3–

4 cells per contract, and potentially automating these processes in the future, would enhance the likelihood the data would be entered correctly and would be a significant improvement over the status quo. Once such an integrated approach to data gathering were implemented, answering questions (such as on the time required to implement corrective action) would become much faster and easier, and results could be reported nearly in real-time or in annual reports as required.

What percentage of the corrective actions taken by the DoD are subsequently protested, and what are the outcomes of those protests?

Congress asked what followed after DoD agencies take corrective action in response to protests. The survey of DoD agencies confirmed that this is a difficult question to answer because of a lack of insight into the data currently within the DoD. The solution for tracking corrective action protests would likely mirror the data entered for initial protests. Where the data were already collected, there could be automation options, but at present, the DoD's data structures are too new (and still evolving) to articulate what specific options exist. As discussed above, if a program creates XML files for solicitations, it would be a significant step in mapping the outcomes of various agency corrections.

Speaking in generalities, the approach for tracking protests through the lifecycle of a procurement effort could function nearly identically, whether tracking initial protests or protests against corrective actions. Any subsequent protest actions would appear in the dataset under the same PIIDs, allowing all related protests to be associated with each other. Because contract modifications occur on a form which is different from the form used to create the initial contract, it would be straightforward for software to delineate between the two document types and properly output the data on corrective actions as relating back to a prior protest.

One significant hurdle to complete automation arises in instances where a protest results in a completely novel solicitation or contract being issued, severing the link between the original PIID pairing discussed in the above paragraph. In such an event, the Contracting Officer managing the procurement would have to associate the new PIID with the original PIIDs by entering the relevant PIIDs in an assigned cell, to be propagated across the relevant data-rows.

Issue 3: Time Spent on Protests During Procurement

Congress also asked how much time is lost to actual or potential bid protests. This study showed, however, that none of the responding agencies analyzes the time spent attempting to prevent, address, or resolve a protest or the efficacy of any actions attempted to prevent the occurrence of a protest. Contracting Officers do, however, retain experience from the protest process that they then may implement in new procurements.

While Professor Tim Hawkins of the University of North Texas has done some work on the time-cost of protest avoidance during the formation and solicitation stages, he largely found that there was insufficient data to make detailed observations. To properly pursue the question, a targeted survey would have to be developed and submitted to a statistically relevant number (at least 1,000) of randomly selected contracting officers to satisfy scientific rigor and render statistically reliable results.

The data collection and reporting methods proposed here, and in the 2021 article *Data Scarcity*, would, if implemented, allow for improved targeting of such efforts. The data could be used (for example) to focus the research on specifically chosen contracting offices which receive above average, average, and below average numbers of sustained protests to be targeted for the surveys. This would allow for information to be collected about the time-costs of avoiding bid protests generally and would also provide insights into what differentiated the outcomes across contracting offices of various performance quality.

The research methods described above have allowed research scientists to associate approximately 2,000 GAO protests with the underlying contracts, contracting offices, and resulting protest. Because this dataset represents approximately 8% of all protests received in the relevant timeframe, it is useful for trend analysis, but outliers within the set should not be seen as representative.

Issue 4: Rates and Outcomes of DoD Protests

Finally, Congress asked that this study assess the number and disposition of protests filed regarding DoD procurements. While procurement personnel in some DoD agencies regularly review protest policies or review protest data for accuracy, no agencies reported that they conduct any analysis of protest data. Only a few of the agencies even track whether the protester ultimately wins the award of the protested contract. Senior DoD officials noted that in key cases (such as those involving major weapon systems), the agency may conduct an "after-action" review to assess lessons learned from bid protests.

For the most part, however—and again, because the Department's evolving acquisition data are largely divorced from the bid protest system—the Department lacks reliable data on the number and disposition of protests filed. On this point, however, this study was able to gather and assess data, using the methodology developed for the 2021 article discussed. The available GAO merits decisions were assayed to identify the types of matters protested and the dispositions of the protests. The results are set forth in Appendix B to this report. While these results are necessarily incomplete and derivative—they are based on a limited number of published decisions and reflect only the information in those decisions—the results do suggest that better information on bid protests is very likely to result in better management decisions at the DoD.

Conclusion

In its conclusion, the Section 809 Panel observed that the mission of the DoD's acquisition system "is to deliver lethality to warfighters by providing innovative products and services that allow warfighters to obtain and maintain technological superiority over near-peer competitors and nonstate actors." In order to achieve that goal, the companies that seek to do business with the DoD must perceive that the acquisition process is competitive and fair.

The goal of the federal bid protest system, as part of the federal procurement system, is to facilitate full and open competition and to improve outcomes in the acquisition process. With a more open and accessible market, costs decrease and quality increases as more vendors can compete to fulfill the users' needs. Participants in the federal procurement system want assurances that it will be fair and provide timely resolution of disputes.

The U.S. bid protest system has been under development for nearly a century. The trend to move more protests from the courts to alternative fora—for example, to the GAO and to agencies—demonstrates Congress' intent to increase the procurement system's efficiency. However, giving contractors multiple venues to bring protests has led to procedural differences with possible substantive effects on protest outcomes. For example, the varying standards in producing the administrative record for a GAO protest and a COFC protest cause protesters to consider carefully which avenue to take in filing a protest, a question that also turns on the issues in their particular matter. Relative costs of proceeding in the fora may also drive decisions about which forum protesters choose.

Furthermore, as contracting methods continue to evolve, such as task or delivery orders and other transaction agreements, new considerations arise in terms of which fora to choose. By specifying standards as to what constitutes the administrative record in all fora, increasing transparency of bid protests and clarifying the agency's jurisdiction over bid protests, for example might increase use of the agency level bid protests. Anecdotally, it appears that the lack of transparency in agency level bid protests drives companies to the GAO or COFC, where it is clear what information will be made available to them. Greater transparency at the agency level bid protest level may also result in sharing innovation and lessons learned across the DoD and all agencies.

In this regard, observers have suggested that agencies could make significant improvements to agency-level bid protests without additional legislative authority by following established best practices from agencies such as the Army Materiel Command. A key goal in promoting agency-level bid protests is to resolve disputes quickly with the least disruption to delivering capability to the warfighter. The current agency-level bid protest process presents potential issues for contractors, which may steer them towards the GAO or the courts instead. For example, at least in the case of post-award protests, the agency protest timeline erodes protesters' opportunity to file a protest at the GAO, leaving them with the sole option, if they want to stop the procurement, of seeking an injunction at COFC, which may require the protester to overcome a stringent standard for preliminary injunctive relief.

To address these types of issues, this study recommends a number of reforms to agency-level protests, reforms which were endorsed by ACUS, and which are already largely reflected in AMC's agency-level bid protest system:

1. Formalize the role of an "Agency Protest Official" to oversee agency-level protest procedures at the agencies.
2. Confirm that agencies have broad authority to hear agency-level protests, so that agencies have the flexibility to address new problems in novel procurement methods, such as procurements using other transaction authority.
3. Leave the standard for standing flexibly bound to that used by the GAO and the courts, to allow agency-level protests to evolve with other protest fora to accommodate new kinds of "whistleblowers" (protesters) in the acquisition system.
4. Clarify the decision-making process in agency-level protests, perhaps by reshaping it to more closely resemble the tiered decision-making called for by the Contract Disputes Act for contract administration claims.
5. Specify the record necessary for agency-level bid protests, to ensure that the issues raised can be fully addressed on the administrative record.
6. Maximize the record shared with agency-level protesters to encourage rapid resolution of issues.
7. Rationalize the stay of performance in the event of an agency-level protest, so that the protester remains confident that the protester's key goal—having an opportunity to recompete fairly for the contract—is not lost to delay.
8. Publish data on agency-level protests, including, potentially, the decisions themselves to reinforce regularity and confidence in the acquisition system.

Resolving these open issues would increase vendors' incentives to file their initial protests at the agency level while preserving their opportunity to file follow-on protests at the GAO and/or COFC if needed.

Congress also asked that this study report on data on bid protests, in part to draw lessons from bid protests as a management tool—as a means of assessing the policy issues that come to the surface in a bid protest. The ability to use protests as a management tool to improve an agency's procurement outcomes is hampered by the lack of data generally on bid protests. This data deficit is not unique to the DoD. What data exists appears to be manually generated and appears to be dependent on the activity within the DoD. Manually collecting such data adds additional burdens to contracting officers and their supporting counsel, allows for data reentry errors, and results in inconsistent data across the DoD. The issue with data impacts other areas of the federal procurement process as well.

This study shows that many of these gaps in data—the inability to identify problems in the acquisition system, or to discern possible solutions—could be resolved by a more integrated and comprehensive "digitalized" acquisition system at the Defense Department, which has been called for by over two decades. While the study was able to address key questions put forward by Congress (such as the numbers and types of decisions that were subject to protest, at least at the GAO), those findings were bounded by the strict limits on the available data.

Methods which could be integrated with the DoD's automated acquisition system are readily available and would significantly improve data reporting on bid protests and other aspects of the acquisition process. There are various options available which could provide varying levels of continuously available, improved data. Additional funding would need to be provided.

Finally, the investigators of this Report identified improvements to integrate the multiple databases that host procurement information. The DoD has a great deal of data; most of it is not easily accessible. Through integration, data analysis could empower Congress, and the policy makers in the DoD, to have a better understanding of what is actually occurring in the procurement system and to empower Contracting Officers to have the confidence to be more proactive in pursuing the CICA mandate to be more creative to better serve their end customers.

Acknowledgements

This paper is a condensed version of a report submitted to Congress, *DoD Bid Protests, September 2022* (Report). Footnotes, Data, Figures, Appendices, and some content have been removed in order to satisfy NPS paper length requirements. The entire Report may be found at https://acqirc.org/publications/. The Report was supported, in whole or in part, by the U.S. Department of Defense through the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD[A&S]) and the Office of the Under Secretary of Defense for Research and Engineering (OUSD[R&E]) under Contract HQ0034-19-D-0003, TO#0309.

The Acquisition Innovation Research Center is a multi-university partnership led by the Stevens Institute of Technology and sponsored by the U.S. Department of Defense (DoD) through the Systems Engineering Research Center (SERC)—a DoD University-Affiliated Research Center (UARC).

Disclaimer

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

No Warranty

This Material is furnished on an "as-is" basis. The Stevens Institute of Technology makes no warranties of any kind—either expressed or implied—as to any matter, including (but not limited to) warranty of fitness for purpose or merchantability, exclusivity, or results obtained from use of the material. The Stevens Institute of Technology does not make any warranty of any kind with respect to freedom from patent, trademark, or copyright infringement.

Copyright © 2023 by Stevens Institute of Technology and the authors. All rights reserved.

References

Acquisition Innovation Research Center. (n.d.). https://acqirc.org/

Assessing bid protests of U.S. Department of Defense procurements. (2018). RAND. https://www.rand.org/pubs/research_reports/RR2356.html

DoD bid protests, September 2022 (Report). (n.d.). https://acqirc.org/publications/

National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2021 (n.d.). https://www.congress.gov/bill/116th-congress/house-bill/6395/actions

PANEL 12. CONTRACTING INNOVATIONS

Wednesday, May 10, 2023	
3:45 p.m. – 5:00 p.m.	**Chair: Major General Alice Treviño,** USAF, Deputy Assistant Secretary for Contracting, Office of the Assistant Secretary of the Air Force for Acquisition, Technology and Logistics ***Small Disadvantage Business Goals: The Effects of Recent Administrative Changes*** Hon. Emily Murphy, George Mason University ***Educational Leadership, Collaboration, and Relevance: A Get Real, Get Better Approach to Innovating Major Weapon Systems Cost/Price Analysis and Contract Negotiations Courses in Higher Education*** Kelley Poree, Naval Postgraduate School ***Fast Following = CSO + OTA*** Keith Gibson, Runyara, LLC

Major General Alice Treviño, USAF—serves as the Deputy Assistant Secretary for Contracting, Office of the Assistant Secretary of the Air Force for Acquisition, Technology and Logistics, the Pentagon, Arlington, Va. She is responsible for all aspects of contracting relating to the acquisition of weapon systems, logistics, operational and enterprise efforts for the Air Force, and provides contingency contracting support to the geographic combatant commanders. She leads a highly skilled staff of mission-focused business leaders and acquisition change agents to deliver $825 billion in Space, Air Superiority, Global Strike, Global Mobility and Information Dominance platforms. Additionally, she oversees the training, organizing and equipping of 8,000 contracting professionals who execute programs worth more than $65 billion annually.

Maj. Gen. Treviño received her commission from the U.S. Air Force Academy in 1993 and is a joint qualified officer with extensive deployment experience in support of combat, humanitarian and peacekeeping/enforcement operations to Croatia, Turkey, Oman, Kuwait and Afghanistan.

Prior to her current assignment, she was the Commander of the Air Force Installation Contracting Center. She has also served as the Deputy Secretary of Defense's Principal Military Assistant; unlimited dollar warranted procuring Contracting Officer for major defense programs; and the Senior Contracting Official-Afghanistan for U.S. Central Command. She has commanded two Air Force units at the squadron level, joint units at the group and wing levels, and an Air Force unit at the wing level.

Small Disadvantage Business Goals: The Effects of Recent Administrative Changes

Emily W. Murphy—has spent the past 26 years working in government contracting, including 9 years as a staff member for committees in the House of Representatives and 7 years in the Executive Branch, most recently as the Administrator of the U.S. General Services Administration. She has also practiced government contracts law and served as an executive for a technology start-up company. Correspondence concerning this article should be addressed to Emily Murphy, Center for Government Contracting, School of Business, George Mason University, 4400 University Drive, Fairfax, VA 22031. [emurph7@gmu.edu]

Abstract

While the diversification of small federal contractors in the industrial base is embraced across administrations and parties, the federal small business goals had not changed from 1997 until 2021. At that time, the Biden Administration increased the Small Disadvantaged Business (SDB) goal to 15% of all prime contract dollars effective Fiscal Year 2025, with incremental increases from the current 5% statutory goal in the intervening years. Concurrently, the Office of Management and Budget directed agencies to "increase baseline spending for the additional socioeconomic small businesses and traditionally underserved entrepreneurs recognized in the Small Business Act," specifically small businesses in the historically underutilized business zone program (HUBZones); women-owned small businesses (WOSBs); and service-disabled veteran-owned small businesses (SDVOSBs).

The Small Business Act prime contracting goals allocate 23% to all small businesses, with subgoals of 5% each for SDBs and WOSBs, and 3% each for HUBZone and SDVOSBs. However, the new SDB goal may increase reliance on 8(a), WOSB, HUBZone, and SDVOSB contracting authorities, harming ineligible SDBs. Without any check on SDB certification, companies may incorrectly claim SDB status, leading to an inaccurate picture on the success of SDBs under the new policy.

Research Statement: This paper will provide a history of the SDB program, then baseline 8(a), non-8(a) SDB, WOSB, HUBZone, and SDVOSB participation in prime contracting prior to the administrative changes in 2021. It will then analyze changes in participation in FY 2021 and FY 2022. It will also examine changes in the number of SDBs and other socioeconomic firms receiving awards and the methods by which competitive contracts versus contract set-aside for the other socioeconomic programs. Finally, it will look at the NAICS code distribution of the procurements, with an eye to determining how changes in this policy are affecting the ways small businesses participate in the industrial base.

Introduction

While the origins of the Small Business Administration's (SBA) Small Disadvantaged Business (SDB) contracting program and its prime contracting goals date to 1958, the history of the program is one of ebbs and flows. While the SDB appellation has applied at both the prime and subcontracting level, this paper will concern itself with prime contracting opportunities. However, before examining the data on the SDB program, it is important to understand the origins and evolutions of the program, as they provide the context necessary to assess the current performance of the program.

Origins of Small Business and SDB Contracting Programs and Goals

In 1958, Congress amended to Small Business Act (the Act) for two purposes related to this paper. First, it explained why contracting with small businesses was important, when it directed that small businesses should

> receive any award ... contract or any part thereof ... as to which it is determined by the [SBA] and the contracting procurement ... agency (1) to be in the interest of maintaining or mobilizing the Nations full productive capacity, (2) to be in the interest of war or national defense programs, [or] (3) to be in the interest of assuring that a fair proportion of the total purchases and contracts for property and services for the Government are placed with small-business concerns. (Pub. L. 85-536 § 2)

Second, it introduced the 8(a) contracting authorities, with the concept of SBA acting as an intermediary between small businesses and federal agencies for contracting purposes. This allowed SBA to act as the prime contractor to another agency and to then sole source a subcontract for the entirety of the work to a small business.

Reforms of the 1970s

In 1968, President Richard Nixon issued two orders to encourage contracting with minority businesses, and SBA began to use its 8(a) authority to support minority-owned businesses. However, Congress did not change the Act for another decade. Only in 1977 did the Act first distinguish between types of small businesses for the purposes of contracting, finding that priority should be given to small businesses in labor surplus areas (Pub. L. 95-89 §502). After this late start, change came rapidly. In 1978, the Act was amended to create programs for socially and economically disadvantaged businesses. Defining socially and economically disadvantaged small businesses as those "at least 51 per centum owned by one or more socially and economically disadvantaged individuals" and whose "whose management and daily business operations are controlled by one or more of such individuals." Congress found that:

> (A) that the opportunity for full participation in our free enterprise system by socially and economically disadvantaged persons is essential if we are to obtain social and economic equality for such persons and improve the functioning of our national economy;
>
> (B) that many such persons are socially disadvantaged because of their identification as members of certain groups that have suffered the effects of discriminatory practices or similar invidious circumstances over which they have no control;
>
> (C) that such groups include, but are not limited to, Black Americans, Hispanic Americans, Native Americans, and other minorities;
>
> (D) that it is in the national interest to expeditiously ameliorate the conditions of socially and economically disadvantaged groups;
>
> (E) that such conditions can be improved by providing the maximum practicable opportunity for the development of small business concerns owned by members of socially and economically ' disadvantaged groups;
>
> (F) that such development can be materially advanced through the procurement by the United States of articles, equipment, supplies, services, materials, and construction work from such concerns; and
>
> (G) that such procurements also benefit the United States by encouraging the expansion of suppliers for such procurements, thereby encouraging competition among such suppliers and promoting economy in such procurements. (Pub. L. 95-507 §201)

The 8(a) subcontracting authority created in 1958 was repurposed to allow direct placement with SDBs under what begins to resemble the modern program (§202). However, the definitions of social and economic disadvantage were fairly vague, with social disadvantage meaning that an individual has "been subjected to racial or ethnic prejudice or cultural bias because of their identity as a member of a group without regard to their individual qualities," and economic disadvantage meaning that an individual's "ability to compete in the free enterprise system has been impaired due to diminished capital and credit opportunities as compared to others in the same business area who are not socially disadvantaged" (§202). While specific groups were identified as qualifying, individuals could self-certify. This presumed-disadvantaged group grew over the next decade, and penalties for misrepresentation were added (Pub. L. 99-272 §18009).

The 1978 legislation also marked the first goaling requirements. It directed that each agency, in consultation with SBA, establish goals for use of small businesses and SDBs as prime contractors (Pub. L. 95-507 §221). At the end of each year, the agencies were then required to report to the SBA on the prime contracts awarded under these goals.

Changes of the 1980s

1986 saw the beginnings of major changes in the SDB program. First, Congress required that each agency "make consistent efforts to annually expand participation by small business concerns from each industry category in procurement contracts of the agency, including participation by SDBs. (Pub. L. 99-500 §921) Next, Congress added a 5% SDB goal for the Department of Defense (DoD; Pub. L. 99-661 §1207). To meet this goal, the DoD was allowed to expedite payments to SDBs, set-aside work for SDBs, provide financial incentives to prime contractors awarding work to SDBs, and apply price evaluation adjustments (PEAs) of up to 10% on SDB offers when a contract was awarded using full and open competition. This was quickly followed by changes to the Alaska Native Claims Settlement Act to require that Alaska Native Corporations be deemed socially and economically disadvantaged (Pub. L. 100-241 §15). Then in 1988, Congress passed the Business Opportunity Development Reform Act (BODRA).

BODRA was a major reform of the SDB/8(a) program. Until this time, all SDBs were eligible for awards under the 8(a) program. However, BODRA required that SBA begin certifying companies, limited each 8(a)-participating company to no more than 9 years in the program, and each individual to only one participating company for qualification purposes (§201). Program participants were required to submit evidence of their SDB status including financial statements, business plans demonstrating a potential for success, and annual updates confirming their eligibility and their progress. Companies that successfully won 8(a) contracts could keep performing that work as long as they remained 8(a) program participants, but the work need to go to other 8(a) firms at the end of the 9 years (§407).

BODRA also changed the goaling framework. Rather than allowing agencies to establish agency-specific goals, the President was required to establish government-wide goals of 20% for small business and 5% for SDB firms, and then to have SBA negotiate agency-specific goals (§502). The SBA was required to annually report on goal attainment, including the methods by which the contracts had been awarded (§503).

Challenges to SDB Contracting

In 1994, this expansion of SDB authorities continued with the passage of the Federal Acquisition Streamlining Act (FASA). FASA made the DoD SDB authorities, including set-asides and PEAs, available to civilian agencies (§7102). The Federal Acquisition Regulatory (FAR) Council rushed to promulgate rules to implement these new authorities, issuing a proposed rule on January 6, 1995 – only 85 days after the passage of FASA. The rule was very expansive, directing that “individuals who certify as members of members of named groups (Black Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, Subcontinent-Asian Americans) are to be considered socially and economically disadvantaged” without any inquiry into financial disadvantage (60 Fed. Reg. 2304). Contracting officers were to give preference to SDB set-asides over small business set-asides (60 Fed. Reg. 2307).

Before a final rule could be issued, the Supreme Court’s decision in Adarand Constructors, Inc. v. Peña (Adarand) forced the Clinton Administration to revisit the application of the SDB contracting programs. In Adarand, the Court found that “government may treat people differently because of their race only for the most compelling reasons” and held “that all racial classifications, imposed by whatever federal, state, or local governmental actor, must be analyzed by a reviewing court under strict scrutiny. In other words, such classifications are constitutional only if they are narrowly tailored measures that further compelling governmental interests” (Adarand 2113).

With the door opened for challenges to the SDB program, President William Clinton announced that his Administration would “reaffirm the principle of affirmative action and fix the practices” and would adopt “a simple slogan: mend it but don’t end it” (New York Times Staff, 1995). The President ordered agencies to eliminate or reform any program that uses race, ethnicity, or gender to create a quota, “preferences for unqualified individuals,” “reverse discrimination,” or which “continues even after its equal opportunity purposes have been achieved” (Clinton, 1995). As a result, the DoD discontinued SDB set-asides (Kaminski, 1995). Civilian agencies never implemented the SDB set-aside, and SBA required that firms be certified as SDBs to receive the PEA or other considerations (63 Fed. Reg. 35772). The PEA was itself only available for industry codes designated by the Department of Commerce, which were ensure the program was narrowly tailored (63 Fed. Reg. 35714).

The DoD’s use of the SDB PEA was limited beginning in 1998, when Congress passed legislation stating that if the Department met the 5% SDB goal in a fiscal year, it could not use the PEA during the next fiscal year (Pub. L. 105-261 §801). As the DoD was regularly meeting the goal, this effectively nullified the PEA. The civilian agency PEA authority lapsed in December 2004 (Auletta, 2004). In 2008, the Federal Circuit found that the DoD’s revised implementation of the SDB program was unconstitutional (Rothe). In 2018, Congress repealed the DoD-specific SDB provisions, including the PEA (Pub. L. 115-232 § 812).

The Biden Administration and SDB Goaling

Until the first day of the Biden Administration, it appeared that for prime contracting purposes, non-8(a) SDB firms would only benefit from the statutory goal. Then, on January 20, 2021, President Joseph Biden signed Executive Order 13985, Advancing Racial Equity and Support for Underserved Communities Through the Federal Government, which directed agencies to identify “potential barriers that underserved communities and individuals may face in taking advantage of agency procurement and contracting opportunities” and then tasked the Office of Management and Budget (OMB) and the agencies to develop a plan for to eliminate “any barriers to full and equal participation in agency procurement and contracting opportunities” (86 Fed. Reg. 7010-11). Then, on June 1, 2021, in remarks commemorating the centennial of the Tulsa Race Massacre, the President stated, “I’m going to increase the share of the dollars the federal government spends to small, disadvantaged businesses, including Black and brown small businesses.

Right now, it calls for 10 percent; I'm going to move that to 15 percent of every dollar spent will be spent."[1]

To implement this policy, OMB issued a directive on December 2, 2021, "to increase spending to SDBs to 15% by [FY] 2025 and to increase baseline spending for the additional socioeconomic small businesses and traditionally underserved entrepreneurs recognized in the Small Business Act ... includ[ing] [WOSBs ,SDVOSBs,] and small business contractors in [HUBZones]" (Miller, 2021). Specifically, agencies were directed to adopt "an agency-specific SDB contracting goal for FY 2022 that will allow the Federal Government to cumulatively award at least 11% of Federal contract spend to SDBs in FY 2022," and increase over the FY2020 achievement of 10.45% (Miller, 2021). A subsequent October 2022 OMB memorandum reported that "agencies awarded a record $62.4 billion to SDBs in FY 2021, totaling 11.01 percent of all contracting dollars and meeting the 11 percent aspirational goal a year early" in addition to awarding "record spending to [SDVOSBs], [HUBZones], and small businesses overall" (Young, 2022). Therefore, in FY 2023, agencies were to "allow the Federal Government to cumulatively award at least 12 percent of Federal contract spending to SDBs." Most recently, President Biden signed Executive Order 14091, Further Advancing Racial Equity and Support for Underserved Communities Through the Federal Government, which confirmed that the FY 2025 SDB goal would be 15%, directed OMB to set a SDB goal for FY 2024, and directed agencies to "undertake efforts to increase contracting opportunities for all other small business concerns as described" in the Act (88 Fed. Reg. at 10831).

Qualifying for the SDB Program

This renewed focus on SDB prime contracting makes it important to understand which firms qualify as SDB under the Act. SBA regulations state that SDBs must be small under the size standard assigned to the six-digit North American Industry Classification System (NAICS) code assigned to the relevant procurement and meet the criteria of social and economic disadvantage established for the 8(a) program. Businesses owned by Indian tribes, ANCs, Community Development Corporations, and Native Hawaiian Organizations will be presumed to be socially and economically disadvantaged (13 C.F.R. § 124.1001). While active participants in the 8(a) program are automatically SDBs, any other firm may self-certify as an SDBs if "it believes in good faith that it is owned and controlled by one or more socially and economically disadvantaged individuals" (13 C.F.R. § 124.1001).

SBA's test for social disadvantaged is complex. In general, socially disadvantaged individuals are "are those who have been subjected to racial or ethnic prejudice or cultural bias within American society because of their identities as members of groups and without regard to their individual qualities" but the "social disadvantage must stem from circumstances beyond their control" (13 CFR § 124.103(a)). Certain individuals are presumed socially disadvantaged, but everyone still must hold themselves out as a member of one of these designated groups,[2] and be identified by others as a member of that group (13 CFR § 124.103(b)). However, others may also qualify as socially disadvantaged by

[1] The SDB statutory goal was, and remains, 5%. However, SBA's annual reports indicate that SDBs were receiving approximately 10% of prime contract dollars.

[2] Per 13 CFR § 124.103(b), social disadvantage is presumed for "Black Americans; Hispanic Americans; Native Americans (Alaska Natives, Native Hawaiians, or enrolled members of a Federally or State recognized Indian Tribe); Asian Pacific Americans (persons with origins from Burma, Thailand, Malaysia, Indonesia, Singapore, Brunei, Japan, China (including Hong Kong), Taiwan, Laos, Cambodia (Kampuchea), Vietnam, Korea, The Philippines, U.S. Trust Territory of the Pacific Islands (Republic of Palau), Republic of the Marshall Islands, Federated States of Micronesia, the Commonwealth of the Northern Mariana Islands, Guam, Samoa, Macao, Fiji, Tonga, Kiribati, Tuvalu, or Nauru); Subcontinent Asian Americans (persons with origins from India, Pakistan, Bangladesh, Sri Lanka, Bhutan, the Maldives Islands or Nepal)."

proving their disadvantage by a preponderance of the evidence (13 CFR § 124.103(c)). This evidence must include:

> (i) At least one objective distinguishing feature that has contributed to social disadvantage, such as race, ethnic origin, gender, physical handicap, long-term residence in an environment isolated from the mainstream of American society, or other similar causes not common to individuals who are not socially disadvantaged;
>
> (ii) The individual's social disadvantage must be rooted in treatment which he or she has experienced in American society, not in other countries;
>
> (iii) The individual's social disadvantage must be chronic and substantial, not fleeting or insignificant; and
>
> (iv) The individual's social disadvantage must have negatively impacted on his or her entry i**nto or advancement in the business world. SBA will consider any relevan**t evidence in assessing this element, including experiences relating to education, employment and business history (including experiences relating to both the applicant firm and any other previous firm owned and/or controlled by the individual), where applicable. (13 CFR § 124.103(c))

To prove disadvantage, the facts must independently establish "the individual has suffered social disadvantage that has negatively impacted his or her entry into or advancement in the business world," with each "instance of alleged discriminatory conduct ... accompanied by a negative impact on the individual's entry into or advancement in the business world" (§ 124.103(c)). SBA cautions that it will "disregard a claim of social disadvantage where a legitimate alternative ground for an adverse employment action or other perceived adverse action exists and the individual has not presented evidence that would render his/her claim any more likely than the alternative ground."

This inquiry becomes especially difficult when asserting disadvantage based on gender. SBA provides several examples of why many women may not qualify. First, the SBA explains that if a woman seeks to prove social disadvantaged based on gender, it is not enough to state that she was paid less than her male colleagues, since "it is no more likely that the individual claiming disadvantage was paid less than her male counterpart because he had superior qualifications or because he had greater responsibilities in his employment position;" instead the woman "must identify her qualifications (education, experience, years of employment, supervisory functions) as being equal or superior to that of her male counterpart in order for SBA to consider that particular incident may be the result of discriminatory conduct" (§ 124.103(c)). Likewise, if a woman claims that she was denied opportunities provided to male employees, she must prove those employees held the same position and that funding was available but denied to her. In the final example, SBA states that clients making derogatory, gender-based statements about a woman is not enough to prove social disadvantage, but that the woman must prove that she lost work because of the derogatory statements (§ 124.103(c)(3)).

In comparison, economic disadvantage is much more objective. SBA regulations provide that "economically disadvantaged individuals are socially disadvantaged individuals whose ability to compete in the free enterprise system has been impaired due to diminished capital and credit opportunities as compared to others in the same or similar line of business who are not socially disadvantaged" (13 CFR § 124.104(a)). Each individual must demonstrate that their net worth is less than $850,000, excluding the value of their principal residence, their equity in the business, and the value of any qualified retirement accounts (§ 124.104(c)(2)). Likewise, average personal income over the past year must be less than $400,000, and the total value of all assets other than qualified individual retirement accounts must be less than $6.5 million (§ 124.104(c)(3)-(4)).

Relationship to Other Programs

It is important to understand the relationship between 8(a), SDB , WOSB, Economically Disadvantaged WOSB (EDWOSB), and Disadvantaged Business Enterprise (DBE) status. All active 8(a) participants are SDBs, but the vast majority of SDBs are not 8(a) companies. As of March 27, 2023, SBA's Dynamic Small Business Search tool listed 6,367 active participants in the 8(a) program, but 177,071 self-certified SDBs. A WOSB must independently meet the social and economic disadvantaged tests to be an SDB. A WOSB that meets the economic disadvantage test is defined as an EDWOSB (13 CFR § 127.203). However, EDWOSBs are not SDB unless they also meet the social disadvantage test.

Unlike SDBs, WOSBs and EDWOSBs, the DBE program is run by the Department of Transportation. Like SDBs, DBEs are defined as small businesses that are "at least 51 percent owned by one or more individuals who are both socially and economically disadvantaged" (49 CFR § 26.1). While all groups presumed to be socially disadvantaged for the SDB program are also considered socially disadvantaged for the DBE program, the DBE program includes additional groups such as women and individuals of Portuguese and Sri Lankan origins to be socially disadvantaged (§ 26.1). The DBE program imposes a net worth cap of $1.32 million on DBEs. (49 CFR § 26.67). Therefore, a WOSB can be a DBE as long as it meets the net worth cap, but that does not make it an SDB. Likewise, an EDWOSB may not qualify as a DBE since its assets may exceed the cap.

The overlap in terminology between these programs creates a substantial amount complexity for any business, and self-certification only enhances this challenge. The System for Award Management (SAM) does not provide any guidance for potential registrants. While 8(a), WOSB, EDWOSB, and DBE, status must be added by a federal agency, self-certifying SDBs are simply asked if their business is "a small disadvantaged business concern? (yes or no)." (SAM, 2023). Thus, it is not surprising to find that there appear to be inaccurate or fraudulent self-certifications. For example, DSBS shows that 16.66% of WOSB are self-certifying as SDBs; however only 10.34% are identified as minority owned. This means that 102,725 non-minority WOSBs are claiming SDB status, presumably based on gender. Even if these WOSBs all met the social disadvantage test, they would also need to meet the economic disadvantage test. As of March 27, 2023, only 0.2% of certified-WOSBs have been certified as EDWOSBs, meaning they met the economic disadvantaged test – the remaining WOSBs did not qualify under the economic disadvantage status. Thus, it appears that 16.64% of WOSB may be incorrectly self-certifying as SDBs, and it is unlikely that WOSBs are the only group confused when self-certifying.

Data Sources and Cautions About Data Quality

The following analysis relies on data pulled from the Federal Procurement Data System (FPDS) portion of SAM. FPDS is a dynamic system, with funds being obligated and deobligated every day, making it difficult to assess whether a particular socioeconomic goal has been met. Consequently, SBA runs an annual report that provides the snapshot for the prior fiscal year, referred to hereinafter as the Static Small Business Goaling Reports (SSBGR), used for SBA's annual procurement scorecard. Whenever possible, this paper relies on that data. However, if the SSBGR were not available or did not allow for the required level of data, information was instead pulled using FPDS's standard reporting function applying the small business goaling criteria (GC). Finally, if data could not be obtained using these sources, ad hoc reports were run.

SBA's annual Small Business Goaling Guidelines set the parameters for the SSBGR and the GC reports. While not an exhaustive list, this means awards using 8(a) procedures are treated as prime contracts both from a goaling standpoint and by the agencies themselves. About 20% of all dollars obligated each year are excluded from the goaling base, prime contracting credit is provided for some Department of Energy subcontract, and certain prime contracts awarded to small businesses located in Puerto Rico or covered territories receive double goaling credit. (FY22 Small Business Goaling Guidelines 9, 18, 19).[3] Therefore, depending on the type of report run and the date the report was run, some variation in numbers is to be expected.

Baseline of SDB and Socioeconomic Achievements

Despite the loss of the PEA, SDBs have continue to gain federal market share. As the chart below demonstrates, SDB prime contracting increased by 1.3% between FY 2008, the last year of the SDB PEA at DoD, and FY 2009. It proceeded to grow through FY 2020, climbing to 9.45% in FY 2014 and 10.39% in FY 2020. Concurrently, small businesses, WOSBs, and SDVOSBs all saw steady growth, with only HUBZone dollars declining. For perspective, in FY2008, only the SDB goal of 5% was being met, with the government failing to meet the 23% small business goal, 5% WOSB goal, 3% SDVOSB goal, and the 3% HUBZone goal. By FY 2020, the government was regularly exceeding the small business, SDB, and SDVOSB goals, making progress on the WOSB goal, and struggling with the HUBZone goal.

Table 1. Small Business Goaling Results FY 2008–2009, FY 2014, and FY2020

Fiscal Year	Small Business	SDB	WOSB	HUBZone	SDVOSB
2008	20.49%	6.27%	3.20%	2.17%	1.39%
2009	21.89%	7.57%	3.68%	2.80%	1.97%
2014	24.99%	9.45%	4.68%	1.81%	3.67%
2020	25.42%	10.39%	4.71%	2.39%	4.23%

SSBGR.

With the increased SDB goals announced by President Biden in January 2021, the following chart illustrates that SDB contracting increased by 0.34% from FY 2020 to FY 2021, and by 0.39% from FY 2021 to FY 22. Simultaneously, overall small business prime contracting dropped by 0.05%, and SDVOSBs grew by 0.32%. WOSB contracts fell to the lowest level since FY 2013, and HUBZones saw minimal growth.

[3] Double credit for Puerto Rican and covered territory businesses applies for FY2019–FY2024. Act, §15(f).

Table 2. Small Business Goaling Results FY2018–FY2022

Fiscal Year	Small Business	SDB	WOSB	HUBZone	SDVOSB
2018	25.06%	9.65%	4.75%	2.05%	4.27%
2019	25.82%	10.13%	5.04%	2.23%	4.34%
2020	25.42%	10.39%	4.71%	2.39%	4.23%
2021	26.11%	10.73%	4.41%	2.44%	4.33%
2022	25.37%	11.12%	4.34%	2.55%	4.45%

Data for FY 2018–2021 is from SSBGR, Data for FY 2022 is from GC.

Analysis of Types of SDB Firms and Contracting Methods

Given that there is no contract method designed to reach non-8(a) SDBs, it is worth examining how these SDB numbers were achieved. As shown in the following chart, from FY2018 to FY 2022, while the percentage of dollars awarded to SDBs increased, the percentage awarded using 8(a) procedures declined, so that rather than 37.88% of dollars to SDBs being awarded via the 8(a) program in FY 2018, by FY 2022 only 31.06% were awarded using these procedures. This also means that only 31.06% of the dollars awarded required any verification of SDB status. While 8(a) awards were declining, awards to ANCs were increasing from 1.64% to 1.94%.

Table 3. Detail of SDB Awards Results FY 2018–FY2022

Fiscal Year	SDB Results	8(a) Procedures	SDB Firms Qualifying for Other Programs	8(a) Procedures as a percent of SDB Spend	ANC-Only Percent
2018	9.65%	3.66%	3.59%	37.88%	1.64%
2019	10.13%	3.62%	3.96%	35.72%	1.79%
2020	10.39%	3.52%	4.19%	33.88%	1.86%
2021	10.73%	3.44%	4.18%	32.08%	1.93%
2022	11.12%	3.45%	4.26%	31.06%	1.94%

FPDS Ad Hoc Reports.

Given that awards using 8(a) procedures have been declining, the question then becomes how are contracting officers reaching SDB firms for the purposes of awards. As detailed below, it becomes clear that when base-lined against the FY 2018 to FY 2020 dollars, the awards of the last 2 fiscal years show that SDB receiving slightly more sole source awards under non-8(a) authorities. These include sole source awards using the EDWOSB, WOSB, HUBZone, and SDVOSB authorities of the Act, and the Veteran-Owned Small Business (VOSB) authorities found at 28 U.S.C. § 8127. As a method to contract with SDBs, 8(a) sole source awards—the preferred method under the Act for 8(a) awards—declined over 4%. Non-8(a) sole source authorities increased slightly during that same period, but most of the dollars appear to have been achieved using small business set-asides and other set-asides. While from FY2018 to FY2020, 8(a) sole source awards accounted for more SDB dollars than did small business set-asides, from FY2021 to FY2022, the use of small business set-asides grew by over 2.3% and surpassed 8(a) sole source awards by almost 5%. Likewise, the combined use of SDVOSB, HUBZone, WOSB, and VOSB set-asides to SDBs increased from 7.83% to 12.34%. This means that much of the growth in SDB awards is coming from awards made under other program authorities.

Table 4. Competition Information for SDB Awards FY 2018–FY022 (Percent of SDB Dollars by Contracting Method)

Fiscal Years	8(a) Sole Source	Sole Source, Not 8(A) Authorities	Restricted Competition, not SB Set-Asides	Restricted Competition, not SB Set-Aside or 8(a)	Small Business Set-Aside
FY2018–FY2020	27.28%	0.54%	48.82%	7.83%	25.82%
FY2021–FY2022	23.25%	0.56%	46.32%	12.34%	28.16%
FY2018–FY2022	25.40%	0.55%	47.65%	9.94%	26.91%

FPDS Ad Hoc Reports.

Relation to Goaling and Effect on Other Socioeconomic Programs

Which authorities, then, are contributing the most to the increase in SDB dollars? As shown below, the authorities outside of the Act have little influence on SDB goaling, with an average of only 0.05% of SDB dollars being obtained using VOSB dollars, and only 0.36% of SDB dollars being obtained using authorities created for Native Americans, including the Buy Indian Act, Indian Economic Enterprise, and Indian Small Business Economic Enterprise (ISBEE) preferences. While HUBZone, WOSB, and EDWOSB authorities make significant contributions, with a combined percentage over 3% each of the last 5 years, it is the SDVOSB authorities that are most often used to meet the SDB goals. SDB dollars arising from SDVOSB set-asides and sole source contracts has risen from 4.49% prior to the increase in SDB goals to 8.63% in the last 2 years.

Table 5. Preference Programs Used to Meet SDB Goals

Fiscal Year	HUBZone Authorities	SDVOSB Authorities	VOSB Authorities	Native American Authorities	WOSB and EDWOSB Authorities
2018	1.75%	7.23%	0.05%	0.32%	1.83%
2019	1.86%	2.92%	0.06%	0.34%	1.95%
2020	1.56%	7.02%	0.03%	0.29%	1.69%
2021	1.78%	8.51%	0.05%	0.34%	1.51%
2022	1.77%	8.73%	0.05%	0.47%	1.46%
Total	1.74%	6.42%	0.05%	0.36%	1.66%
2018–2020	1.71%	4.49%	0.05%	0.31%	1.81%
2021–2022	1.77%	8.63%	0.05%	0.41%	1.48%

FPDS Ad Hoc Reports.

Given that these other authorities are being utilized to meet the SDB goal, it is worth exploring how each of the five statutory small business categories does independently of each of the other categories. Therefore, the next chart looks at the percentage of prime contract dollars awarded to small businesses that have no other socioeconomic qualifiers, SDBs, WOSBs, HUBZones and SDVOSBs where the firms are exclusively participants in their respective programs. This reveals that SDBs are the only socioeconomic group to meet their statutory goal independent of any other program. However, there has been a substantial drop in awards to small businesses that are not participants in other programs. WOSBs have fared the worst, with about 0.3% of dollars being awarded to businesses that are only WOSBs or EDWOSBs. This number has also substantially declined, although at no point over the past 5 years did WOSBs qua WOSBs account for even a third of the statutory goal. In FY 2022, only 0.35% of the 5% goal was met by WOSBs operating only in the WOSB program, and the overall WOSB performance fell to the lowest level in a decade.

Dollars to HUBZone firms not qualifying for other programs has remained remarkably steady over the past 5 years. However, this low percentage means that only one in five of every dollars awarded to HUBZones, and only one in six of every dollar goaled for HUBZones, is being awarded to firms that are exclusively HUBZone firms. Aside from SDBs, SDVOSB come the closest to meeting the statutory goal using only SDVOSB firms, and over half of the dollars attributed to the SDVOSB goal were awarded to SDVOSB-only firms. However, while the percentage of all dollars awarded to SDVOSBs has been increasing, growth appears to be with firms that qualify for multiple programs, as exclusively-SDVOSB dollars have remained steady.

Table 6. Goal Attainment When Analyzing Businesses with Only One Socioeconomic Designation

Fiscal Year	Small Business	SDB	WOSB	HUBZone	SDVOSB
2018	11.22%	6.06%	1.55%	0.59%	2.46%
2019	11.09%	6.17%	1.68%	0.65%	2.67%
2020	11.08%	6.21%	1.60%	0.68%	2.61%
2021	11.16%	6.55%	1.56%	0.59%	2.62%
2022	9.88%	6.86%	0.35%	0.69%	2.60%

Effects on the Number of Firms Doing Business with the Government

Having examined the percentage of dollars awarded to SDBs and the methods by which SDB are obtaining those dollars, it is worth considering whether the Administration's changes to SDB goaling have resulted in more SDB firms receiving awards. This requires a look at the number of unique entity identification (UEI) codes that received awards over the past 5 years. As the following table demonstrates, the overall number of entities doing business with the government continued its well-documented drop from FY2018 to FY2022. During that period, 27,996 fewer businesses received contracts with the government, a decline of nearly 23%. The number of unique small businesses dropped even quickly, with a 23.34% drop in the number of firms receiving awards. SDBs, WOSBs, and SDVOSBs, declined as well, albeit at a slower rate. The number of SDVOSBs fell by 17.81%, WOSBs fell by 11.6%, and SDBs fell by 9.79%. HUBZone businesses were the only category to increase, adding 244 new firms.

It appears that the Biden Administration's SDB policies may have slowed the decline in the number of SDB firms. SDB firms dropped by 6.23% from FY 2018 to FY 2020, but the rate of decline slowed to 3.8% from FY 2020 to FY 2022. Aside from the HUBZone program, which added 60 firms in the last two years, SDBs had the slowest rate of decline of any category.

Table 7. Unique Entities Receiving Awards, FY2018–FY2022

Fiscal Year	All UEI	Small Business	SDB	WOSB	HUBZone	SDVOSB
2018	123,230	80,399	29,867	14,300	3,023	2,841)
2019	110,549	72,065	27,830	13,474	3,115	2,761
2020	105,599	68,727	28,007	13,280	3,207	2,585
2021	99,762	64,774	27,418	12,823	3,388	2,463
2022	95,234	61,716	26,941	12,641	3,267	2,335

FPDS Ad Hoc Report

While the Biden Administration efforts have slowed the rate of SDB decline, it is worth examining trends within the various types of SDBs. Of all types of SDB firms, the greatest decline happened among 8(a) firms, with the number of UEIs dropping by 12.56% in the last five years. However, most of this change—10.21%—occurred between FY2018 and FY2020, with only a 2.62% drop after the new SDB goals took effect. Unexpectedly, SDBs that were not 8(a) firms or 8(a) Joint Ventures (JVs) declined the fastest during the FY 2020–FY2022 time period—the very period which should have encouraged firms to register as SDB. Indeed, presumably these were the very firms the Administration sought to encourage to contract with the government. Interestingly, two categories of SDBs saw significant increases during these 5 years. 8(a) JV firms increased by 24.8% overall, with more than 10% of that growth in the past 2 years. Likewise, ANC-owned firms also increased by 11.83% over 5 years, with much of the growth in the past 2 years.

Table 8. Trends in Types of SDB Entities Receiving Awards, FY2018–FY2022

Fiscal Year	All UEI	Small Business	SDB	SDB, not 8(a) or 8(a) JV	8(a)	8(a) JV	ANC Owned
2018	123,230	80,399	29,867	23,563	5,818	500	786
2019	110,549	72,065	27,830	21,931	5,395	524	792
2020	105,599	68,727	28,007	22,232	5,224	567	821
2021	99,762	64,774	27,418	21,676	5,152	606	838
2022	95,234	61,716	26,941	21,246	5,087	624	879
Change 18–20	14.31%	14.52%	6.23%	5.65%	10.21%	-13.40%	-4.45%
Change 20–22	9.82%	10.20%	3.81%	4.44%	2.62%	-10.05%	-7.06%
Change 18–22	22.72%	23.24%	9.80%	9.83%	12.56%	-24.80%	-11.83%

FPDS Ad Hoc Report

Average Size of Awards

Of SDBs that received contracts in the 5-year period, the average amount they earned increased by 57.51%. This was a slower rate of growth than found in the average total contract value for small businesses. Interestingly, the largest growth occurred among firms that are neither an 8(a) or 8(a) JVs, with the average amount earned to these companies nearly doubling between 2018 and 2022, increasing by a remarkable 92.8%. While slightly more growth occurred in the years prior to the increased SDB goals, it may be attributable more of these firms leaving the industrial base in the prior years. Only 8(a) JV firms saw a decline in the mean total award value, with the average peaking in FY 2020. This may be partially explained by the fact that 8(a) JVs also had the largest growth in the number of firms receiving contracts. The average total award to an ANC firm grew by over $3 million during the 5-year period, compared to less than a million in growth for small, SDB, non-8(a) SDBs and 8(a) JVs. Awards to traditional 8(a) firms grew by approximately $1.5 million, or roughly half as much as awards to ANCs.

Table 9. Mean Total Award by Type of SDB Entities Receiving Awards, FY2018–FY2022

Fiscal Year	Small Business	All SDB	SDB, Not 8(a) or JV	8(a)	8(a) JV	ANC
2018	$1,555,260.08	$1,696,155.32	$883,485.04	$4,753,384.14	$4,422,213.67	$11,082,800.36
2019	$1,822,339.50	$1,945,387.19	$1,077,528.30	$5,213,420.03	$4,615,087.99	$11,602,658.62
2020	$2,145,009.37	$2,211,131.38	$1,252,230.96	$5,919,238.34	$5,629,919.17	$13,243,333.29
2021	$2,333,834.60	$2,365,491.79	$1,394,820.10	$6,083,848.78	$5,484,094.69	$13,650,769.39
2022	$2,531,292.38	$2,671,628.76	$1,703,325.85	$6,393,270.46	$5,298,229.25	$14,113,532.95

FPDS Ad Hoc Report

Having examined average awards by type of SDB contractor, next this paper will look at average awards to firms qualifying for only one socioeconomic category. Compared to SDB-only firms, small business-only firms had lower average contract values, and the disparity increased from $433,336.89 in FY 2018 to $723,601.69 in FY 2022. In contrast, while the average value of contracts awarded to an SDB-only in FY 2018 was $224,231.57 less than that awarded to all SDBs, but by FY 2022 the difference had dropped to only $154,590.34. SDB-only awards were larger than WOSB-only awards, a gap that is growing each year. However, SDVOSB-only and HUBZone only firms did substantially better than SDB-only firms, with $3.1 million and $1.7 million more in FY2018 awards, respectively. This difference grew to over $4.1 million and $2.8 million by FY 2022.

Table 10. Mean Total Award by Unique Socioeconomic Designation, FY2018–FY2022

Fiscal Year	SB-Only	SDB-Only	WOSB-Only	HZ-Only	SDVOSB-only
2018	$1,038,586.87	$1,471,923.75	$1,049,156.71	$3,244,900.29	$4,598,504.11
2019	$1,292,450.85	$1,757,410.73	$1,324,560.11	$3,934,264.51	$5,262,882.25
2020	$1,522,518.10	$1,972,058.17	$1,449,691.94	$4,594,841.26	$6,133,941.96
2021	$1,679,849.00	$2,189,450.12	$1,555,034.19	$4,036,639.32	$6,589,183.89
2022	$1,793,436.73	$2,517,038.42	$1,837,544.87	$5,365,391.66	$6,685,814.32

FPDS Ad Hoc Report

However, it is possibly that these disparities could be accounted for by a few very large awards distorting the mean, so it is necessary to also look at median awards. In this 5-year period, for SDBs that received contracts, the median total of award size increased by 95.17%, with nearly 50% of the growth occurring prior to the Biden Administration's SDB initiatives, and only 30.63% growth since FY 2020. This was roughly the same rate of growth found in median small business awards - 30.43%. Again, the greatest relative growth occurred among SDB firms that are neither an 8(a) or 8(a) JVs, with the median award doubling between 2018 and 2022, and with a growth rate of 101.15%. Similarly, 8(a) JV firms saw a decline in the average total award value, with the median in FY 2020 exceeding the median in FY 2022 by almost half a million. While the change in mean dollars could have been explained by the increased number of 8(a) JVs, this is belied by finding the same trend in median values. Instead, it reflects that 8(a) JV firms were less successful in FY 2021 and FY 2022. The median award per ANC firm grew by over $1.6 million during the 5-year period, so that the median ANC award is now over 3,479% higher than the median award to small businesses, 2,604% higher than the median award to SDBs, and 261% higher than the median award to 8(a) firms. Median awards to 8(a) firms grew by approximately $200,000, roughly only 20% as much as median awards to ANCs.

Table 11. Median Total Award by Type of SDB Entities Receiving Awards, FY2018–FY2022

Fiscal Year	Small Business	SDB	SDB, Not 8(a) or JV	8(a)	8(a) JV	ANC
2018	$51,752.19	$66,837.00	$38,000.00	$1,081,458.76	$1,270,414.90	$2,357,193.48
2019	$64,317.37	$82,890.00	$48,350.00	$1,183,694.00	$1,591,642.05	$3,167,686.93
2020	$74,851.92	$99,857.00	$55,888.49	$1,312,482.02	$1,953,659.50	$3,452,984.25
2021	$83,202.44	$109,349.49	$64,300.74	$1,211,899.10	$1,320,202.22	$3,071,126.58
2022	$97,632.90	$130,443.21	$76,438.50	$1,299,306.00	$1,519,998.98	$3,397,567.59

FPDS Ad Hoc Report

When a similar analysis is conducted for the median total awards to firms qualifying for only once socioeconomic category, the results are mixed. Compared to SDB-only firms, small business-only firms had lower median contract values, and the disparity increased during these 5 years. In FY 2019, small business-only firms had median contract values of 80.7% of SDB-only firms, and this fell to 66.4% in FY 2022. As with mean awards, median SDB-only awards were larger than WOSB-only awards. Likewise, this gap is increasing each year. Similarly, SDVOSB-only and HUBZone-only firms did substantially better than SDB-only firms, with $274,464.82 and $217,813.66 more in FY2018 awards, respectively. This difference grew to over $429,569.61 and $330,971.56 by FY 2022. While the SDVOSB growth may be explained by increases in contracting with SDVOSB firms by the Department of Veterans Affairs. However, when coupled with the half percent increase in HUBZone goaling and the increase in HUBZone UEIs receiving awards, the increase in HUBZone mean and median awards is noteworthy.

While the difference between mean SDB and SDB-only awards fell between FY 2018 and FY 2022, the median difference between the two categories grew, from $18,670.66 more for all SDB firms in FY 2018 to $34,959.23 more in FY 2022. This suggests that there were several large awards to SDB-only firms in the past few years, but that the average SDB-only firm has not seen its awards grow at the same pace as firms with large awards.

Table 12. Median Total Award by Unique Socioeconomic Designation, FY2018-FY2022

Fiscal Year	Small Business Only	SDB-Only	WOSB-Only	HUBZone	SDVOSB
2018	$38,889.48	$48,166.35	$39,995.00	$265,980.00	$322,631.16
2019	$47,250.00	$60,697.96	$49,899.80	$323,134.01	$381,534.75
2020	$52,000.00	$69,447.70	$55,750.00	$307,542.82	$432,852.55
2021	$53,890.20	$78,506.58	$64,761.30	$372,023.38	$525,685.10
2022	$63,484.63	$95,483.98	$71,191.83	$426,455.54	$525,053.59

FPDS Ad Hoc Report

The median awards to small businesses, small business-only, SDB, SDB-only, WOSB, and WOSB-only firms fall below the simplified acquisition threshold, meaning that unless a multiple award contract was used, these were required to be set aside for small business (FAR 19.502-2(a)).

Industrial Classification of SDB Awards

Finally, it is necessary to examine whether policy changes affected the sourcing of goods and services by industrial category. When examining the 24 sector categories, or two-digit NAICS codes, a few trends emerge. Regardless of socioeconomic category, in FY 2022 all small businesses received a higher percentage of prime contracts in the Mining, Quarrying, and Oil and Gas Sector (Mining); Educational Services Sector (Education); and Public Administration Sector than they had received in FY 2018. Similarly, all firms improved from FY 2020 to FY 2022 in five sectors: Mining; Utilities; Construction; Manufacturing (Metals, Machinery, Computer Electronics, Electrical Transportation Equipment, Furniture, Miscellaneous) and Public Administration. Overall, small businesses did better in two-thirds of sectors since FY 2020, but declined in two-thirds of sectors since FY 2018. SDBs fared better: they improved in 16 sectors since FY 2020, and only declined in nine since FY 2018. This is a better performance than any other socioeconomic group, with WOSBs improving in 15 categories in the past 2 years but declining in 14 categories over 5 years; HUBZones improving in 11 categories since FY 2020 but declining in 10 since FY 2018; and SDVOSB improving in 12 since FY 2020 and declining in 13 since FY 2018. Apart from the sectors mentioned at the beginning of this paragraph, if SDB performance improved, at least one other socioeconomic saw a reduction. This was especially noteworthy in Manufacturing (Paper, Printing, Petroleum, Coal, Chemical, Plastics, Rubber, Nonmetallic Mineral) sector, where SDB increases were offset by a decline among all other categories, including small businesses overall.

Table 13. Awards by Industry Sector, FY 2018–FY 2022

Sector		Small Business	SDB	WOSB	HUBZone	SDVOSB
Agriculture, Forestry, Fishing and Hunting	Change 2020–2022	14.31%	9.75%	3.58%	-1.36%	2.04%
	Change 2018–2022	3.64%	9.26%	0.58%	-3.72%	1.67%
Mining, Quarrying, and Oil and Gas Extraction	Change 2020–2022	26.34%	22.45%	3.64%	8.45%	0.82%
	Change 2018–2022	30.51%	21.39%	1.18%	7.38%	0.83%
Utilities	Change 2020–2022	2.40%	1.17%	0.33%	0.22%	2.60%
	Change 2018–2022	-0.41%	0.70%	-0.02%	-0.26%	2.54%
Construction	Change 2020–2022	6.50%	3.92%	0.88%	0.52%	0.67%
	Change 2018–2022	-1.91%	0.62%	-0.62%	0.38%	-0.12%
Manufacturing (Food, Textile, Apparel, Leather)	Change 2020–2022	-1.81%	-0.87%	-2.43%	-1.19%	1.45%
	Change 2018–2022	-2.37%	5.45%	-0.26%	-0.65%	1.89%
Manufacturing (Paper, Printing, Petroleum, Coal, Chemical, Plastics, Rubber, Nonmetallic Mineral)	Change 2020–2022	-6.81%	0.94%	-0.43%	-0.11%	-1.79%
	Change 2018–2022	-1.29%	1.91%	-0.38%	-0.62%	-2.60%
Manufacturing (Metals, Machinery, Computer Electronics, Electrical Transportation Equipment, Furniture, Miscellaneous)	Change 2020–2022	2.70%	0.53%	0.37%	0.24%	1.44%
	Change 2018–2022	1.12%	0.51%	-0.10%	0.19%	2.56%
Wholesale Trade	Change 2020–2022	1.91%	0.53%	1.73%	0.00%	-0.49%
	Change 2018–2022	-4.30%	0.59%	-1.07%	-0.14%	-5.24%
Retail Trade (Motor Vehicle, Furniture, Electronics, Building Material, Food, Health, Gasoline, Clothing)	Change 2020–2022	5.35%	0.62%	1.82%	-4.29%	-0.71%
	Change 2018–2022	11.55%	5.51%	6.08%	-4.48%	-1.56%
Retail Trade (Sporting Goods, General Merchandise, Miscellaneous)	Change 2020–2022	-0.55%	0.78%	-1.55%	0.53%	-0.08%
	Change 2018–2022	-8.30%	-5.92%	0.56%	0.70%	-1.79%
Transportation and Warehousing	Change 2020–2022	2.72%	2.57%	0.38%	-0.02%	-0.14%
	Change 2018–2022	4.83%	2.62%	0.13%	0.06%	-3.03%
Postal Service, Courier/Messenger, Warehousing	Change 2020–2022	2.97%	-0.48%	-1.98%	2.73%	6.18%
	Change 2018–2022	-2.31%	-0.50%	-3.04%	1.60%	0.83%
Information	Change 2020–2022	1.19%	1.08%	0.31%	-0.32%	-2.34%
	Change 2018–2022	0.30%	-0.33%	-1.31%	-0.06%	4.37%
Finance and Insurance	Change 2020–2022	-0.47%	-0.41%	0.07%	0.03%	-13.88%
	Change 2018–2022	-2.50%	-0.63%	-1.40%	0.01%	43.21%
Real Estate and Rental Leasing	Change 2020–2022	2.37%	-7.72%	-1.14%	-4.90%	2.35%
	Change 2018–2022	1.82%	-0.90%	2.98%	0.79%	-0.11%
Professional, Scientific, and Technical Services	Change 2020–2022	0.39%	0.82%	-0.73%	0.20%	0.26%
	Change 2018–2022	1.87%	1.82%	-0.34%	0.52%	0.47%
Management of Companies and Enterprises	Change 2020–2022	0.17%	-0.28%	-0.16%	0.14%	2.18%
	Change 2018–2022	-0.51%	0.16%	-0.53%	0.55%	0.24%
Educational Services	Change 2020–2022	4.10%	4.12%	-0.57%	2.74%	-1.38%
	Change 2018–2022	7.30%	4.20%	0.06%	3.47%	0.76%
Health Care and Social Assistance	Change 2020–2022	1.07%	-0.30%	-1.84%	0.37%	3.69%
	Change 2018–2022	-6.95%	-3.19%	-2.96%	0.21%	-1.49%
Arts, Entertainment, and Recreation	Change 2020–2022	-6.38%	-0.55%	1.33%	-3.11%	-5.53%
	Change 2018–2022	-15.31%	-4.02%	3.25%	-7.23%	-10.59%
Accommodation and Food Services	Change 2020–2022	-4.48%	-3.23%	0.68%	0.20%	-7.01%
	Change 2018–2022	-3.05%	-1.17%	-1.41%	0.49%	-5.72%
Other Services (except Public Administration)	Change 2020–2022	-0.97%	-0.09%	0.38%	0.27%	-2.15%
	Change 2018–2022	-3.38%	0.60%	0.33%	0.15%	-6.04%
Public Administration	Change 2020–2022	1.90%	0.64%	0.33%	0.01%	11.49%
	Change 2018–2022	1.64%	0.75%	0.20%	0.02%	12.43%

FPDS Ad Hoc Reports

However, not all sectors, or industries, are created equal in terms of Federal procurement. Taking the 50 six-digit NAICS with the highest total spend FY 2018 to FY 2022, a different picture emerges. First, 11 of these NAICS represent industries where SBA issued Non-Manufacturer Rule (NMR) class waivers or the NAICS represented a wholesaler.[4] Among these 11 NAICS, small businesses consistently well represented, with between 28.5 and 37% of dollars going to small primes. This far exceeds the 23% prime contract goal but does not significantly strengthen the industrial base. None of the socioeconomic programs meet their respective goals within these categories. While SDB contracts increased through FY 2021, they dropped again in FY 2022. SDVOSBs provide almost none of these items.

Table 14. Percentage of Prime Contracts in Top 11 NMR and Wholesaler NAICS

Fiscal Year	Small Business	SDB	WOSB	HUBZone	SDVOSB
2018	29.89%	3.85%	4.94%	2.05%	0.01%
2019	28.50%	3.32%	4.57%	1.90%	0.00%
2020	36.84%	4.17%	3.06%	1.10%	0.00%
2021	37.00%	4.98%	2.71%	1.33%	0.00%
2022	30.47%	3.19%	3.92%	1.76%	0.00%

FPDS Ad Hoc Report

Of the remaining 39 NAICS in the top 50, on average small businesses and SDBs improved in both the 2-year and 5-year period, while all other groups declined. Small businesses improved in 90% of the sectors over 2 years, and in 70% over 5 years. This was slightly better than SDBs, which improved in 80% and 70% of sectors in the 2-year and 5-year periods. Both small firms and SDBs improved in 80% of sectors between FY 2020 and FY 2022, and in 60% between FY 2018 and FY 2022. In contrast, SDVs only improved half the time, while WOSBs declined in 70% of sectors over 5 years, and HUBZones declined in 90% of sectors during the same period. All socioeconomic groups did better in construction over the 2- and 5-year period. While all groups also did better in Information Technology from FY 2020 to FY 2022, WOSBs and HUBZones saw a decline in this area over a 5-year period. Only SDBs saw a gain in the accommodation and food service sector over 5 years. It was in manufacturing that SDBs saw the greatest gains, outpacing small businesses over the past 2 years with an 8.7 increase, and having received an amazing 18.26% of all prime contract dollars awarded in these NAICS in FY 2022.

[4]For industries with NMR waivers, SBA has determined that “no small business manufacturer or processor of the product or class of products is available to participate in the Federal procurement market” (13 CFR § 121.406 (b)(5)). Wholesalers are only required to regularly deal in the item, and the value they add is by stocking the item (13 CFR § 121.402). The 11 NAICS are: 311421, Fruit and Vegetable Canning; 331410, Nonferrous Metal (except Aluminum) Smelting and Refining; 331491, Nonferrous Metal (except Copper and Aluminum) Rolling, Drawing and Extruding; 332994, Small Arms, Ordnance, and Ordnance Accessories Manufacturing; 333314, Optical Instrument and Lens Manufacturing; 333318, Other Commercial and Service Industry Machinery Manufacturing; 334210, Telephone Apparatus Manufacturing; 334516, Analytical Laboratory Instrument Manufacturing;334517, Irradiation Apparatus Manufacturing; 339113, Surgical Appliance and Supplies Manufacturing; and 424210, Drugs and Druggists’ Sundries Merchant Wholesalers.

Table 15. Changes to Percentage of Awards to Each Socioeconomic Category in the Top 39 Non-NMR NAICS

Sector	Small Business	SDB	WOSB	HUBZone	SDV
Accommodation and Food Services					
Change 2020–2022	4.23%	0.62%	0.14%	0.28%	-1.78%
Change 2018–2022	-2.95%	2.67%	-0.51%	-31.37%	-2.33%
Administrative and Support & Waste Management & Remediation Services					
Change 2020–2022	4.35%	-0.10%	0.51%	1.92%	4.29%
Change 2018–2022	4.06%	1.41%	-1.22%	-5.34%	3.69%
Construction					
Change 2020–2022	14.37%	5.02%	0.85%	3.93%	8.42%
Change 2018–2022	10.89%	5.73%	0.72%	2.63%	7.13%
Educational Services					
Change 2020–2022	3.70%	2.88%	-1.49%	3.64%	0.88%
Change 2018–2022	7.08%	2.18%	-1.81%	-1.07%	3.83%
Finance and Insurance					
Change 2020–2022	0.66%	0.41%	0.00%	0.00%	0.00%
Change 2018–2022	-2.45%	-0.16%	0.37%	-0.40%	0.00%
Health Care and Social Assistance					
Change 2020–2022	-26.77%	-13.44%	-0.45%	0.23%	-0.48%
Change 2018–2022	-15.79%	-7.75%	-0.29%	-6.71%	-0.31%
Information					
Change 2020–2022	2.46%	2.75%	0.05%	0.48%	0.33%
Change 2018–2022	1.23%	2.78%	-0.34%	-9.34%	0.30%
Manufacturing					
Change 2020–2022	7.80%	8.70%	-0.13%	-2.35%	-1.18%
Change 2018–2022	20.08%	7.73%	0.28%	-4.23%	1.24%
Professional, Scientific, and Technical Services					
Change 2020–2022	8.97%	2.04%	0.44%	-2.47%	0.20%
Change 2018–2022	2.72%	0.66%	-0.15%	-2.87%	-2.87%
Utilities					
Change 2020–2022	5.81%	0.25%	0.00%	0.01%	-0.04%
Change 2018–2022	6.36%	-0.14%	-0.04%	-14.52%	-0.03%

FPDS Ad Hoc Report.

Two NAICS have historically had very high small business representation: 42412 and 54159. In NAICS 424120, Stationery and Office Supplies Merchant Wholesalers, over 70% of dollars are routinely awarded to small firms. In FY 2020, small business received 82.55% of dollars spent in this classification, but SDBs accounted for only 6.49% of those dollars. By FY 2022, the small business percentage had fallen to 45.06%, but SDBs now account for 19.56% of this spend. NAICS 541519, Other Computer Related Services, is particularly interesting for two reasons. First, the government has spent over $20 billion a year in this sector the last 3 years. Second, NAICS 541519 includes Information Technology

Value Added Resellers (ITVARs). Of every dollar spent with ITVARs, at least 15% and not more than 50% may be services provided by the small firm, with up to 85% coming from the cost of goods the ITVAR is reselling to the government (13 CFR 121.201). In FY 2020, small firms received 55.96% dollars spent in this industry, and SDBs accounted for 24.85% of this spend. By FY 2022, small business spend had increased 4.74%, and SDB spend totaled 28.34%, translating to about $3.1 billion in additional SDB spend.

Conclusion and Recommendations

The federal government has been exceeding the statutory SDB goal for nearly 30 years. Prior to the Administration's administrative goal change, in recent years SDB have received about 10% of prime contract dollars. While the initiative has increased reported dollars spent with SDBs, this success has several complications. First, despite statements by the President and in the OMB memo about increasing spending with "traditionally underserved entrepreneurs" such as WOSBs and HUBZones, the percent of spend being awarded to WOSBs has declined under each year of the initiative and HUBZones have seen only meager increases. The government has never met the statutory HUBZone goal, and has only met the WOSB goal twice, raising questions about why the has moved away from meeting the congressional goals.

The second complication is the method of contracting with SDBs. While the SDB goal has always been met using firms that do not qualify as WOSBs, HUBZones, or SDVOSBs, the majority of the increased spending has come from contracts with ANCs, WOSBs, SDVOSBs, and HUBZones that are certifying as SDBs. Indeed, there has been nearly a 5% increase in contracts being set-aside to SDBs using HUBZone, WOSB, and SDVOSB set-aside authorities, and a 2.5% increase using small business set-aside authorities, while 8(a) awards declined. This means that aside from the ANCs companies, increases are coming at the expense of traditional 8(a) companies and WOSB, SDVOSB, and HUBZone firms that do not qualify as SDBs. This is especially true for the SDVOSB program, which had an 8.6% increase in set-aside and sole source awards to SDB firms in the past 2 years, and where the mean and median awards to firms that were both SDVOSBs and SDBs grew faster than awards to SDVOSBs alone.

Third, absent a certification program or protest process, there is no way to know whether this increased spend is reaching true SDBs. The complicated requirements for qualifying as an SDB coupled with a push to award more dollars to SDB may lead to companies incorrectly self-certifying. The data on WOSB registrations certainly suggests that a large number of firms are certifying based on gender, even though women are not presumed disadvantaged. Likewise, it suggests that firms are not applying the economic disadvantage test.

Fourth, despite the Administration's efforts to increase the number of SDBs participating in federal procurement, the number of SDBs has fallen by nearly 10% in the past five years. While this is a slower rate of decline than small businesses overall, the only growth in SDB qualifying firms has come from ANCs and 8(a) JVs. The former were already participating in the industrial base but have added new subsidiaries, and the latter represent partnerships with non-SDB firms. ANCs also saw a 27.35% increase in mean awards per company, and a 44% increase in media award size.

Finally, while SDBs improved their representation across industry sectors – more than any other socioeconomic category, including small businesses – other programs did not fare well. They improved in 15 sectors and only declined in nine since FY 2018. In contrast, WOSBs declined in 14 sectors, HUBZones declined in 10, and SDVOSB 13. 13 since FY 2018. Generally speaking, SDB increases were offset by a decline among all other categories. Of the 39 NAICS with the highest federal spending but not subject to NMR waivers, SDBs improved in 80% of the sectors since the 2021 policy changes, but SDVOSB declined in 50% of industries, WOSBs declined in 70% of industries, and HUBZones declined in 90% industries. A substantial amount of increased SDB spend also came from industries where much of the cost reflects reselling goods.

Therefore, as the Administration continues to pursue ever higher levels of SDB spending, it should consider the following adjustments:

1. It should make it clear that increases in SDB spending must not come at the expense of the other socioeconomic programs, and it should make it a priority to meet all of the statutory small business goals before seeking to increase spending with other programs.
2. Clarify how businesses qualify for the SDB program so that firms are neither inadvertently or fraudulently self-certifying, and either institute a certification program or allow for competitor size-status protests.
3. Align goals to NAICS codes or industry sectors where the government could benefit from new entrants or additional SDB participation so that agencies do not seek the path of least resistance to goal attainment.

References

8(a) Business Development/Small Disadvantaged Business Status Determinations, 63 Fed. Reg. 35772 (June 30, 1998). (https://www.govinfo.gov/content/pkg/FR-1998-06-30/pdf/98-17195.pdf

Adarand Constructors, Inc. v. Peña, 115 S.Ct. 2097 (1995). https://casetext.com/case/adarand-const-v-pena

Alaska Native Claims Settlement Act Amendments of 1987, Pub. L. 100-241, 100 Stat. 1788 (1988). https://www.fns.usda.gov/pl-100-241

An Act to Amend the Small Business Act of 1953, as Amended, Pub. L. 85-536, 72 Stat. 384 (1958). https://www.govinfo.gov/link/statute/72/384

An Act to Amend the Small Business Act and the Small Business Investment Act of 1958, Pub. L. 95-89, 91 Stat. 533 (1977). https://www.govinfo.gov/content/pkg/STATUTE-91/pdf/STATUTE-91-Pg419.pdf

An Act to Amend the Small Business Act and the Small Business Investment Act of 1958, Pub. L. 95-507, 92 Stat. 1757 (1978). https://www.govinfo.gov/content/pkg/STATUTE-92/pdf/STATUTE-92-Pg1757.pdf

Auletta, L. (2004, December, 27). *Expired program authority for the price evaluation adjustment for Small Disadvantaged Business Program* (Civilian Agency Acquisition Council Letter 2004-04). https://www.acquisition.gov/sites/default/files/page_file_uploads/2004-04.pdf

Business Opportunity Development Reform Act of 1988, Pub. L. 100-656, 102 Stat. 3853 (1988). https://www.congress.gov/bill/100th-congress/house-bill/1807/text

Biden, J. (2021, June 1). *Remarks by President Biden commemorating the 100th anniversary of the Tulsa race massacre.* https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/06/02/remarks-by-president-biden-commemorating-the-100th-anniversary-of-the-tulsa-race-massacre/

Clinton, W. (1995, July 19). *Memorandum on affirmative action*. https://www.govinfo.gov/content/pkg/WCPD-1995-07-24/pdf/WCPD-1995-07-24-Pg1264.pdf

Consolidated Omnibus Budget Reconciliation Act of 1985, Pub. L. 99-272, 100 Stat. 82 (1986). https://www.govinfo.gov/content/pkg/STATUTE-100/pdf/STATUTE-100-Pg82.pdf

Executive Order 13,985 of January 20, 2021, Advancing Racial Equity and Support for Underserved Communities Through the Federal Government, 86 Fed. Reg. 7009 (2021). https://www.federalregister.gov/documents/2021/01/25/2021-01753/advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government

New York Times Staff. (1995, July 20). Excerpts From Clinton talk on affirmative action. *New York Times*, B10. https://www.nytimes.com/1995/07/20/us/excerpts-from-clinton-talk-on-affirmative-action.html
Executive Order 14091 on Further Advancing Racial Equity and Support for Underserved Communities Through The Federal Government 88 Fed. Reg 10825 (2023). https://www.federalregister.gov/documents/2023/02/22/2023-03779/further-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal
Federal Acquisition Regulation; Small Business 60 Fed. Reg. 2302 (January 6, 1995). https://www.govinfo.gov/content/pkg/FR-1995-01-06/pdf/95-2.pdf
Federal Acquisition Regulations for Small Disadvantaged Businesses, 63 Fed. Reg. 35714 (June 30, 1998). https://www.govinfo.gov/content/pkg/FR-1998-06-30/html/98-17157.htm
Federal Acquisition Streamlining Act of 1994, Pub. L. 103-355, 108 Stat. 3243 (1994). https://www.congress.gov/bill/103rd-congress/senate-bill/1587
John S. McCain National Defense Authorization Act for Fiscal Year 2019, Pub. L. No. 115-232, 132 Stat. 1635 (2018). https://www.congress.gov/bill/115th-congress/house-bill/5515/text?r=1&q=%7B%22search%22%3A%5B%22PUBLIC+LAW+115-232%22%5D%7D
Kaminski, P. (1995, October 25). *Air Force acquisition circular (AFAC) 92-50*. https://www.acquisition.gov/reg-change-notice/afa9250
Making Continuing Appropriations for the Fiscal Year 1987, Pub. L. 99-500, 100 Stat. 1783 (1986). https://www.govinfo.gov/content/pkg/STATUTE-100/pdf/STATUTE-100-Pg1783.pdf
Miller, J. (2021, December 2). *Advancing equity in federal procurement* (M-22-03 2). https://www.whitehouse.gov/wp-content/uploads/2021/12/M-22-03.pdf
National Defense Authorization Act for Fiscal Year 1987, Pub. L. 99-66, 100 Stat. 3816 (1985). https://www.congress.gov/99/statute/STATUTE-99/STATUTE-99-Pg164.pdf
Notice of Determination Concerning Price Evaluation Adjustment, 63 Fed. Reg.35714 (June 30, 1998). https://www.govinfo.gov/content/pkg/FR-1998-06-30/pdf/98-17157.pdf
Rothe Dev. Corp. v. Dep't of Defense, 545 F.3d 1023 (Fed. Cir. 2008). https://casetext.com/case/rothe-dev-v-dept-of-defense
Small Business Act of 1958, as Amended, Pub. L. 85–536 as Amended Through Pub. L. 117–328 (2022, December 29). https://www.govinfo.gov/content/pkg/COMPS-1834/pdf/COMPS-1834.pdf
Small Business Administration. (2022). *NMR class waiver database of June 2022*. https://www.sba.gov/document/support-non-manufacturer-rule-class-waiver-list
Small Business Administration. (2022, March). *FY22 small business goaling guidelines*. https://www.sba.gov/sites/default/files/2022-06/FY22%20Small%20Business%20Goaling%20Guidelines_Final_220623%28R%29.pdf
Strom Thurmond National Defense Authorization Act for FY 1999, Pub. L. 105-261, 112 Stat. 3007 (1998). https://www.govinfo.gov/content/pkg/PLAW-105publ261/html/PLAW-105publ261.htm
System for Award Management. (2023). *Entity registration checklist*. https://sam.gov/content/entity-registration
Title 13 - Business Credit and Assistance, Chapter I – Small Business Administration, 13 C.F.R. § 101 et seq. (2022). https://www.govinfo.gov/content/pkg/CFR-2022-title13-vol1/xml/CFR-2022-title13-vol1-chapI.xml
Title 48 - Federal Acquisition Regulations System, Part 19 – Small Business Programs, 48 13 C.F.R. § 19 (2021). https://www.govinfo.gov/content/pkg/CFR-2021-title48-vol1/xml/CFR-2021-title48-vol1-part19.xml
Title 49 – Transportation Part 26, Participation by Disadvantaged Business Enterprises in Department of Transportation Financial Assistance Programs, 49 C.F.R. § 26 (2021). https://www.govinfo.gov/content/pkg/CFR-2021-title49-vol1/xml/CFR-2021-title49-vol1-part26.xml
Young, S. (2022, October 4). *Increasing the share of contract dollars awarded to small disadvantaged businesses* (M-23-01). https://www.whitehouse.gov/wp-content/uploads/2022/10/M-23-01.pdf

Educational Leadership, Collaboration, and Relevance: A Get Real, Get Better Approach to Innovating Major Weapon Systems Cost Analysis, Price Analysis, and Contract Negotiations in Higher Education

Kelley Poree—is the Contract Management Area Chair for the Department of Defense Management, Naval Postgraduate School (NPS). Prior to joining NPS in 2019, Poree completed a recalibration tour, where after retiring as the Deputy Chief of Contracts for the Fighter Bomber Directorate, Chief of Contracts for the Development, and Integration Division, and warranted contracting officer (unlimited) in 2015 at Wright-Patterson Air Force Base, OH, he entered civil service as a contract specialist, 2015–2017. After that, he participated in the limited and unlimited warrant contracting officer boards from 2017–2019. This recalibration tour highlighted gaps between acquisition theory and practice as well as opportunities to build bridges. Poree holds an MBA with a concentration in strategic purchasing (NPS, 2009). He is also a third-year doctoral student at Indiana Wesleyan University and received the 2021 Future of Pricing Award. [kelley.poree@nps.edu

Abstract

Against the backdrop of the need to accelerate advantage through decision making and process improvements, this auto-phenomenological study explored an educational leader's implementation of the U.S. Navy's Get Real, Get Better (GRGB) methodology to innovate major weapon systems cost analysis, price analysis, and contract negotiations courses, and the extent to which this action improved student learning outcomes at the Naval Postgraduate School in Monterey, California. The contribution of this paper lies in the adaptation and application of the U.S. Navy's GRGB methodology in assessing and implementing viable solutions to modernize MN3320/MN3321Cost Analysis, Price Analysis, and Contract Negotiations Courses. The findings support educational leadership, collaboration, and relevance are essential components that underpin the GRGB methodology for continuous improvement.

Introduction

Leadership and collaboration are crucial for success in today's complicated and fast evolving national security environment. Nowhere is this more apparent than in the Defense Acquisition System (DAS), where, on the one hand, the key weapon systems acquisition execution domain leaders are continuously responding to acquisition cost, schedule, and performance management challenges and personnel turnover. On the other hand, leaders in the education domain must continually innovate to stay current. Traditional approaches to educational leadership, collaboration, and relevance in this regard, have, in part, led to a limited focus on technological advancements, evolving stakeholder expectations, and the need for real-world application (Halabieh et al., 2022, p. 15).

These technological advancements in a cost/price analysis and contract negotiations environment higher education context, include proposal development analysis software used by most major defense contractors—ProPricer Contractor Edition (CE). This overlooked area also includes a limited awareness of the complementary proposal analysis software—ProPricer Government Edition (GE)—used by some DoD agencies within the major weapon systems execution domain; for example, Naval Strategic Systems Program Office and the F-35 Joint Strike Fighter Program Office (Cooper, 2022, p.i). In response, the U.S. Naval Postgraduate School's Contract Management Area implemented activities aligned with the Chief of Naval Operation's Get Real Get Better (GRGB) concepts and methodology to innovate major weapon systems cost/price analysis and contract negotiations courses. Honest assessments, learning from mistakes and fostering a culture of continuous improvement are hallmarks of the GRGB leadership philosophy (Gilday, 2022; Lescher, 2021). While several successful GRGB process implementations such as the Naval Facilities Engineering Command (Korka, 2022) exist across the Naval Enterprise, this is the first application of the GRGB methodology in a DoD higher education context.

Purpose

This study examined the lived experience of an educational leader's implementation of the U.S. Navy's GRGB methodology, and the extent to which these activities shaped the quality of education, and improved student learning outcomes in the Naval Postgraduate School's Cost Analysis, Price Analysis, and Contract Negotiations courses in Monterey California, from the winter quarter 2021 to the summer quarter of 2022. Ultimately, the alignment of higher education activities with the realities of the mission area affects major weapon systems acquisition program outcomes.

Literature Review

Before discussing educational leadership, collaboration, and relevance in higher education, it is important to first define the GRGB methodology and underlying theories, namely, Von Bertalanffy's (1972) General Systems Theory (GST), which seeks to explain how system parts interact with the whole, and Schein's (2017) theory on culture, which emphasizes how fundamental assumptions, values, and norms, convey meaning and shapes individual behavior. Equally important is the need to provide background on the major weapon systems cost analysis, price analysis, and contract negotiations execution and higher education domain challenges.

GRGB Methodology

The U.S. Navy's GRGB methodology is a Navy-proven leadership and problem-solving philosophy focused on enabling a culture of continuous improvement through rigorous self-assessments and root-cause analysis at organizational levels (Gilday, 2022; Lescher, 2021). The Get Real (GR) element emphasizes interrogating personal beliefs and assumptions based on data, facts, and diverse input. The Get Better (GB) of element of GRGB encourages leaders to self-correct based on the GR results through accountability and collaboration (Lescher, 2022). When combined, these elements require organizational leaders to build trust, be courageous, and experiment to find the best solution by using a learning mindset (Lescher, 2022).

Implicit in the requirement for leaders to possess a learning mindset in the GRGB approach is the need to understand system-level organizational complexities and associated cultural elements. For example, the organizational and cultural differences between the higher education domain and the execution domain. Von Bertallanfy (1972) described this phenomenon of organizations through a GST, defining it as a set of elements, hierarchically structured into interactive systems (p. 417). GST explains the internal and external exchanges between the system (or organizations) and the environment across several unifying concepts (a) systems philosophy, (b) systems science, and (c) systems technology (Von Bertallanfy, 1972, p. 414, pp. 412–423). Systems philosophy refers to how leaders define the system, or "nature of the beast" (p. 421). Thus, without a definitional consensus on the system, observers in the cost analysis/price analysis, and contract negotiations execution and education domains may view the system as real, inferred from observation, or as conceptual, with differing perspectives on reality (Von Bertallanfy, 1972, p. 422). However, with a definitional consensus on the system, leaders in both domains can understand how one area of the system interacts and affects other areas of the system.

These interacting elements establish the systems science as aspect of GST, supporting the scientific exploration of the system as a whole (Von Bertallanfy, 1972, p. 415). The final element of GST involves system technology and refers to the growing technological demands of the system—both hardware and software—in response to increasing system complexities (Von Bertallanfy, 1972, p. 420). Coupled with the GRGB approach, GST requires leaders in the education domain to consider the implications on the execution domain, and for both leaders to consider the collective implications on the DAS, as a whole.

A related system-level consideration for leaders using the GRGB approach in this context, is organizational culture. According to Schein (2017) culture refers to cumulative organizational learning of beliefs and norms through which members perceive and behave (p. 5). From a similar organizational theory perspective, Hatch (2013) noted that organization consists of culture, social structure, technology, and physical structure (p. 16). Culture also includes adopted beliefs and values. Schein (2017) also emphasized that all group learning stems from someone's original beliefs and values, establishing the foundation for "the sense of what ought to be" (p. 18). This foundation of what ought to be could vary widely in both domains, depending on organizational performance imperatives (Zaccaro & Kilimoski, 2001, p. 11), or corresponding mission pressures. Shared group experiences, on the other hand, establish this sense of what ought to be through social validation, that is, groups learn behaviors and beliefs through the interactions with founders (Schein, 2017, p. 20). Over time, these values and beliefs become a shared philosophy in dealing with risks and uncertainty (Schein, 2017, p. 20). While the relationship between both domains contributes to the DAS risks and uncertainties as a whole positively, or negatively, Senge (2006) argued that most organizations do a poor job of understanding systemic problems (p. 315).

Execution Domain Cost/Price Analysis and Contract Negotiations Challenges

For more than three decades, the DoD has continued experience systemic challenges in the weapon systems acquisition execution domain (GAO, 2021). The historical works of the GAO, RAND, and those of others, revealed three interrelated challenges—people, products, and process—to major weapon systems cost analysis, price analysis, and contract negotiations. In the first challenge area, the acquisition workforce (people), a 2019 RAND Assessment of Gaps in Business Acumen of Knowledge of Industry within the Defense Acquisition Workforce concluded that knowledge gaps within the acquisition workforce exist in the areas of business acumen, industry operations and, industry motivations to an indeterminant extent (Weber et al., 2019, p. 112). Further, and from a process standpoint, these knowledge gaps impact the workforce's ability to develop requirements, conduct cost/price analysis, and negotiations (p. 112). Similarly, the GAO's 2019 Weapon Systems Assessment of the DoD's $1.9 trillion portfolio of major weapon systems programs concluded that inconsistent application of knowledge-based acquisition practices cascades risks over the entire acquisition cycle (p. 2), primarily supported by non-competitive cost/price analysis and contract negotiation activities (process) to deliver the major weapon system (product). Recommendations to improve these challenge areas focus on implementing knowledge-based practices, clarifying business acumen needs and industry-related knowledge, a focus on back to basics, and the need for government-industry co-education (GAO, 2021; OUSD[A&S], 2020, p.1; Weber et al., 2019, pp. 199–120). Although these recommendations for what to do exist, leaders in the execution domain must consider how to implement these recommendations in the context of dynamic organizational leadership performance imperatives—cognitive, social, personal, political, technological, financial and staffing (Zaccaro & Klimoski, 2002, p. 11)—the realities of mission area.

Education Domain Cost/Price Analysis and Contract Negotiations Challenges

Similar people, product, and process challenges areas also exist in the higher education domain. From a people perspective, a broad range active-duty military from all service component and DoD civilians attend in resident and distance learning cost/price analysis and contract negotiation courses. McCabe et al. (2020), compared the acquisition career development paths of Navy, Marine Corps, and Army acquisition officers (program management and contracting) and found that each service has different entry points in the acquisition career field (p. 90). DoD civilians attend these courses within the education domain at different career points with between five and 10 years of acquisition experience (p. 138). Contained in the idea of students with different entry points into the career field and higher education is the notion of a diverse group of learning styles. Kolb (2015) defined student learning types as divergers, assimilators, convergers, and accommodators. Divergers process information reflectively, perceive information concretely, and learn by feeling and watching. Assimilators process reflectively and perceive information abstractly. Convergers process information through active experimentation and perceive reality through abstract conceptualization. Accommodators process through active experimentation and perceive information through concrete experience (p.114). Educational domain leaders, then, must consider the challenges associated with a broad range of active-duty military and DoD civilians with various, career field experiences, as well diverse learning styles.

Product and process challenges also exist in the education domain. Products challenges center on curriculum and content design challenges, and process challenges include the active learning of the acquisition and contracting process of the execution domain. Halebiah et al. (2022) identified several problems facing institutions of higher learning: weak utilization of technology, limited pedagogical improvements, outmoded teaching methods and content, and lack of training and career-relevant skills. These researchers in educational leadership also call for contemporary researchers to investigate ways to best educate and train students to work cooperatively, to develop tolerance for differing viewpoints, and engage in civil discourse that is productive and not polarizing (Halabieh et al, 2022, p. 13).

Educational Leadership, Collaboration, and Relevance

Educational leadership involves the process of creating **collaborative** learning environments, relevant and worthwhile curricula, and innovative partnerships for the common good (Halabieh et al., 2022, p. 12; Sternberg, 2005, p. 203; Toker, 2022, p. 234). Halabieh et al. (2022) argued that curriculum relevance emphasizing the tools required for success in the workplace such as critical and creative thinking, problem-solving, co-operation, tolerance, and collaboration are essential elements for consideration by leaders in the education domain (p. 2). These concepts are important as educational leaders develop new generations of thinking to address critical issues across multiple disciplines (Halabieh et al., 2022, p. 3). Sternberg (2005) underscored that a model of educational leadership involves wisdom, intelligence, creativity, and synthesis; in particular, a great educational leader uses creativity to generate possible solutions of problems; analytical intelligence to evaluate the quality and depictions of solutions of problems; practical intelligence implements decisions and to persuade others of their value; and wisdom to ensure the help of the common good (p. 204).

Consistent with this perspective on the common good, Toker (2022) argued that educational leaders must, through education, create students that will become future leaders, who have clear visions and mission, as well as the ability to perform in the real-world (p. 234). Educational domain leaders should consider the relationships between the historical, contemporary, and future contexts that current and future military and civilians will likely encounter and incorporate these elements into the education process. Moreover, adult learning theorist Cyril O. Houle (1996) argued that the fundamental system of education design centers on the idea that, “the analysis for planning educational activities must be based on the realities of the human condition and the state of constant change” (p.42). In light of the focus on building future leaders, these perspectives on educational leadership, collaboration, and relevance, coupled with Houle’s (1996) view on the fundamental systems of education design suggests that educational and execution domain leaders should consider these concepts earlier in the professional development process for both buyers and sellers within the U.S. Government.

Methods

Analyzing the GRGB implementation process and the extent to which the GRGB methods improved education quality and student outcomes in cost analysis, price analysis, and contract negotiations higher education courses involved data collection and analysis using two parts within two related phases of the GRGB Process Framework (Figure 1). The first phase, Get Real, included two parts: (1) determining the current state of major weapon systems cost analysis, price analysis, and contract negotiations execution and education domains, and (2) establishing a standard through an analysis of execution and education domain data. The second phase for the GRGB, Get Real, also involved two parts: (1) identifying the problem and developing solutions included a comparison of the execution and domain data, as well using Kolb’s (1984) experiential learning cycle within a higher education contexts, and (2) continuously improving and learning centered on analyzing course evaluations across four course offerings: Winter 2021, Summer 2021, Winter 2022, and Summer of 2022, respectively. This study explored three research questions:

1. How did an educational leader integrate the U.S. Navy’s GRGB approach into existing cost analysis, price analysis, and contract negotiations curricula and course structure?
2. To what extent, if any, did the implementation of the GRGB approach improve or sustain student understanding of the cost analysis, price analysis, and contract negotiations principles?
3. What were the leadership outcomes, best practices, and lessons learned?

Figure 1. The GRGB Process Framework.
(U.S. Navy, 2021).

Get Real (GR): Determine the Characteristics of the Execution and Education Domains

To understand the characteristics of the Major Weapon System Cost/Price Analysis, and Contract Negotiations execution domain (GR part 1), data from the FY20–FY23 Department of Defense (DoD) Program Acquisition Cost by Weapon Systems were analyzed in terms of mission area categories, major defense contractors, and service departments. Corresponding Federal Procurement Next-Generation Data (FPDS-NG) were also analyzed for each major defense contractor in the FY20–FY23 DoD Program Acquisition Cost by Weapon System to gain insight into contract types, contract methods, appropriation types, and typical negotiation environments (sole-source, non-competitive, negotiations process) for each mission area category. The final analysis of the GR element involves a review of Zach Cooper's (2022) *Perceptions on the Feasibility of Implementing Innovative Cost and Pricing Analysis Software Across Naval Sea Systems Command*.

MN3320 Cost/Price Analysis and MN3321 Contract Negotiations student demographics, course content/design, and learning objectives, were analyzed to determine the characteristics of the higher education domain. First, student demographics were analyzed to understand the entry points into the acquisition career field. Second, course content/design were analyzed to understand the extent to which course content and structure were aligned with the major weapon systems cost/price analysis and contract negotiations processes. Third, learning objectives were categorized and aligned with course content according to progressive levels of theory and practice using Bloom's Taxonomy. Specifically, learning objective action verbs were categorized into one of six Bloom categories, representing the cognitive activities requirements for successful course completion.

GR: Establishing Alignment as a Standard

The results from the education domain analysis results were compared to execution domain results to determine opportunities for alignment and the rationale to establish a standard. The intellectual foundation for this standard involved Houle's (1972) fundamental system of education design and Kolb's (1984) experiential learning theory.

Get to the Root Cause: Learn to See and See to Learn

As depicted in Figure 1, this phase of the process, establishing a standard, is based on understanding potential root causes and informs the bridge to between the GR and GB phases. After understanding the alignment opportunities between the cost/price analysis execution and education domains, additional class and researcher observations were considered to understand to potential root cause.

GB: Identify Problems and Solutions, Continuously Improve and Learn

Data from the preceding GR phase were analyzed to develop potential solutions and to continuously improve. Continuous Improvement and Learning centered on incorporating Kolb's (1984) Experiential Learning Model into a more cohesive course design for MN3320/MN3321 Cost Analysis, Price Analysis, and Contract Negotiations.

Regarding continuous improvement and learning, course evaluation forms (CEFs) were analyzed from each of the eight course offerings in Winter 2021, Summer 2021, Winter 2022, and Summer 2022, respectively. CEF statements included five statements in three categories related to learning, course content and design, and instructor performance.

Results

Analysis of the FY20–FY23 Program Acquisition Costs by Weapon System and the corresponding FPDS-NG data revealed several characteristics of the Major Weapon Systems Acquisition cost analysis, price analysis, and contract negotiations execution domain. Table 1 shows that between FY20 and FY23, the DoD and service components acquired 83 Major Defense Acquisition Programs (MDAPs) across seven primary mission area categories: Aircraft and Related Systems, C4I Systems, Ground Systems, Missile Defense, Munitions, RDT&E, Shipbuilding and Space Programs.

Table 1. Mission Area Categories. (DoD, 2022).

Mission Area Category	Count of Major Weapon Systems Summary
Aircraft and Related Systems - Joint Service	6
Aircraft and Related Systems - US Air Force	11
Aircraft and Related Systems - US Army	3
Aircraft and Related Systems - US Navy / US Marine Corps	7
C4I Systems - Joint Service	1
C4I Systems - US Army	1
Ground Systems - Joint Service	1
Ground Systems - US Army	6
Ground Systems - US Marine Corps	1
Missile Defeat and Defense Programs - Joint Service	3
Missile Defeat and Defense Programs - US Army	2
Missiles and Munitions - Joint Service	4
Missiles and Munitions - US Air Force	3
Missiles and Munitions - US Army	2
Missiles and Munitions - US Navy	4
Missles and Munitions - Joint Service	6
Missles and Munitions - US Army	1
Shipbuilding and Maritime Systems - US Navy	11
Space Based Systems - US Air Force	10
Grand Total	83

Table 2 captures fifteen major defense contractors (MDC) who produce and sustain these weapon systems across the mission area categories. For example, as a prime or subcontractor, Lockheed Martin produced and sustained between 11 and 15 MDAPs. The Boeing Company produced and sustained at least 10 MDAPs across the remaining mission area categories as either a prime or subcontractor.

Table 2. Mission Area Categories Major Defense Contractors. (DoD, 2022).

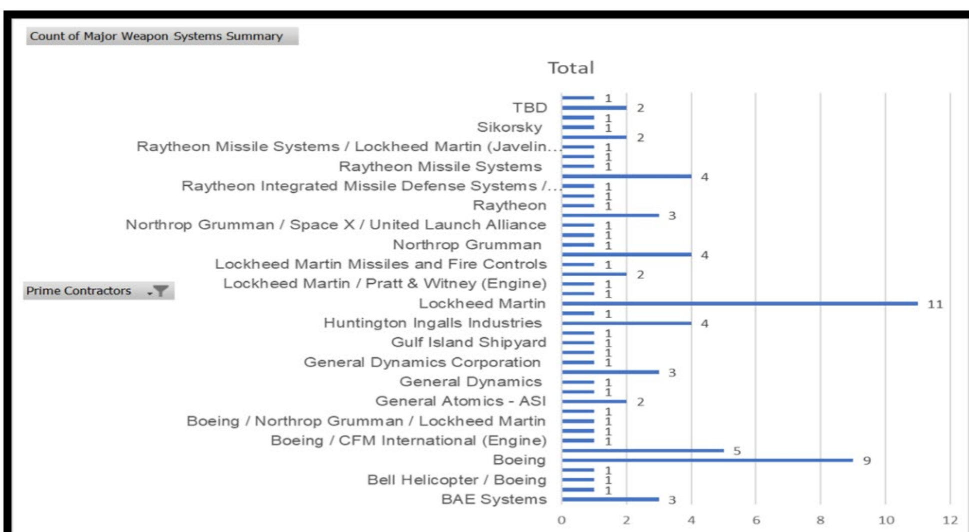


Table 3. Major Defense Contractors and Execution Domain Characteristics. (FPDS-NG, 2023).

Mission Area Category	Count of Weapon Systems
Aircraft and Related Systems - Joint Service	6
C-130J Hercules	1
Lockheed Martin	1
FA862520D3000	1
FAR 15 Sole-Source	1
O &S Sustainment	1
Multiple Types	1
Procurement, RDT&E	1
F-35 Joint Strike Fighter	1
Lockheed Martin / Pratt & Witney (Engine)	1
N0001917C0001	1
FAR 15 Sole-Source	1
O &S Sustainment	1
Fixed Price Incentive / Cost	1
Procurement, RDT&E, FMS	1
MQ-1B / MQ-1C Predator/Gray Eagle	1
General Atomics - ASI	1
W58RGZ19C0027	1
FAR 15 Sole-Source	1
O &S Sustainment	1
CPIF	1
O&M	1
MQ-4C /RQ-4 Triton/GlobalHawk/NATO AGS	1
MQ-9 Reaper	1
V-22 Osprey	1
Grand Total	6

Mission Area Category	Count of Weapon Systems
Aircraft and Related Systems - Joint Service	6
C-130J Hercules	1
F-35 Joint Strike Fighter	1
MQ-1B / MQ-1C Predator/Gray Eagle	1
MQ-4C /RQ-4 Triton/GlobalHawk/NATO AGS	1
Northrop Grumman	1
N0001919C0008	1
FAR 15 Sole-Source	1
O &S Sustainment	1
FFP	1
Procurement	1
MQ-9 Reaper	1
General Atomics - ASI	1
FA868920D2020	1
FAR 15 Sole-Source	1
O &S Sustainment	1
FPIF	1
Procurement	1
V-22 Osprey	1
Bell Helicopter / Boeing	1
N0001917C0015	1
FAR 15 Sole-Source	1
O &S Sustainment	1
Fixed Price Incentive / Cost	1
Procurement, O & M	1
Grand Total	6

Results from the corresponding mission area category FPDS-NG data revealed service component contracting organizations typically used various contract types and Federal Acquisition Regulation (FAR) Part 15 Contract by Negotiations (non-competitive/sole source). Table 3 shows the following characteristics of the Aircraft and Related Systems—Joint Service for the C-130J FY20–FY23:

- C-130J Hercules Prime Contractor: Lockheed Martin
- Procurement Instrument Identifier: FA862520D300
- Contract Method: Contract by Negotiation (Sole-Source)
- Acquisition Life Cycle Phase: Operations and Sustainment
- Contract Types: Multiple Types
- Appropriation Types: Procurement and RDT&E

These results were not only consistent across remaining MDAPs in this mission area category, but also the remaining six mission area categories in Table 1.

Table 4. Major Weapon Systems Execution Domain Process Characteristics. (Poree, 2023).

Characteristics of Major Weapon Systems Cost Analysis, Price Analysis, and Contract Negotiations Environment	Execution Domain	
	Buyers	Sellers
83 Major Defense Acquisition Programs	X	X
Appropriation Types: RDT&E, Procurement, and O&M	X	X
Contract Types: Cost and Fixed Priced Variants	X	X
Contract Methods: FAR 15 Contract by Negotiations (Sole-Source)	X	X
Sole-Source Contracting Process	X	X
Buyers Release Request for Proposal (RFP) (Letter)	X	
Sellers Receive RFP		X
Sellers Develop Proposals Using Software		X
Buyers Receive Seller's Proposal / Determine Adequacy	X	
Buyers Conduct Fact-Finding	X	X
Technical Evaluations (Excel Spreadsheets)	X	
Proposal Analysis Software	/	X
Cost/Price Analysis (Active / Buyer-Developed Excel Spreadsheets)	X	
Pre-Price Negotiation Memorandum	X	
Business Clearance	X	
Negotiations (Using Proposal Analysis Software)	/	X
Final Price Negotiation Memoradum	X	
Contract Clearance	X	
Contract Award	X	X

Table 4 captures the 83 MDAPs, common appropriation types, typical contract method/types, and the supporting sole-source contracting process in the execution domain. The “X” indicates buyer and seller participation and awareness of the execution domain task or characteristic. The “/” indicates a limited buyer or seller awareness of the execution domain task or characteristic. These particular results were captured during the first week of each course. Supporting a limited buyer awareness exists regarding the seller’s use of proposal development software, Cooper’s (2022) study, Perceptions on the Feasibility of Implementing Innovative Cost/Price Analysis Software in Naval Sea Systems Command (NAVSEA), concluded that some organizations such as Navy Strategic Systems Programs, the F-35 Joint Strike Fighter Program Office implemented ProPricer Government Edition (GE) software to analyze proposal with favorable outcomes. However, other organizations such as Naval Sea Systems Command (NAVSEA) were unaware of the software (p. i). By extension, buyers also had a limited awareness of using the ProPricer GE in the negotiations process. Conversely, Cooper’s (2022) study also showed that nine of the 10 major defense contractors used ProPricer Contrator’s Edition to develop proposals.

Table 5. Education Domain Characteristics: Students Demographics. (Poree, 2023)

Course	Number of Military	Number of Civilians	Total
MN3320/MN331 Winter 2021	31		31
MN3320/MN331 Summer 2021	10	24	34
MN3320/MN331 Winter 2022	22		22
MN3320/MN331 Summer 2022	10	14	24
Grand Total			**111**

Analysis of the student demographics for each course offerings in Table 5 revealed a total of 111 students participated during this evaluation period; 31 active-duty students from different service components and entry points in the career field participated in MN3320/MN3321 in Winter 2021. A total of 34 active-duty military and civilians participated in MN3320/MN3321 in Summer 2021. In Winter 2022, a total of 22 active-duty military participated in the courses. Finally, a diverse group of active-duty military and DoD civilians participated in the educational events in Summer 2022.

Table 6. Major Weapon Systems Execution and Education Domain Comparison. (Poree, 2023).

Characteristics of Major Weapon Systems Cost Analysis, Price Analysis, and Contract Negotiations	Execution Domain		Education Domain		Alignment Areas	
	Buyers	Sellers	Buyers	Sellers	Buyers	Sellers
83 Major Defense Acquisition Programs	X	X	/	X	X	X
Appropriation Types: RDT&E, Procurement	X	X	/	X	X	X
Contract Types: Cost and Fixed Priced Variants	X	X	X	X		
Contract Methods: FAR 15 Contract by Negotiations (Sole-Source)	X	X	X	X		
Sole-Source Contracting Process	X	X	X	X		
Buyers Release Request for Proposal (RFP) (Letter)	X		X			
Sellers Receive RFP		X	X	X		
Sellers Develop Proposals Using Software		X	X	X	X	X
Buyers Receive Seller's Proposal / Determine Adequacy	X		X	X		
Buyers Conduct Fact-Finding	X	X	X	X		
Technical Evaluations (Excel Spreadsheets)	X		X			
Proposal Analysis Software	/	X	X	X	X	X
Cost/Price Analysis (Active / Buyer-Developed Excel Spreadsheets)	X		X			
Pre-Price Negotiation Memorandum	X		X			
Business Clearance	X		X			
Negotiations (Using Proposal Analysis Software)	/	X	X	X	X	X
Final Price Negotiation Memoradum	X		X			
Contract Clearance	X		X			
Contract Award	X	X	X	X		

A comparison of the Execution Domain and Education Domains revealed cost/price analysis and contract negotiations concepts captured in the course content as indicated by a *black "X."* A *red "X"* indicated concepts not captured in the initial course content; with concepts partially addressed in the course content, captured by the *red "/"* in Table 6. For example, in the Education Domain course concepts highlighted major weapons, but did not specifically address the 83 MDAPs, common major defense contractors, contract methods, contract types and the sole-source contract negotiations captured in Table 1 and Table 2 above. Further, the results showed a limited awareness regarding sellers and buyers using ProPricer CE and ProPricer GE to develop and analyze proposals, as well as using the software in the contract negotiations process.

The Execution and Education Domain Comparison also revealed areas of alignment as indicated by a green "X." The first area, 83 MDAPs, highlighted opportunities to focus on the top 15 major defense contractors in Table 1 and the characteristics of the Execution Domain identified in Table 3. The results also showed several additional opportunities to align domains more closely by bringing a higher level of awareness of: common appropriation types, seller's proposal development software, buyer's proposal analysis software, conducting contract negotiations with the software.

Table 7. Education Domain: Informing Experiential Learning, Cohesive Course Design. (Poree, 2023)

Characteristics of Major Weapon Systems Negotiations Environment	**MN3320/MN3321**		**Cohesive Course Design**		**Kolb's Experiential Learning Cycle**	**Bloom's Taxonomy**
	Buyers	Sellers	Weeks	Themes /Activity	Kolb's Learning Cycle Elements	Bloom's Taxonomy Level
83 Major Defense Acquisition Programs	X	X	1	Understand Environment (Lecture)	Concrete Experience	Understanding
Appropriation Types: RDT&E, Procurement, and O&M	X	X	1	Understand Environment (Lecture)	Concrete Experience	Understanding
Sellers Develop Proposals Using Software	X	X	3	ProPricer GE Lab 2 Sellers Receive RFP / Lecture	Concrete Experience Reflective Observation	Evaluating and Creating
Proposal Analysis Software	X	X	4	ProPricer GE Lab 3 Technical Evaluations / Lecture	Abstract Conceptualization	Analyzing
Negotiations (Using Proposal Analysis Software)	X	X	6, 7, 8	ProPricer GE Lab 5: Turning Offers and Counteroffers	Abstract Conceptualization Active Experimentation	Evaluating and Creating

The preceding results in Tables 1 through 6, and the alignment opportunities in Table 7 (i.e., 83 MDAPs, Appropriation Types, Sellers Develop Proposals Using Software, and Negotiations Using Proposal Analysis Software) resulted in a more cohesive course design that incorporated ProPricer GE labs into the cost/price analysis and contract negotiations education process. Analysis resulted in incorporating ProPricer GE in week two and three, with an emphasis on concrete experiences and Bloom Taxonomy Level of Evaluating and Creating.

Table 8. Course Evaluation Form Scores and Outcomes by Course Offering. (Python, 2021, 2022)

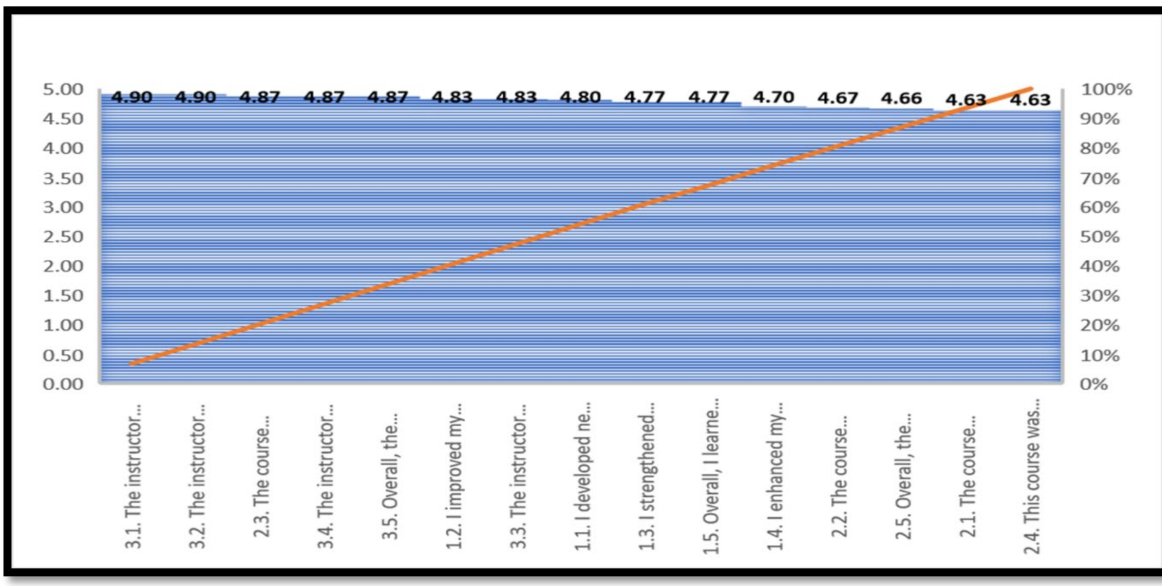
Course Evaluation Statements	MN20 W-21	MN21 W-21	MN20 S-21	M21 S-21	MN20 W-22	MN21 W-22	MN20 S-22	MN21 S-22	Avg.	Total	% Of Total
1.1. I developed new skills and abilities.	4.80	4.87	4.37	4.42	4.82	4.86	4.92	4.92	4.75	5.00	95%
1.2. I improved my understanding of the subject.	4.83	4.83	4.37	4.32	4.91	4.82	4.92	4.92	4.74	5.00	95%
1.3. I strengthened my analytic capabilities.	4.77	4.77	4.32	4.32	4.77	4.86	4.92	4.92	4.71	5.00	94%
1.4. I enhanced my ability to think critically.	4.70	4.70	4.26	4.26	4.82	4.86	4.92	4.92	4.68	5.00	94%
1.5. Overall, I learned a great deal.	4.77	4.80	4.21	4.21	4.86	4.86	4.92	4.92	4.69	5.00	94%
2.1. The course material engaged me in the subject matter.	4.63	4.86	4.37	4.35	4.86	4.91	5.00	5.00	4.75	5.00	95%
2.2. The course assignments reinforced course content.	4.67	4.79	4.42	4.45	4.86	4.91	5.00	5.00	4.76	5.00	95%
2.3. The course content was relevant to my program of study.	4.87	4.93	4.53	4.60	4.82	4.86	5.00	5.00	4.83	5.00	97%
2.4. This course was academically challenging.	4.63	4.71	4.21	4.40	4.86	4.82	4.75	4.83	4.65	5.00	93%
2.5. Overall, the course was well designed.	4.66	4.79	4.21	4.20	4.91	4.91	4.75	4.75	4.65	5.00	93%
3.1. The instructor created a productive classroom environment.	4.90	4.83	4.50	4.50	4.91	4.91	5.00	5.00	4.82	5.00	96%
3.2. The instructor encouraged student participation.	4.90	4.90	4.72	4.70	4.91	4.91	5.00	5.00	4.88	5.00	98%
3.3. The instructor was helpful when I had difficulties or questions.	4.83	4.90	4.56	4.55	4.91	4.91	5.00	5.00	4.83	5.00	97%
3.4. The instructor provided constructive feedback.	4.87	4.87	4.50	4.40	4.95	4.91	5.00	5.00	4.81	5.00	96%
3.5. Overall, the instructor was effective in teaching this course.	4.87	4.87	4.50	4.30	4.95	4.91	5.00	5.00	4.80	5.00	96%

In Table 8, Course Evaluation Form (CEF) scores from Winter 2021, Summer 2021, Winter 2022, and Summer 2020, revealed a range of consistent average scores across 15 CEF statements. CEF design captured three question categories based on learning, content and course design, and instructor performance, with five questions related to each question category, for a total of 15 questions. The response options were based on a six-point Likert Scale, with 0 = No Comment, 1 = Strongly Disagree, 2 = Disagree, 4 = Agree, 5 = Strongly Agree, respectively.

Data Collection Procedures. Data collection procedures included capturing course evaluation form data at the end of each 12-week course offering for MN3320 and MN3321, anonymously and online. Data Analysis. Descriptive statistics were used to analyze course participant responses from eight class offerings: Winter 2021, Summer 2021, Winter 2022, and Summer 2022, respectively. participant CEF responses 83 out of 111 course participants completed CEFs for MN3320 Cost/Price Analysis: 84 out of 111 course participants from MN3321 Contract Negotiations, resulting in 75% and 76% response rates, respectively.

For Learning Outcome Statements 1.1–1.5, the average scores were 4.75, 4.74, 4.71, 4.68, and 4.69, respectively. Course Content and Course Design Statements, statements 2.1–2.5, the average scores were 4.75, 4.76, 4.83, 4.65, and 4.65. Finally, Instructor Performance Statements (Leadership) 3.1–3.5, the average scores across the period were 4.82, 4.88, 4.83, 4.81, and 4.80. The overall average for all CEF scores across the 15 statements ranged from 4.65–4.88 or 93%–98%, respectively.

Table 9. Course Evaluation Form Data in Descending Frequency Order. (Poree, 2023; Python 2021, 2022).



Finally, Table. 9 shows the CEF score data in descending frequency order. The results changed the initial order of the CEF statements to the following:

- 3.1 The instructor created a productive environment for the class (4.90/5.00 or 98%).
- 3.2 The instructor encouraged student participation (4.90/5.00 or 98%).
- 2.3 The course content was relevant to my program (4.87/5.00 or 97.4%).
- 3.4 The instructor provided constructive feedback (4.87/5.00 or 97.4%).
- 3.5 Overall, the instructor was effective in teaching (4.87/5.00 or 97.4%).
- 1.2 I improved my understanding of the subject (4.835/5.00 or 96.6%).
- 3.3 The instructor was helpful when I had difficult questions (4.83/5.00 of 96.6%).

- 1.1 I developed new skills and abilities (4.80/5.00 or 96%).
- 1.3 I strengthened my analytical capabilities (4.77/5.00 or 95.4%).
- 1.5 Overall, I learned a great deal (4.77/5.00 or 95.4%).
- 1.4 I enhanced my ability to think critically (4.70/5.00 or 94%).
- 2.2 The course assignments reinforced course content (4.67/5.00 or 93.4%).
- 2.5 Overall, the course was well designed (4.66/5.00or 93.2%).
- 2.1 The course material engaged me in the subject matter (4.63/5.00 of 93.2%).
- 2.4 This course was academically challenging (4.63/5.00 of 92.6%).

Discussion

The results of the research, as presented in Tables 1 through 9, revealed the process of implementing the GRGB methodology into existing cost/price analysis and contract negotiations course, the extent to which the GRGB implementation process improved or sustained student understanding of the cost/price analysis and negotiation principles, and the leadership outcomes and best practices.

Get Real: Assess and Align Execution and Education Domains

The process of implementing the GRGB process into cost/price analysis and contract negotiation courses began with using the Get Real concept to assess the major weapon systems execution domain. Table 1 captured 83 MDAPs across seven mission area categories that the Department of Defense either conducted research and development test and evaluation activities or invested in more capabilities, FY20–FY23 (DoD Budget Requests, 2020–2023). This data provided insight into acquisition patterns in the major weapon systems execution domain. Further, Table 2 showed the corresponding FPDS-NG data and highlighted the common suppliers, contracting types, contracting methods, appropriation types, and acquisition life cycle phase. For example, there are a limited number of major defense contractors in the Aircraft and Related Systems—Joint Service category, with contracts awarded under FAR Part 15 Contract by Negotiations (Sole-Source). The primary contract types are Fixed Price Incentive and Cost and the typical appropriation types are procurement, RDT&E, FMS. Finally, most of the MDAPs are in the Operations and Sustainment Phase of the Acquisition life cycle. Information Tables 3 and 4, which shows the supporting sole-source contracting process, provided characteristics of the execution domain and the realities of the emission area. Adult learning theorist Cyril O. Houle (1996) argued that the fundamental system of education design centers on the idea that, “the analysis for planning educational activities must be based on the realities of the human condition and the state of constant change” (p.42).

Armed with the intellectual foundation and data to establish the characteristics of the major weapon systems execution domain, the next logical step in the GR approach involved assessing the major weapon systems education domain to understand gaps and alignment opportunities. Table 4 captured the demographic results for the MN3320 and MN3321 course offerings, Winter 2021, Summer 2021, Winter 2022, and Summer 2022, respectively. The results showed a wide range of active-duty military and Department of Defense civilians with different entry points into the acquisition and contracting career field as well as experiences. The analysis and comparison of the major weapon systems cost/price analysis and contract negotiations execution and education domains revealed several alignment opportunities. As depicted in Table 5, alignment opportunities included incorporating: (1) more information of the 83 MDAPs, (2) common appropriate types, (3) common contract types, (4) the sellers use of software to develop proposal, (5) buyers use of proposal analysis software, and (6) the use of the software by both buyers and sellers in a simulated business environment. Collectively, this formed the basis to incorporate ProPricer

Government Edition (GE) into the course content, thereby, establishing a more cohesive course design.

Get Better: Use Kolb's Experiential Learning Model, ProPricer GE, and Cohesive Design

A shown in Table 7, this data informed the use of Kolb's (1984) experiential learning theory to support the incorporation of ProPricer GE into the course content and design. In brief, the knowledge sequence involved lectures to familiarize student with cost/price analysis and contract negotiations concepts and then a ProPricer Lab to reinforce the concepts through a concrete experience, reflective observations, abstract conceptualizations, and active experimentation. Specifically, students encounter a concrete experience through the introductory lab, and then complete the rest of the experiential learning cycle through different phases of the course to include reflective observations, abstract conceptualization, and active experimentation in the contract negotiations phase, between weeks six and seven.

As shown in Table 8, students from a total of eight experiential learning experiences completed CEF for courses under the revised coursed design, Winter 2021, Summer 2021, Winter 2022, and Summer 2022. MN3320/MN3321 students across the eight courses scored no less than an average of 4.68 (or 94%) on statements 1.1–1.5 related to learning outcomes such as understanding cost/price analysis and contract negotiations skills, enhancing analytical skills, increasing the ability to think critically. The scores for statements 2.1–2.5, related to course content and design, showed average scores of no less than 4.65 (or 93%). Finally, the instructor-related leader and collaboration statements 3.1–3.5 revealed scores no lower than 4.81 (or 96%) in this assessment area. This suggests that a wide range of active-duty military and DoD civilians with diverse cultural backgrounds viewed the course content and design favorably. These results are significant in that DoD civilians in the distance learning program experienced both the educational and execution domain simultaneously. Results such as these are consistent with Von Bertallanfy's (1972) General Systems Theory (GST) in that the researcher considered the interactions of one part of the system on the whole and the growing technological demands of the system in the process, as well Schein's (2017) perspective on organizational culture and leadership.

The Importance of Educational Leadership, Collaboration, and Relevance

Educational leadership, collaboration, and relevance are essential in using the GRGB methodology in a DoD higher education context. Table 9 captured a reordering of the CEF statement based on a descending frequency order, with leadership, collaboration, and relevance-related statements capturing the upper third of the reordered statements. In particular, of the original 15 CEF statements in numerical order, statements 3.1, 3.2, 2.3, 3.4, and 3.5 were the top five statements based on descending order frequency. Statement 3.1, "The instructor created a productive environment for the class," suggests a favorable relationship to leadership and collaboration. This is also consistent with the second statement in the new order, 3.2. The third statement in the revised order, 2.3, "The course content was relevant to my program," suggests high support for relevance to students and practitioners. Similarly, the middle third of responses captured similar themes with statements 1.2, 3.3, 1.1, 1.3. The lower-third statement order included statements 1.4, 2.2, 2.5, 2.4 (the course content-related statements). The combined reordered responses suggest that educational leadership, collaboration, and relevance are critical element in the GRGB process, with an aim of educating a diverse group of active-duty military and DoD civilians, consistently.

Leadership Lessons, Best Practices, and Lessons Learned

Underpinning the leadership and course outcomes are several best practices. The first best practice is to establish a collaborative partnership with the developers of ProPricer GE to bring the software to the classroom. This collaborative relationship was established early in the planning phase based on the researcher's personal experience with the software in 2015. The next best practice is to consider both quantitative data and qualitative data in the Get Better continuous improvement phase by asking questions and documenting observations. For example, the initial introduction to ProPricer GE included a total of seven (CLINs) in the scenarios, with seven tasks and associated basis of estimates, for students in the Winter of 2021. During the course students struggled with applying concepts across seven CLINs and this was also reflected in CEF comments. As a result, the next course offering included a total of four CLINs in the scenario. The final best practice is to continuously improve. While the major weapon system execution domain has frequent acquisition patterns in terms of major defense contractors, contract types, contract, etc., the dynamics of the environment are constantly changing. Therefore, educational leaders must also consider Sternberg's (2005) model of educational leadership which includes involves wisdom, intelligence, creativity, and synthesis for the common good (p. 204). In particular, consideration of the common good should also include the wisdom to identify researcher limitations in the process.

Limitations

While the preceding tables and results demonstrate the efficacy of the GRGB methodology in a higher education context from the researcher's perspective, several study limitations exist. First, an auto-phenomenological study relies on the researcher's personal experience and, therefore, is inherently subjective. Second, other researchers may interpret the same phenomenon differently, which could lead to inconsistencies in the findings. Third, studies such as these can also introduce researcher bias, making it difficult to separate the phenomenon under study from personal experience. Including objective CEF data from anonymous participants was one way to balance limitations.

Conclusion and Recommendations for Future Research

This auto-phenomenological study examined the lived experience of an educational leader's implementation of the U.S. Navy's Get Real, Get Better (GRGB) methodology to innovate higher education cost/price analysis and contract negotiation courses and the roles of educational leadership, collaboration, and relevance in the process. Key findings show these interrelated concepts are essential in the GR and GB methodology phases. The GR phase requires educational leadership, collaboration, relevance to assess the education and execution domain gaps to align educational activities with realities of the major weapon systems cost/price analysis and contract negotiations mission area. Educational leadership, collaboration, and relevance are also essential to incorporating ProPricer GE proposal analysis software and Kolb's (1984) experiential learning models to support a revised, cohesive course design. This cohesive course placed active-duty and DoD civilians in an active cost/price analysis, and contract negotiations environment aligned with the realities of the mission area. Students from diverse organizational cultural backgrounds, and with different learning styles increased the ability to think critically about major weapon systems cost/price analysis and contract negotiations principles in and active learning business environment. While this research focused on innovating cost/price analysis and contracting in higher education, where military and civilian members participate, future research should focus on the feasibility of establishing a framework to sequencing Government-Industry co-education in an environment where government buyers and actual major defense contractor sellers go through the process in the education domain, well before conducting cost/analysis and contract negotiations in a dynamic and hyper-turbulent major weapon systems execution domain. Future researchers should also consider the extent to which educational leadership, collaboration, and relevance support the GRGB methodology to align in other functional area education and execution domains.

References

Cooper, Z. H. (2022). *Perceptions on the feasibility of implementing innovative cost and price analysis software across Naval Sea Systems Command* [Master's thesis]. https://calhoun.nps.edu/handle/10945/70648

Federal Procurement Next Generation. (2023, March). *Major weapon systems execution domain characteristics by major defense contractor.* https://www.fpds.gov/ezsearch/

Gilday, M. M. (2022, October). Get real, get better. *34th Surface Navy Association National Symposium*. https://www.navy.mil/Press

Government Accountability Office. (2021, November). *High-risk series: An update* (GAO-21-119SP). https://www.gao.gov/products/gao-21-119sp

Halabieh, H., Hawkins, S., Bernstein, A. E., Lewkowict, S., Kamel, B. U., Fleming, L., & Levitin, D. (2022). The future of higher education: Identifying current educational problems and proposed solutions. *Education Sciences, 12*(12), 888. https://doi.org/10.3390/educsci12120888

Hatch, M. J. (2013). *Organization theory: Modern, symbolic, and postmodern perspectives* (3rd ed.). Oxford.

Houle, C. O. (1996). *The design of education*. Jossey-Bass Higher and Adult Education Series. Jossey-Bass.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development.* Jossey-Bass.

Kolb, D. A. (2015). *Experiential learning: Experience as the source of learning* (2nd ed.). Pearson.

Korka, J. (2022). Get real, get better. *The Military Engineer, 114*(739), 64–67. https://www.jstor.org/stable/pdf/48668680.pdf

Lescher, W. K. (2021). *Learning from and preventing future mishaps.* U.S. Government House Armed Services Committee. https://docs.house.gov/meetings

Mccabe, A. R., Rittahawon, P., & Wilder, D. J. (2020). *Uniformed military acquisition officer career path development comparison* [Master's thesis]. https://calhoun.nps.edu/bitstream/handle

Office of the Under Secretary of Defense Comptroller. (2022). *Program acquisition cost by weapon system*. https://comptroller.defense.gov/Portals/FY2023_Weapons.pdf

Schein, E. H. (2017). *Organizational culture and leadership* (5th ed.). Jossey-Bass.

Senge, P. M. (2006). *The fifth discipline: The art & practice of the learning organization* (2nd ed). Penguin Random House.

Sternberg, R. J. (2005). WICS : A model of positive educational leadership comprising wisdom, intelligence, and creativity synthesized. *Educational Psychology Review, 17*(3). https://doi.org/10.1007/s10648-005-5617-2

Toker, A. (2022). Importance of leadership in the higher education. *International Journal of Social Sciences & Educational Studies*, *9*(2), 230–236. https://doi.org/10.23918/ijsses.v9i2p230

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2020, September 2). *“Back-to-basics” for the defense acquisition workforce* [Memorandum]. https://4edacm.dau.edu/assets/Back_to_Basics_Memo_2_Sep_2020.pdf

Von Bertalanffy, L. (1972). The history and status of general systems theory. *Academy of Management Journal*, *15*(4), 407–426. https://doi.org/10.5465/255139

Werber, L., Ausink, J. A., Daugherty, L., Phillips, B., Knutson, F., & Haberman, R. (2019). *An assessment of gaps in business acumen and knowledge of industry within the defense acquisition workforce*. RAND Corporation. https://apps.dtic.mil/sti/pdfs/AD1086560.pdf

Zaccaro, S. J., & Klimoski, R. J. (2002). *The nature of organizational leadership : Understanding the performance imperatives confronting today’s leaders* (Vol. 12). John Wiley & Sons.

Fast Following = CSO + OTA

Keith Gibson—is a managing partner at RUNYARA, LLC. [kgibson@runyara.com]

Abstract

Acquisition and technology professionals are rushing to understand the Commercial Solutions Opening (CSO). Forward thinking policy makers have handed us 10 USC 3458: Authority to Acquire Innovative Commercial Products and Commercial Services Using General Solicitation Competitive Procedures; a broadly worded acquisition authority that, if used to its fullest potential, can shift the current contracting paradigm. With this shift in the contracting paradigm comes disruption. With that disruption comes better, faster, and stronger capabilities, and at a lower cost to the taxpayer. The lack of official guidance and data need not scare the acquisition community. In fact, this works in our favor. Having designed and implemented a CSO for innovative technologies utilized by the Joint Artificial Intelligence Center (JAIC) now Chief Digital and Artificial Intelligence Office (CDAO), we aim to demystify the CSO. We will discuss concepts and tactics of the TryAI Commercial Solutions Opening model for rapid, low-cost demonstrations of innovative commercial products. This paper outlines the mechanics of designing and executing a Commercial Solutions Opening that impacts your organization.

Introduction

"Acquiring defense technology is not simply a matter of buying things, it is a matter of creating and sustaining capabilities that keep pace with the threat and maintain our military superiority. Unfortunately, the Department of Defense's acquisition process has become an impediment to our ability to maintain that edge."

—John McCain, former U.S. Senator, and Chairman of the Senate Armed Services Committee.

As members of the Defense department, we are acutely aware of the challenges facing the DoD's technology acquisition process. The acquisition process can be complex and bureaucratic, leading to significant delays and cost overruns. These challenges can hinder our ability to acquire critical technologies on time and within budget, which can impact our combat readiness and ability to maintain our military edge.

One of the primary challenges we face is the inflexibility of the acquisition process. The process can be overly prescriptive, making it difficult for industry to innovate and resulting in over-engineered systems that are expensive to build and maintain. Furthermore, the DoD's reliance on legacy systems and outdated technologies can limit our ability to integrate new systems and expose us to modern threats.

To address these challenges, we are continually exploring ways to improve our technology acquisition process. We are working to reduce bureaucratic hurdles, increase competition among contractors, and adopt more agile development processes. Additionally, we are exploring emerging technologies such as artificial intelligence and machine learning to improve our capabilities and stay ahead of emerging threats.

We understand that improving our technology acquisition process is critical to maintaining our military superiority and keeping our nation safe. By embracing innovation and streamlining the acquisition process, we can ensure that we have the technologies we need to defend our nation, protect our interests, and maintain our position as a global military leader.

Background

"The first recommendation is to create a cohort of warfighting exercises resourced by innovation funds. The goal should be operationalizing prototypes and validating requirements. ***A merit-based selection process such as commercial solutions opening should be used by chief technology officers to allocate component-specific funds of roughly $100 million each****. Congress could create 'boards of advisors' to monitor use of the funds in the year of execution."*

The Department of Defense (DoD) took a risk when it designed and authorized the Commercial Solutions Opening Pilot Program (CSOP) in 2017. The CSO's regulations are a loose set of guidelines that quickly allows acquisition professionals to "learn the rules like a pro, so you can break them like an artist." This is because the rules are straight forward, and easily understandable. Operating as a General Solicitation, like a Broad Agency Announcement, the CSO is new, but feels familiar. It is being used by creative acquisition professionals to solve some of the Department's most difficult problems. It does not yet have an entrenched set of unwritten rules and local business policies that begin to slowly erode its appeal.

Acquisition professionals are complimenting the CSO (solicitation) by executing agreements (contract) under other transaction authority (OTA). Simple, straightforward agreements help bring the CSO's robust market research capability to life. Some say the CSO is the ultimate market research tool. Adding to the CSO's appeal, it allows the Department to turn market research into a contract with minimal additional justification. This concept of merit-based decision making puts the decision power where it should be, in the technologist's hands. The CSO + OTA acquisition model allows acquisition professionals to be trusted advisors and business enablers for our technical counterparts.

This paper describes the TryAI project, its innovations, and its unique acquisition approach in a way that enables other programs to emulate TryAI. After describing the basics of the TryAI CSO and its key concepts, the author will walk through the steps associated with executing this acquisition strategy. The paper then provides recommendations for successful implementation and actions that can be taken to promote low-cost demonstrations of highly innovative technologies.

Innovation Concept

The concept for solving the problem is the design of a Commercial Solutions Opening (CSO) focused specifically on artificial intelligence capabilities. The hypothesis is that a CSO can be paired with Other Transaction Authority (OTA) to facilitate rapid demonstrations of advanced capabilities.

A key feature of this innovation concept is merit-based decision making; a process that involves evaluating proposals and selecting the best solution based on a set of predetermined criteria. In the context of commercial solutions openings (CSO), merit-based decision making is used to evaluate proposals from private companies and select the solution that best meets the government's needs.

The merit-based decision-making process involves evaluating proposals based on a set of predetermined criteria and allows avoidance of time-consuming down selects or source selection panels.

Project Results

Following 24 months of research and implementation, TryAI has proven the CSO + OTA model is well adapted for demonstrations of innovative commercial technologies, to include artificial intelligence and machine learning.

TryAI has seen the most interest in the Data Readiness AI Focus Area. We've concluded that Data Readiness is the most broadly defined focus area, which is likely a contributing factor. It is also indicative of a data centric focus.

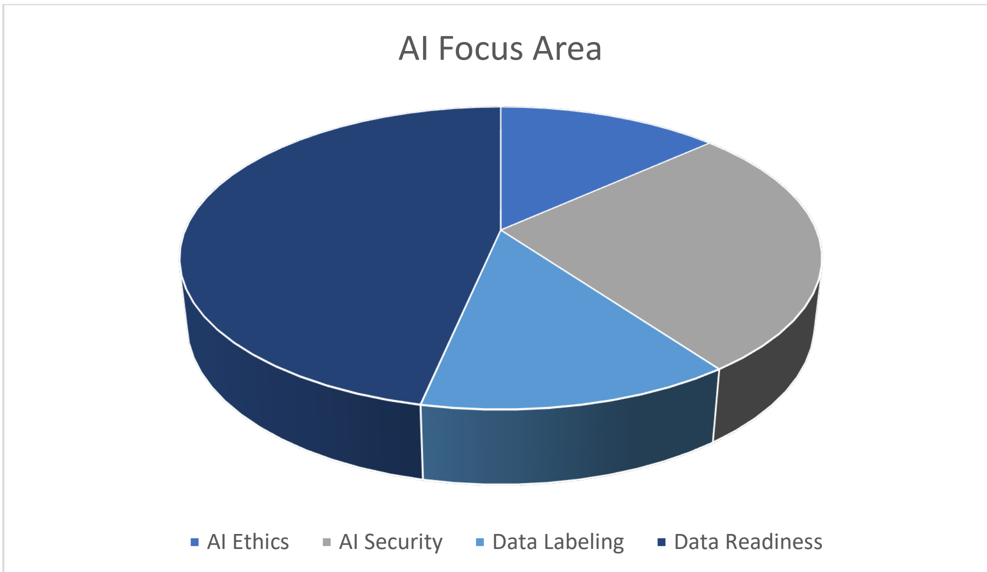


Figure 1. AI Focus Area

Demonstrations have varied in length from 30 to 365 days, with 90 days being the most common.

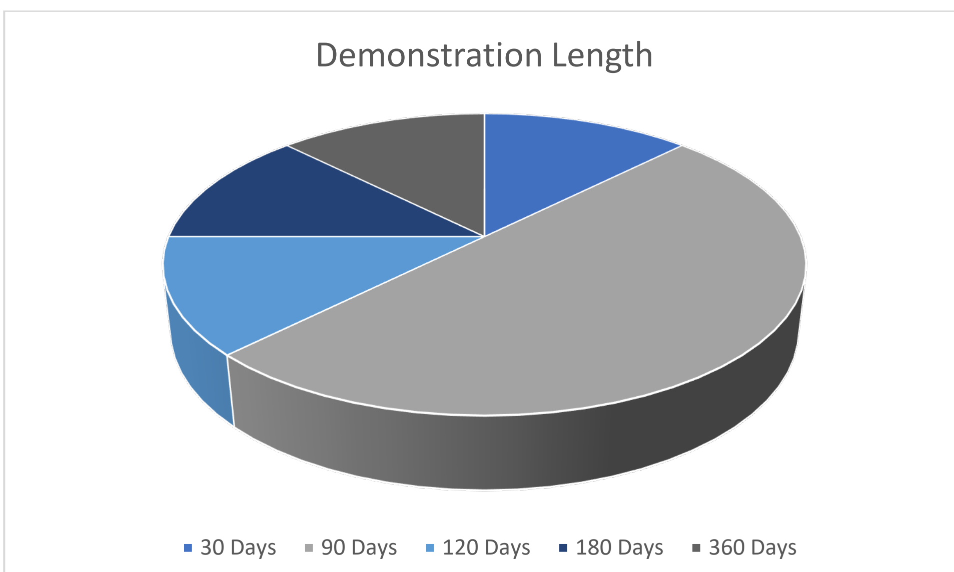


Figure 2. Demonstration Length

We've seen an almost even split between monetary and non-monetary compensation, with an average monetary compensation of approximately $50,000.

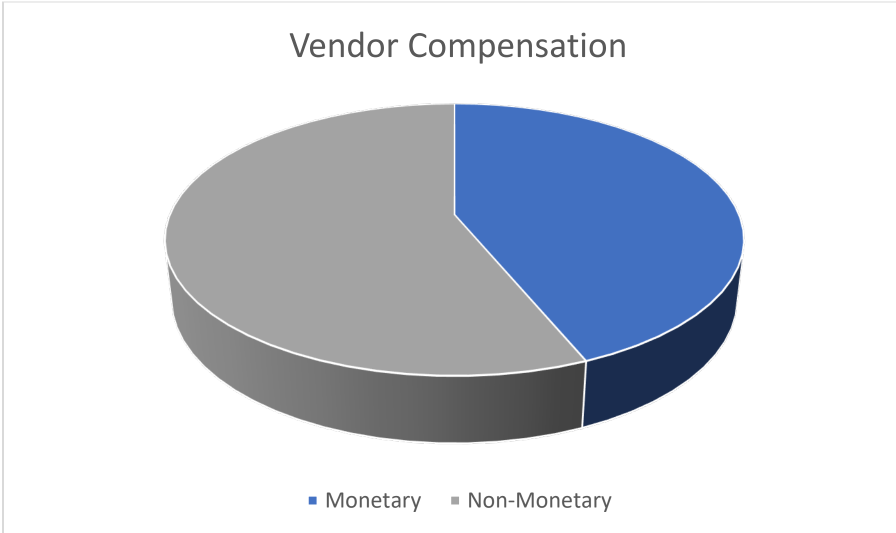


Figure 3. Vendor Compensation

Acquisition Model

To successfully execute this acquisition model, it is critical to understand the distinction between CSO and OTA. As depicted in Figure 4, the CSO and OTA are complimentary, as the CSO is a solicitation, more specifically, it is a general solicitation. You cannot award a CSO. You solicit via CSO, and you award a contract based on your CSO's competitive procedure. Let's dig deeper into the distinction.

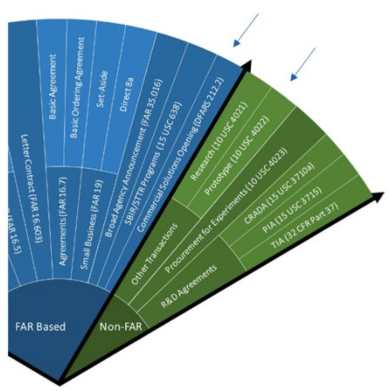


Figure 4. Acquisition Model

Commercial Solutions Opening

The Department of Defense (DoD) Commercial Solutions Opening Pilot (CSOP) program was established in 2016 as a new procurement approach to help the DoD acquire cutting-edge technology solutions more efficiently. The program is designed to promote innovation and open the field to non-traditional defense contractors, including start-ups, small businesses, and commercial firms that might not have considered doing business with the government before.

Before the creation of the CSO program, the DoD faced significant challenges in acquiring emerging technologies quickly and efficiently. The CSO program aims to solve this problem by streamlining the procurement process and creating a platform for non-traditional defense contractors to offer their solutions to the DoD.

One of the key features of the CSO program is the use of a competitive evaluation process to select the most promising solutions. The process is designed to be transparent, objective, and fair. It begins with an initial screening of proposals, followed by a detailed evaluation of the technical and business aspects of the proposals, and ends with a final selection of the most promising solutions. This process ensures that the DoD selects the best solutions from a wide range of non-traditional defense contractors.

Another key feature of the CSO program is that it offers non-traditional defense contractors a way to get involved in government procurement opportunities. This approach promotes innovation and opens the field to new perspectives and ideas. The CSO program seeks to build partnerships with non-traditional defense contractors, with the aim of developing and deploying emerging technologies that will provide significant benefits to the DoD. The program represents a significant shift in the way the DoD acquires emerging technologies.

Other Transaction Authority

The Department of Defense (DoD) Other Transaction Authority (OTA) was first authorized by Congress in the 1958 Space Act. The OTA allows the DoD to enter into agreements with private companies and other non-traditional contractors to develop prototypes, conduct research, and carry out production activities for new technologies or services. The OTA was created to enable the DoD to work with private industry to develop advanced technology solutions that could be quickly deployed to meet national defense needs.

One of the key features of the OTA is that it allows the DoD to enter into agreements with non-traditional defense contractors who may not have the resources or experience to navigate the traditional procurement process. This approach has been particularly useful in the development of emerging technologies, such as artificial intelligence and cybersecurity, where the expertise and innovation of private industry are crucial to success.

Another feature of the OTA is its flexibility. Unlike traditional procurement contracts, which are subject to a wide range of federal regulations and guidelines, the OTA allows the DoD to negotiate terms and conditions that are tailored to the needs of a specific project or initiative. This flexibility enables the DoD to move quickly and efficiently in response to changing national defense needs, and it allows non-traditional defense contractors to bring their innovative ideas to the table.

The OTA also offers a streamlined process for the development and deployment of new technology solutions. Because the agreements are negotiated directly between the DoD and the non-traditional defense contractor, there are fewer bureaucratic hurdles to overcome. This means that projects can be developed and deployed more quickly, allowing the DoD to stay ahead of emerging threats and challenges.

The OTA has been successful in promoting innovation and collaboration between the DoD and private industry. By working together, the DoD and non-traditional defense contractors have been able to develop and deploy advanced technology solutions that might not have been possible through traditional procurement processes. This collaboration has helped the DoD in its attempt to remain at the forefront of technological innovation and meet national defense needs now and in the future.

Fast Following

Mike Brown, the former director of the Defense Innovation Unit (DIU), coined the term "fast-following" to describe a strategy for acquiring emerging technologies. The concept of fast-following is based on the idea that the DoD cannot always be at the forefront of innovation and may not be able to develop new technologies as quickly as the commercial sector. Instead, the DoD should focus on quickly acquiring and adapting existing commercial technologies that have already been proven successful.

Fast-following involves identifying emerging technologies that are commercially available and have already been tested and proven successful in the market. The DoD can then quickly acquire these technologies, adapt them to meet military requirements, and rapidly field them to the warfighter. By adopting a fast-following approach, the DoD can save time and resources, reduce development costs, and get the latest technologies into the hands of the warfighter faster.

This approach also enables the DoD to leverage the commercial sector's research and development efforts, which often have greater resources than the DoD. By acquiring commercially developed technologies, the DoD can capitalize on the private sector's investment in innovation and quickly adopt the latest advancements.

Overall, the concept of fast-following offers a practical solution to the DoD's technology acquisition challenges. By leveraging existing commercial technologies and adapting them to meet military requirements, the DoD can quickly field new capabilities and stay ahead of emerging threats. The question is, how do you design an acquisition model that allows the DoD to fast follow?

Sharing Spectrum: JAIC's Unique Need

The Joint Artificial Intelligence Center (JAIC) was established in 2018 as a result of growing recognition that artificial intelligence (AI) would play a significant role in the future of national defense. The JAIC was created under the direction of the DoD's Chief Information Officer (CIO) to serve as the DoD's focal point for accelerating the adoption of AI across the department.

The JAIC was established to centralize the DoD's AI efforts and provide leadership, guidance, and resources to ensure that the department is effectively leveraging AI to support its mission. The JAIC merged with several other DoD organizations to become the Chief Digital and Artificial Intelligence Office (CDAO) and is responsible for several key tasks, including developing AI strategy and policy, identifying, and executing AI initiatives, and promoting collaboration and coordination across the DoD.

The early JAIC uncovered a need for a rapid, low-cost acquisition vehicle to *try before they buy* innovative technologies. The JAIC needed to quickly move from solution identification to product demonstration in under 30 days, and at price points that were sometimes below industry standards. In many instances the JAIC did not have funding to pay the vendor for their technology demonstration but had alternate "non-monetary" means of compensation. The JAIC was determined to avoid paying for a software license or product that never led to a scalable capability. The team was determined to be good stewards of the taxpayers' dollars and provide mission impact for the warfighter.

This need sparked the design, implementation, and execution of an Artificial Intelligence focused Commercial Solutions Opening later named TryAI.

Tactically Executing the Acquisition Model

1a: Design / Marketing

Designing a CSO has some of the same challenges as designing any complex requirement with the Department of Defense. It often requires various stakeholders to come together and agree on the problem they are trying to solve. To decrease the complexity, we asked stakeholders to think of this as market research, which is a primary advantage of the CSO. We didn't need to know exactly what we were looking for, rather we needed to articulate the broader field of study in which we were interested. We didn't know if industry had a brute force mathematics solution to solve our computer vision problems, but we knew we needed the market to understand that we were looking for computer vision solutions.

As a team, we determined that an 80% solution was acceptable, and we could refine our CSO announcement as we received feedback from the market and our government stakeholders. The goal is to get a "line into the water" and not suffer analysis paralysis to the point of inaction. When we designed TryAI, there simply weren't a lot of CSOs in the ecosystem that we could reference, which added to the challenge. No one we knew was using a CSO + OTA model for no-cost demonstrations of advanced technologies, which increased the complexity and opportunity. We essentially had a blank slate to design exactly what we wanted and needed, and then had the flexibility to iterate on that idea.

One thing I'd like to point out; I stated no one we knew was using a CSO + OTA model for no-cost demonstrations of advanced technologies, and I cannot conclude that no one truly was. DoD acquisition professionals are innovative and forward thinking, and our organization has many pockets of great ideas transpiring concurrently, so I don't want to imply that we did it first. On that note, we continue to refine our CSO and update the focus areas as the needs of our organization change.

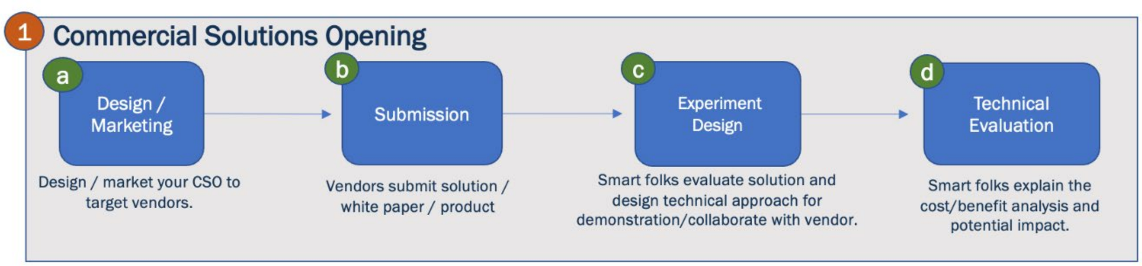


Figure 5. Commercial Solutions Opening

During the design phase, I'd encourage program leads to socialize the idea to the maximum extent practicable but be aware that personalities will need to be managed. I'd also encourage having "buy-in" at a high-level and a champion who can step-in and be the final authority, should stakeholders find themselves gridlocked. I'd encourage not trying to "boil the ocean" and ensure your focus areas are sending the correct message to industry. Pursue focus areas that are relevant to your need and ensure you have qualified personnel to evaluate submissions that propose within those focus areas.

We found that finding the right partners was critical to our success. This included the commercial vendor, but also the government requirement owner. Level setting expectations via candid conversation was critical in forming a common understanding that this process was going to be clunky, at least at first. We found motivated government program leads, with a problem they were eager to solve, and then had to sell industry vendors on the concept of not being paid for their efforts. he concept of non-monetary compensation didn't resonate with every vendor, but it did with many of them, and that's who we chose to work with.

Starting small and finding strategic partnerships to ensure we worked through major hurdles in our CSO process was critical. We deliberately did not market TryAI to the DoD, as we feared a spike in the use of a half-baked acquisition vehicle would lead to a poor user experience, poor feedback, and a failed initiative. We made a tactical decision to start small and try to get a few early wins, before marketing the CSO more broadly.

Once we decided to increase the marketing, we found that vendors had issues navigating Sam.gov to find our announcement, so we did two things that paid dividends in the long run. First, we named the CSO, TryAI, so it could be searched. Then we built an inexpensive landing page (www.tryai.tech) with a 1-click redirect to the TryAI CSO announcement on Sam.gov. These small ideas had a major impact on the user experience and overall success of the program.

Guidance for the Future

- Start small and find trusted stakeholders invested in your success
- Socialize design ideas and focus areas with key leadership stakeholders
- Find creative marketing strategies to increase digital footprint when scaling

1b: Submission

As acquisition professionals, it seems we're always trying to find the balance of not overwhelming the vendor into not responding to a solicitation, while also trying to obtain the appropriate level of information. We are also trying to balance response flexibility with response standardization. Our white paper instructions consisted of answering three questions about the product or solution by submitting:

Page 1: Cover Page

Page 2: Answers to Proposal Questions

Page 3: Answers to Proposal Questions

Page 4: Rough Order of Magnitude (as needed)

We found that our technical leads could quickly determine if something was innovative, and worth taking a deeper look. This balance has worked well from an evaluation perspective, but it may be different for the needs of individual organizations.

In the previous section on Design/Marketing, we discussed starting small and then scaling your marketing efforts. With scaling comes more submissions and a likely need for process automation. Once the process was defined, we utilized a cloud-based platform to receive submissions, catalogue them appropriately, and provide an easier review process for technical leads. Depending on our organization and anticipated number of submissions, you may want to consider automated processes at the onset of the project.

Like many organizations, we relied heavily on human oversight and organization in the early days of TryAI. The upside to this strategy is our process was well defined when we began moving towards automation, leading to a smoother implementation. We also were not sure the acquisition model would succeed, candidly.

Guidance for the Future

- Establish a repeatable process then look for opportunities to automate
- Balance the need for information with the need for streamlined submissions

1c: Experiment Design

As an acquisition professional who enjoys technology discussions, the experiment design phase is a favorite. Due to the open nature of the Commercial Solutions Opening, the design phase is an honest discussion between government and vendor. It's the government program lead's chance to ask questions and gain a better understanding. Going back to our reason for designing TryAI, we're trying to avoid the pursuit of technologies that do not lead to mission impact.

With respect to timeline, I've seen design sessions last 30 minutes and I've seen them span several weeks of back-and-forth discussions. What's great about this phase of the process is the empowerment of the technical leads, and the ability for the vendor to get clarity on expectations. When operating with buy-in on both sides, we see higher quality outcomes in success and in failure. If the experiment design phase lasts hours and the demonstration never kicks-off, that can be success. IF the experiment does not set the vendor and government up for accomplishment, it's best to not pursue the opportunity. We believe what we choose to *not* pursue is as important as what we choose to pursue.

Guidance for the Future

- Be aware of the sunk cost fallacy; its ok to walk away from a project
- Empower technical leads to collaborate openly and clarify expectations

1d: Technical Evaluation

The technical evaluation, called a Peer Evaluation, is designed to allow technical leads to make decisions and take calculated risks. The critical concept behind this is merit-based review, meaning the technical lead has discretion to determine if this product / platform merits a demonstration. This is important for several reasons, not the least of which is the ability for technical leads to make technical decisions without being hindered by the acquisition process. They are empowered to find innovative technical solutions that solve their problems, and begin a demonstration, or experiment, to test their theories and hypothesis.

It is also important, from an evaluation perspective, because when dealing with advanced technologies, it is often difficult to compare products and platforms. In the merit-based construct, there is an understanding that the innovative capability has been deemed by the technical lead to show promise in solving a problem. Here is an example: a technical lead is trying to pursue a platform that enhances computer vision for the warfighter. The platforms have similar outputs, but very different means of achieving those outcomes (see Figures 6 and 7).

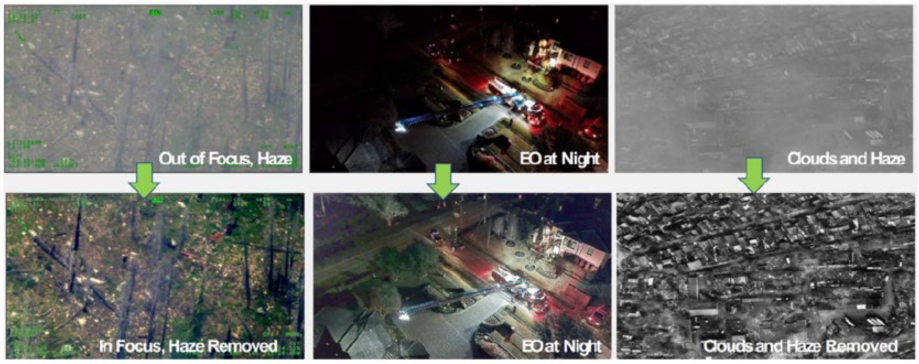


Figure 6. Vendor A Capability—GPU-Accelerated Multifilter Image Processing

Figure 7. Vendor B Capability—Brute Force Mathematical Scoring and Adjusting of Pixel Values

Advanced technologies are complex and nuanced, and often to not provide an "apples to apples" comparison. The merit-based evaluation concept allows technical leads increased flexibility and opportunity to accept calculated risks based on their technical judgement. We find that when government program managers find an exciting new technology and *own* the experiment via merit-based evaluation, they feel empowered and able to make an impact, which ultimately leads to better outcomes.

<u>Guidance for the Future</u>

- Trust your team's technical judgement and enable a merit based evaluation
- Do not expect an "apples to apples" comparison

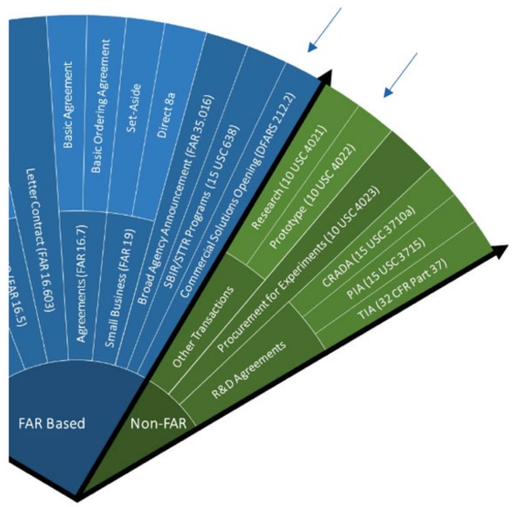


Figure 8. DAU Contracting Cone

Following the technical evaluation portion of the CSO process, we transition into the Other Transaction Agreement. Conceptually, we are transitioning from the solicitation (CSO) to the contract (OTA). The solicitation provided required documentation (white paper, experiment plan, peer evaluation) that is needed to execute the agreement portion of a TryAI CSO award. We will spend less time on the OTA portion of the process, as the reader is likely more familiar with Other Transaction Agreement, and how they function and operate. Given that OTAs are more broadly used across DoD and for a much longer period of time, we opted to adopt best practices from the DoD rather than try to design a new path.

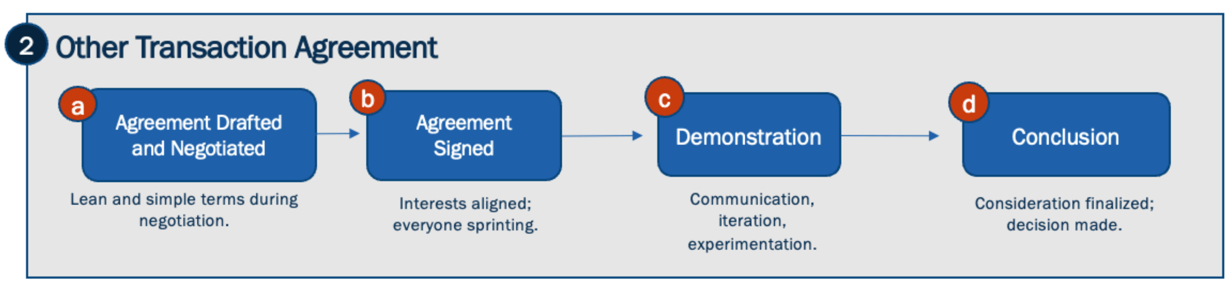


Figure 9. Other Transaction Agreement

2a: Agreement Drafted and Negotiated

We've found that simple, standard language leads to a smooth and timely negotiation process. We use a standard template and modify as needed, based on the complexity of the requirement. We also use this section of the process to think about hedging risk. The government does not always have the same leverage as private sector counterparts but can adapt its advantages for a better outcome. Our team utilizes shorter periods of performance and lower monetary compensation to hedge cost risk. We also try to make the demonstration, or experiment, an accurate representation of the longer-term project.

For example, when we ensure that our computer vision demonstration is on the same data set, in the same cloud environment, with the same constraints as the longer-term production project, we can mitigate execution risk substantially. It allows government program managers to show the true impact of the project, rather than a proposed impact. This provides government program managers with valuable data points when asking for more funding, should they see the merit in continuing the project.

2b: Agreement Signed

This is an opportunity to align interests between vendor and government and build rapport. Both parties have invested time and effort to this point and are contractually agreeing to continue this pursuit. It's an opportunity to clarify expectations and get the team excited for the project. When all parties have a clear understanding of risks and potential outcomes, chances of success (however that is defined) increase. Ensure a proper kick-off and take time to ensure all roles and responsibilities are defined. Celebrate overcoming the challenges of the DoD acquisition process.

2c: Demonstration

Program management is the key to success once the demonstration has kicked off. Constant communication and a sprint cadence commensurate with the complexity and length of the project is important. Since the government technical lead has signed the peer evaluation and the vendor has signed the agreement (contract) there should be ample buy-in on both sides. Both parties should be owning the demonstration outcome and having candid conversations about what is, and what is not, working. Like most complex endeavors, success ultimately comes down to communication and hard work.

2d: Conclusion

At the conclusion of the TryAI demonstration period of performance, we reach a pivot or persevere decision. Essentially, the technical leads have the flexibility to see more of the demonstration, or hedge risk by concluding the demonstration and allocating resources elsewhere. We find that government technical leads appreciate the flexibility of having these options, and it allows them to make decisions in the best interest of the current mission.

Persevere

A persevere decision could extend the period of performance in the event the government wants to see more of the demonstration. We could opt to add another phase of the demonstration, which allows certain flexibilities with respect to the scope of the effort. We could award a FAR-based contract, like an IDIQ or BPA. The persevere function of this process can vary widely, and that flexibility is beneficial for ensuring the demonstration leads to an acquisition strategy for a viable solution that benefits the mission. The ability to award a follow-on contract is important to the overall structure and appeal of the CSO.

Guidance for the Future

- The goal or a persevere decision is to "fast follow"

Pivot

A pivot decision, for the TryAI CSO, varies based on whether the consideration for the demonstration was monetary. Basically, it depends on if we paid the vendor or not. If we did not, then we typically provide a demonstration report as consideration. If we paid the vendor, then consideration was already received, and we typically conclude with a demonstration out-brief. It is important to note that this is just how TryAI has operated to this point and there are other creative ideas around vendor consideration.

Defense Innovation Unit has a Memorandum of Success, which we think is a fantastic idea and intend to incorporate into our process. We’ve also seen organizations use a DoD Form DD254 Contract Security Classification Specification as consideration. Understanding what is valuable to the vendor, in lieu of cash, is helpful when structuring your agreement. The goal of a pivot is to “fail fast,” or “learn fast.”

Dual Prototyping

One important concept that deserves mentioning is dual prototyping or conducting two or more demonstrations at the same time. The CSO + OTA process we outlined above remains the same, but now you have several vendors attacking the same problem. There are advantages to this approach, as you increase learning exponentially. You also increase competitive leverage, as you have competition between demonstrators. This can help when negotiating key attributes like pricing and intellectual property.

Dual prototyping also adds to the complexity of managing the demonstrations and will require additional technical and financial resources. There is a trade-off decision that must be made when considering this approach, and we’ve seen the benefits outweigh the costs in several instances.

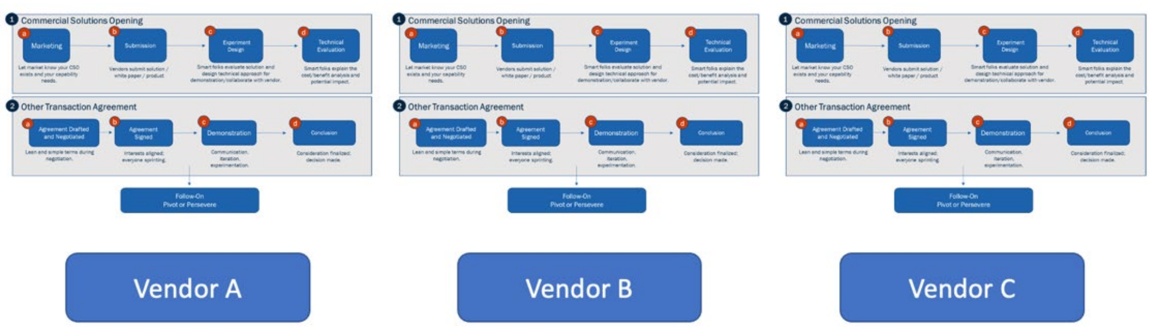


Figure 10. Dual Prototyping

Centralized Versus Decentralized CSO

We found a few critical advantages of having a centralized CSO, meaning your organization owns, operates, and administers the CSO. The main advantage is control. We found that technical leads spent countless hours fostering an environment of trustworthy collaboration and calculated risk-taking. They are often solving complex problems and need key stakeholders to understand the problem and proposed solution. When a technical lead has to reach outside of the organization for acquisition support, they can be disadvantaged. They risk losing the foundation of trust they’ve worked hard to establish, which is critical for risk-taking. They risk losing the influence that is essential for successful execution of complex strategies.

Decentralized models allow organizations to use another organizations CSO, allowing the user to avoid upfront costs and administrative burden associated with designing and implementing a CSO. With this cost and clerical advantage comes a tradeoff in the form of less control and oversight during the acquisition process.

This lack of oversight and influence in the decentralized model becomes apparent in the funding process. It’s no secret that funding projects in the Department can be challenging and executing an inter-departmental transfer of funds can be costly and time consuming. Funding process and timeline is a key consideration in implementing the CSO model. We would point to Defense Innovation Unit (DIU) as an example of a decentralized CSO with mature processes that impact the department at scale.

Conclusion

The TryAI CSO program, and the CSO + OTA model continues to promote innovation in the DoD with a rapid capability for demonstrations of advanced technologies. With the use case proven within CDAO, a framework is set for all DoD agencies to replicate this model and provide their CTOs with the acquisition flexibility required to achieve mission objectives. Every CTO in the DoD should have a CSO, whether centralized of decentralized, that is designed to meet their needs.

Resources:

https://www.armed-services.senate.gov/hearings/16-04-26-defining-defense-acquisition-reform-today-and-tomorrow

References

Innovation Funds (Center for Government Contracting, George Mason University) https://acquisitiontalk.com/2022/10/bridging-the-valley-of-death-in-dod-does-not-require-new-laws/

Matching New Technology Solutions with CSOs. https://www.ncmahq.org/Shared_Content/CM-Magazine/CM-Magazine-December-2022/Matching-New-Technology-Solutions-with-CSOs.aspx

A Fast Follower Strategy for the Department of Defense (DoD). https://assets.ctfassets.net/3nanhbfkr0pc/1Gkew4PQ4ZnRIChEIRb6BM/01f6ad3a22268141abe7dfb2f0818cd3/2022_Fast_Follower_Strategy.pdf

A Hedge Strategy to Strengthen Defense Capabilities. https://assets.ctfassets.net/3nanhbfkr0pc/5yjMUWh2OHke1R19XUN4eo/9b03f20e3f9e7fa732387ef22c7e7c00/Hedge_Strategy_MB_PS_LS_2022_ONR_Edits_07.13.22.pdf

DoD Can't Escape Claims It Overlooked AI Firm In $376M Deal. https://www.law360.com/articles/1584588/dod-can-t-escape-claims-it-overlooked-ai-firm-in-376m-deal

PANEL 13. OVERCOMING OBSTACLES TO IMPROVE ACQUISITION

Wednesday, May 10, 2023	
3:45 p.m. – 5:00 p.m.	**Chair: David H. Lewis,** VADM USN, (Ret), Senior Vice President, Maritime, Leidos ***Understanding the Valleys of Death*** Jason Thomas, Naval Air Warfare Center Aircraft Division ***DOD Weapon Systems Acquisition Progress and Challenges on GAO's High Risk List*** Anne McDonough, U.S. Government Accountability Office ***Improving Defense Acquisition: Insights from Three Decades of RAND Research*** Jonathan Wong, RAND Corporation Obaid Younossi, RAND Corporation

David H. Lewis, VADM USN, (Ret)—before joining Leidos, Lewis served as the Naval Postgraduate School Chair of Acquisition and in the United States Navy in operational, engineering, and acquisition related billets. Upon selection to flag rank in 2009, he served as vice commander of the Naval Sea Systems Command, followed by four years as Program Executive Officer (Ships), where he directed the delivery of 18 ships and procurement of an additional 51 ships. From 2014-2017, he served as commander of the Space and Naval Warfare Systems Command, where he led a global workforce of 10,300 civilian and military personnel who designed, developed and deployed advanced communications and information capabilities for the Navy. His final assignment was Director for the Defense Contract Management Agency.

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

Understanding the Valleys of Death

Jason Thomas—serves as the Digital Transformation Lead at the Naval Air Warfare Center Aircraft Division (NAWCAD) in Patuxent River, MD, where he is responsible for establishing, integrating, and implementing the command's digital transformation strategy. Primary lines of effort include, but are not limited to, MBSE, MBE, sustainment, data analytics, digital infrastructure, workforce development, and test and evaluation across NAWCAD and its Echelon IV commands. He is a Joint and Information Warfare–Qualified Aerospace Engineering Duty Officer in the Navy Reserve with experience in space operations, surface, air, and information warfare, and is a systems engineering PhD student at Naval Postgraduate School. [Jason.j.thomas34.civ@us.navy.mil].

Abstract

The Department of Defense (DoD) is falling behind in delivering capability at the speed of relevance. One way to accelerate capability delivery is to leverage industry and early research technologies and transition them to a program of record, cutting down on the time to deliver the capability. This also allows for small businesses, academics, researchers, and many others to support the warfighter in tangible, meaningful ways who otherwise would be apprehensive with horror stories of getting involved in DoD acquisition. To date, the focus on what has become known as the "valley of death," the gap between promising technology and transitioning it to a program of record, has been on government's unwillingness to accept new technology or "bureaucracy." What are rarely discussed are the influences of the Planning, Programming, Budgeting, and Execution (PPBE) process, the ill-defined requirements and interfaces for the new technology, or other factors that need to be better understood and highlighted so industry, academics, and researchers can better partner with willing entities to solve warfighting problems. This paper discusses those obstacles and challenges and makes recommendations to avoid the pitfalls.

Introduction

The Department of Defense (DoD) acquisition process is a monolith of complexity, intricacies, and enigmas wherein the output are products and services that support current or future service or joint weapon and support systems. The acquisition process starts with a capability gap being identified and validated through an evaluation process, and—if a material solution is deemed necessary—early development begins. During the early development phase, key technology aspects are identified and monitored for progress and planned for insertion into the program at the appropriate time. The process of assessing the level of maturing a particular technology is done through Technology Readiness Levels (TRLs; AcqNotes, n.d.-b). The purpose of TRLs is to measure the maturity of technology components for a system. The measurement allows project personnel an understanding of how much development a certain technology needs before being utilized. TRL is based on a scale from 1 to 9, with 9 being the most mature technology and 1 being basic principles observed and reported. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technologies.

The Technology and Risk Reduction (TMRR) phase is the dedicated phase for new technologies to be matured so they can be inserted into the allocated baseline of the program, thus reducing risk to the program (AcqNotes, n.d.-c). Previous iterations of the acquisition process had a System Design and Development (SDD) phase wherein it was assumed the technology would mature and be integrated into the weapon system baseline without a dedicated focus to mature the technology. The recognition of the risks associated with technology development and maturation, and specific action to track and measure it during the acquisition process, were positive and necessary adjustments. The DoD is developing and advancing the state of the art in technology with significant investment of resources, and more assurances are necessary. In addition to new program development, new technologies could be identified or proposed to address a need during the Production and Deployment (P&D) or Operation and Support (O&S) phases of an existing program. The general process remains the same wherein technology is identified, matured to a viable state, and then transitioned to a program of record (POR). These technologies may be in the form of computational advancements and specific algorithms, new material or coatings, advanced processing systems, communication systems, or any other myriad of advancements. Regardless of the technology, they all start at some early stage of concept and mature to a point of graduation where they are viable solutions for production systems.

As weapon systems become more complex and technologies are sought to fulfill emerging needs, DoD systems are becoming more complex and taking significantly more time to develop, field, and maintain (Greenwalt & Pat, 2021, pp. 21–22). These weapons and support systems, whether new developmental programs or fielded systems, rely heavily on technology maturation and integration to meet performance goals. Technology is both an opportunity and a liability. Technology insertion may come from large defense contractors or through Small Business Innovative Research (SBIR) proposals. One the challenges with integrating technology in the DoD ecosystem is the belief that the DoD doesn't want to or can't leverage advanced technologies in a broad sense. The so-called valley of death has been coined to explain how promising technologies are identified and desired but something in the ecosystem prevents them from transitioning to a POR (Landreth, 2022). Much of the ire for this valley of death is aimed at either the belief that the DoD is unwilling to engage with industry on new technologies or the belief that the acquisition process is too inflexible with respect to its ability to fund and adapt or transition new technologies. While there is some truth to both of these challenges in certain areas, it is important to understand there are a number of other of ways this valley of death can manifest and result in new technologies not transitioning to PORs. For the purpose of this discussion, the term *valley of death* will exclude those technologies planned for during the development of new programs and instead focus on the challenges of defining, developing, maturing, and transitioning technologies during the P&D and O&S life cycle phases. The focus of this research is to highlight additional areas to be considered when discussing the so-called valley of death and not solely blame a complex acquisition process with a number of checks and balances.

DoD Acquisition Process

The DoD acquisition process starts and ends with the warfighter. Operational personnel receive products and services, and once the battlespace changes, they generate operational needs statements to fulfill the newly identified gap. The full acquisition process for a major defense system is shown below, and is commonly referred to as the "wall chart" or "horse blanket chart" (Figure 1). The chart outlines the major steps and milestones a program progresses through as it matures. Each milestone is either an assessment or system maturity or formal review with required acquisition documents signed by the respective executive agents to confirm that all technical and program reporting requirements are met and on track. Anything that jeopardizes program development timelines is carefully monitored and dealt with; programs are cancelled, and careers go "off-track" if the program does not progress as intended. Within the acquisition process, a program will need to resource to its current and future needs. These resources may be in the form of personnel with specific skill sets or funding streams to "pay the bills" with the right appropriation of funding. The major appropriation categories are Research, Development, Test and Evaluation (RDT&E), Procurement, Operations and Maintenance (O&M), Military Personnel (MILPERS), and Military Construction (MILCON). Each category has subcategories for more specialized uses, and each appropriation has a specific, lawful use. For example, the Procurement appropriation is used to fund the purchase of aircraft, ships, and so on, and cannot be used to fund, say, depot maintenance activities. Additionally, using O&M funding for research and development of analytical infrastructure projects would also be a misappropriation of funds. The program must carefully plan the development of their weapon system with the right phasing of personnel and appropriation funds to execute and stay on track (AcqNotes, n.d.-a). Technology insertion and development is usually funded with RDT&E funds, which are more abundant in a programs' early development phases, and significantly reduced in the P&D and O&S phases. This is one of the common arguments in valley of death discussions where the case is argued that more RDT&E funding would allow new technologies to be transitioned to PORs. While this is true in theory, in practice we can look at other areas of challenges for adoption of new technologies.

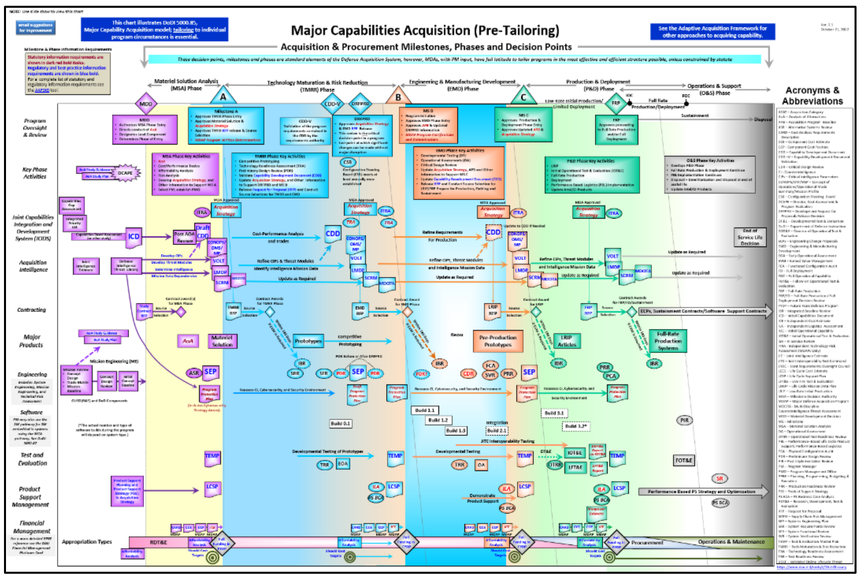


Figure 1: Major Defense Acquisition Process

Understanding PPBE

"The Planning, Programming, Budgeting, and Execution (PPBE) process is the Department of Defense (DoD) internal methodology used to allocate resources to provide capabilities deemed necessary to accomplish the Department's missions" (Defense Acquisition University [DAU], 2023). Planning in this process is less about general planning as any civilian may understand it, and more about alignment of defense to the National Security Strategy (NSS). Planning in this process is about "Big P" planning, as opposed to the act of "planning" an activity, wherein national interests are identified, the president sets priorities, and the DoD establishes a plan to meet those objectives via the National Defense Strategy (NDS). Programming is about the allocation of resources within the DoD to accomplish those goals. Here, programming is identified as both which programs (weapon systems) will satisfy the objectives as well as the forces, funding, and manpower to meet those objectives. Budgeting is led by the Under Secretary of Defense (USD) Comptroller and is where the budget is determined, across all appropriations on what will be funded and to what level. For RDT&E, some line items may be more descriptive than others, where a specific research effort is funded or, alternatively, research in a general area is funded. Lastly, the Execution phase is where programs and organizations receive their funding and execute in accordance with the appropriate and designated use. The PPBE process is a single process but with overlapping cycles and steps that span multiple years (Figure 2; Congressional Research Service, 2022c). In a given year of execution, a program must contend with their execution year budget, planning year aspirations and requirements via the Program Objective Memorandum (POM), and programming and budgeting for years on the immediate horizon. For example, in the current Fiscal Year (FY) 2019, programs are submitting requirements for the POM2021 cycle for FY2022–2026 across all appropriations.

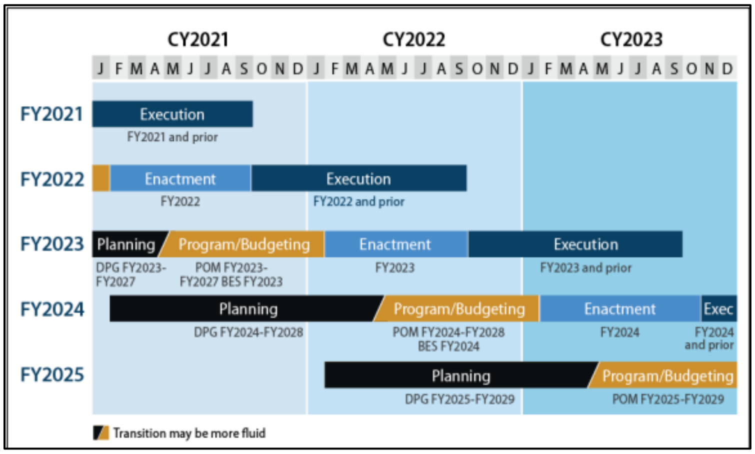


Figure 2: PPBE Process

This can be a difficult task to coordinate and align with known products and services for near term more well understood and defined compared to future year assumptions or unknowns requiring detailed planning to ensure all requirements are captured and phased appropriately. All programs follow this process and timeline; therefore, there is an incredible amount of planning, scoping, refining, defending, and evaluating of budget submittals against priorities and, ultimately, in context of what the nation can afford. Once a budget is finalized, it can be difficult to impossible to gain or move (i.e., reprogram) funding from one appropriation or “color of money” to another for emergent needs or new technologies. The unmalleable nature in reprogramming funding is a valley of death that is discussed at length because it is seen solely as an impediment for technology development, maturation, and insertion. While those arguments are valid, it also highlights a need for better awareness and socialization of needs, opportunities, and maturation timelines to fully take advantage of these circumstances. One of the main reasons for this is the intricate way the allocations and budgeting fit together to balance the entire defense portfolio, based on review and validation of capability gaps, material and nonmaterial solutions, new program starts, along with retiring older systems and other modernization efforts. While it is monolithic in nature, there is an argument to be made that this is more of a feature than a bug.

If the process were easy to manipulate and move funding about, the planning and review of requirements would mean less and less. A clear vision and strategy are required to fully leverage new technologies and the opportunities they provide, because without one it’s always easy to blame the process. The associated checks and balances of the PPBE process are also its strengths and weaknesses. In the 2022 National Defense Authorization Act (NDAA), an independent commission was established called the “Commission on Planning, Programming, Budgeting, and Execution Reform.” This commission is comprised of civilian employees not employed by the federal government who are skilled in data analysis and are recognized experts in PPBE within the DoD and in innovative budgeting and resource allocation methods in the private sector. The purpose of the commission is to (1) examine the effectiveness of the PPBE process and adjacent practices of the DoD, particularly with respect to facilitating defense modernization; (2) consider potential alternatives to the process and practices to maximize the ability of the DoD to respond in a timely manner to current and future threats; and (3) make legislative and policy recommendations to the process and practices in order to field the operational capabilities necessary to outpace near-peer competitors, provide data and analytical insight, and support an integrated budget that is aligned with strategic defense objectives (Commission on PPBE Reform, n.d.). While the commission's scope was broader than speeding up technology insertion and innovation adoption in the DoD, within that broader scope it is accurate to note that the PPBE process is recognized as a large, slow-moving, difficult-to-align process that was established in 1961 by then Secretary of Defense McNamara as a framework for linking strategic objectives with resources (Congressional Research Service, 2022a). In 1961, the budgets were smaller, and there were fewer programs. Six decades on, the world is a much more complex environment, and the commission seeks an innovative approach for what truly can be called a "wicked problem."

Along with the PPBE process, other common examples of the valley of death in technology transition are the "bureaucracy" of the DoD system and the belief that the DoD is averse to accepting new technologies or innovation. Part of the bureaucratic argument is discussed above with the PPBE process, and the appearance of rigid rules and process, but additional issues emerge, from the hierarchical nature of the organizations and in a mismatch of skill sets and personnel. There is a common belief that bureaucracy will take charge of the process, stifle progress, and prevent the necessary agility of, say, a startup or an organization that needs to move quickly (RAND Corporation, 2019). There is no shortage of seemingly overburdensome rules, requirements, processes, and procedures in any government organization. An alternative view may be that these perceived impediments are the rigor required for the DoD's weapons systems given they are intended to protect national interests, carry and support the warfighter, and are built at the taxpayer expense. Or, as no less an authority than the Dalai Lama has stated, "Learn the rules so you know how to break them properly." Two primary challenges occur in these situations. The first is someone may become frustrated with a process that is not fully understood and end up quitting, trying to transition a technology, or working with a particular partner. The second primary perspective is that the process is cumbersome and has the appearance of an unwavering clutching to procedures that, at least on the surface, offers no value to the customer or provider. We must simply follow the process thus extending the timeline to transition. In both cases, funding becomes at risk, or the capability need changes and the DoD falls further behind even having expended resources in the process. The position that "DoD has a problem with innovation and technology" has been discussed at length. The perspectives and conversations tend to follow the viewpoint and experience endured, and reality may or may not be consistent with those experiences. One such summary offered some perspective and experience of where root causes may reside (Johnson, 2023).

More to the Story

As previously discussed, the DoD acquisition process, the lengthy PPBE process, and the belief of how accepting to new technologies are challenges to crossing the so-called valley of death. Also discussed were counterpoints and highlights of alternative perspectives on why those may be real or perceived. However, seldom are other areas discussed as to why more technologies and innovations are not being realized across the DoD. Some of these additional topics include the basic premise of technology TRL and how it is being applied, specific funding for the technology level, identifying a transition partner, and the acquisition workforce understanding of the technology and the warfighter requirements. These are what we'll define as "additional valleys of death" for a more complete picture of the landscape of the myriad of functions, assumptions, and dependencies required to successfully transition technology to the warfighter.

RDT&E Appropriations

Within each appropriation, Procurement, MILPERS, O&M, and so on, there are separate accounts or subaccounts specifying which funding can be used for which activities, and RDT&E is no different. Within RDT&E, there are eight budget activity (BA) codes with specific purposes (Congressional Research Service, 2022b). The BA codes span from 6.1 for Basic Research, 6.2 for Applied Research, 6.3 for Advanced Technology Development, 6.4 for Advanced Component Development and Protypes, 6.5 for System Development and Demonstration, 6.6 for RDT&E Management Support, 6.7 for Operational System Development, and a new category in the 2022 NDAA, 6.8 for Software and Digital Technology Pilot Programs. At a glance, the BA codes mirror the TRLs based on technology maturity and using those specific funds for efforts to mature the technology—for example, using 6.1 funding for TRL 1 or 2, 6.2 funding for TRL 2–3, and 6.5 funding for more mature technologies in the TRL 6–9 range. While we don't always know what technology will be needed tomorrow, the science and technology (S&T) and research and development communities are typically funded with 6.1 and 6.2 funding to ensure emergent technologies are monitored and initial evaluation is conducted. In recent years, these could be in the areas of hypersonic weapons or intelligent systems. The DoD doesn't always know the "what" but tends to understand there will be something new on the horizon that requires investigation and research. The challenge then becomes three-fold. First, what if the basic and applied research takes longer, and additional resources are consumed? Second, what if a technology simply doesn't mature or pan out as expected? Third, what if a maturing technology progresses faster and resources need to be reallocated to continue development? If any of these cases occur, the particular department, the Navy for example, may have to request a reprogramming action in accordance with the DoD financial management regulations (Under Secretary of Defense [Comptroller], 2021). In some of these cases, a formal presentation or letter must be sent to Congress and other agencies for approval, which further prevents possible available resources from being reallocated to other S&T efforts in a timely fashion. Detractors will say this is a major hindrance, while others will say it is a structured process that prevents fraud and offers stability until a definitive event has occurred. A deep technical understanding, coupled with an understanding of risk management and risk tolerance, are inherent when deciding to continue to advance the technology or when the projected path is unlikely to bear fruit. So, just as metrics are in place to measure the efficacy of the acquisition process, so too must there be metrics associated with the enabling processes, such as those which fund S&T efforts.

Sourcing Solutions

Taking advantage of cutting-edge technologies only makes sense when there is a logical program to transition it to fulfill a defined capability gap. Newer, more innovative solutions and technologies supporting programs in the P&D and O&S phases tend to come from small businesses. The Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs are highly competitive programs that encourage domestic small businesses to engage in federal research/research and development (R/R&D) with the potential for commercialization (SBIR-STTR, n.d.). Through a competitive awards-based program, SBIR and STTR enable small businesses to explore their technological potential and provide the incentive to profit from its commercialization. Companies are given a small award for a Phase 1 effort, and larger for Phase 2 and beyond. This is seen as a win-win scenario, as the DoD gains fruitful capability and inserts where needed, and the small business stimulates their company economically. A summary of the SBIR health by year is shown below (Figure 3).

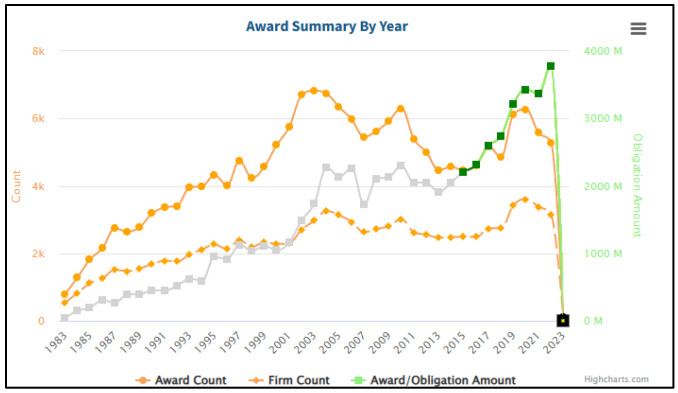


Figure 3: SBIR Awards by Year

SBIR data show an interesting trend in contract awards increasing into the early 2000s but then a cyclic pattern for the last 20 years. Over this same time, the total obligations and investments have increased. This may be one of the reasons why the valley of death appears to be discussed more in recent years. But why? In looking at the data, only 30% of the efforts make it to Phase 2 historically, and 38% in the last 4 years. That seems incredibly low given Phase 1 efforts are “to establish technical merit, feasibility, and commercial potential for the technology” and last anywhere from 5 to 12 months. There are a number of possible reasons for this, including the small business not fully understanding the solution space or the government not understanding the level of knowledge from the company and principal investigators. Another anecdotal belief is the motivations or the parties involved and if volume is the metric instead of progress. A thorough analysis of the data across a number of factors may provide insight to that belief. These are some possible reasons for the low conversation rate but are important factors when discussing the valley of death.

Technology Maturity

TRLs offer guidance on how the DoD defines the readiness or maturity of a particular technology, for both PORs and the S&T community. These establish standards, goals, and guidelines for the government to impartially test and validate assertions, as well as for partners to strive to and build out a development plan. Some technologies require significant investment and are truly game-changing (i.e., hypersonics, artificial intelligence [AI], etc.) and require multiyear investments to mature the technology, applications, and form factors. This is a challenge with any technology maturation effort and can vary from technology to technology, as some areas of research and applications are more mature or well-established than others. Another consideration is the technology in an operationally relevant environment. Informal surveys and anecdotal experiences from within the government yield a general impression from companies approaching PORs directly, which is usually “good idea, but not mature enough.” This has led to the integration of S&T professionals in a number of PORs, as well as at the warfare centers, to guide and assist industry to interpret the level of maturity needed and work a transition strategy and identify potential POR partners. The warfare centers are comprised of research, S&T, and acquisition professionals that develop, integrate, test, and field technologies and capabilities for the warfighter. These warfare centers are usually the entry point for SBIRs and STTRs, and are considered the experts in the current state-of-the-art for a given domain and application of technology. PORs also have the option to reach out to an industry partner directly, but with some risk if they don’t have extensive knowledge of the technology landscape and solution space. While TRLs offer guidance as to how to measure the readiness or maturity of the technology, it does not explicitly state the assumptions or specific criteria for some applications. Expert knowledge and experience play a role in defining technology maturity. For example, a commercial-off-the-shelf (COTS) product may state the product has been fielded in its final form under mission conditions and has been successful (TRL 9); however, the use case was less rigorous than other customer needs and environments and, therefore, can be assessed as the basic components are integrated reasonably well, but a prototype is needed in that environment (TRL 4–5). If this circumstance arises, the impression is that the DoD is unwilling to work with the partner and is imposing additional regulations, rather than a more detailed understanding of what an operational environment means to the DoD customer. Another example may be in the data analytics and AI realm. The public are consumers of AI every day, whether they know it or not. From applications to weather predictions, route recommendations, or purchase patterns, AI is integrated into the commercial space in a number of applications. In the 2019 *Department of Defense Posture for Artificial Intelligence* report, the RAND Corporation (2019) found that “the current state of AI verification, validation, test and evaluation (VVT&E) is nowhere close to ensuring the performance and safety of AI applications,” and that while “this is not a problem unique to the DoD, it is one that significantly affects DoD.” AI in one application is fielded and being used today (TRL 9), but with the DoD and poor data quality measures and handling and preparation for AI, the TRL is much more immature. Data are a unique case as well, but there is a systems-of-systems approach to how it is moved, curated, stored, access, handled, and used that can affect its readiness for use in a wide range of applications. Without understating the full value chain, environment, applications, and desired end-state, technology readiness may be a valley of death even with defined guidance.

Transition Partner

Another challenge for industry and academics is the knowledge of a suitable DoD organization and customer for the technology. The technology may be mature or in its infancy, but there is a lack of knowledge of who to speak with, the idea remains in a state of potential and doesn’t migrate to kinetic. For engagement on technology transition partners, a company should consider one of the many DoD S&T organizations in addition to specific PORs (DAU, n.d.). For example, the Office of Naval Research (ONR) coordinates and sponsors scientific research and technology development for the U.S. Navy and Marine Corps through partnerships with academia, industry, and government (Office of Naval Research, n.d.-a). In the case of ONR, their mission areas are defined by a specific focus to help facilitate which group may be best suited for willing partners to engage. The belief that researches or S&T within the Navy is cumbersome or confusing is assisted with clear delineations of focus areas to enhance success. ONR also defines funding opportunities to accelerate integration and maturation of technologies. While these measures are helpful, it is important to review the specific details and translate what is being portrayed. For example, some groups may have a “research division” and an “applications division.” These are important nuances, as the BA codes for funding will align more accurately to the work being proposed or sought. Not knowing the differences or the implications on funding or demand signal may give the impression the DoD is unwilling to work with partners or has the ability to work with partners, and therefore resulting in a valley of death experience.

Workforce Understanding of the Problem and Needs

Within any organization, there are different groups and teams supporting various functions, from business development, contracting, finance, life cycle management, product development, engineering, testing, and more. The DoD is no different with its diverse set of skills and perspectives to design, test, build, certify, and support complex weapons systems. The DoD S&T community is comprised of warfare centers, research labs, and collaboration with industry and academia. Researchers and S&T professionals invest an inordinate amount of time and years researching, developing, analyzing, and testing theories, applications, and solutions to address needs of the warfighter via capability gap assessments and innovative solutions. It is generally agreed that those closest to the area of focus may be both the most informed on a topic, but also the most biased. A researcher may be so focused on an area of expertise and sees it as ground-breaking but not know how it directly applies to a warfighter need. In these cases, someone may be motivated to see that solution or area of application be transitioned and implemented. Additionally, the individual may have zeal for a technology, which may blind them to its proper use or shortcomings, the technology maturity for the given application, or its readiness for employment given a full picture of needs and considerations. Conversely, you may have someone who spent 20 to 30 years in the military or working in the space for years and knows the challenges, but also may not know why they are manifesting, or have a predetermined solution in mind but without knowledge in the full array of options or considerations to implement the change needed. In both cases, there exists a misalignment of needs and solutions.

There are a number of ways these gaps are being addressed. First, services are leveraging their respective reserve component personnel to "translate" between operational warfighting and S&T disciplines. Two examples are the ONR Reserve Component (RC) and the Air Force Reserves (Office of Naval Research, n.d.-b; U.S. Air Force, 2023). In both cases, the service is leveraging personnel with advanced degrees in S&T and warfare-qualified personnel to help bridge a knowledge gap and understanding between warfare centers, academics, researchers, operationally supported warfighters and other DoD leaders. Another initiative to help bridge the gap is the Scientist to Sea program (Tropiano, 2005). Directed out of ONR, the Scientist to Sea program gives civilian personnel who support the Navy an opportunity to learn about life at sea for military personnel and to observe naval equipment and procedures. This is a critical initiative as even those supporting DoD acquisition may only see defined requirements without a full understanding of the projected operational environment or required operational capabilities in the specifications. When industry and academics engage with "the DoD," it is important to consider how well-informed the DoD personnel are of the challenges and what technologies and technical advancements are needed. Some technologies may show promise and meet operational performance measures but are not operationally suitable in the military environment.

Conclusions and Recommendations

When discussing the valley of death in DoD acquisition and S&T, it is critically important to understand the various perspectives, processes, procedures, and levels of understanding from all involved. To say the DoD doesn't want to partner or collaborate with industry, academia, or other partners would be inaccurate. It is also incorrect to state unequivocally that the acquisition and PPBE process are overburdensome and unnecessary. The DoD acquisition system is a monolith that has inefficiencies that need to change for it to deliver capabilities at the speed of need. This must be balanced with considerations as to the number of guardrails in place to offer stability and a focus for investments and definition of what technology maturity means. Also highlighted were the workforce's understanding of the challenges and technology, an understanding of the funding complexities, the various transition partners available, and how to source the right solutions. S&T cannot be a one-way street. At the 2023 Sea-Air-Space Expo, Rear Admiral Keith Hash, Commander Naval Air Warfare Center Weapons Division (NAWCWD) and Vice Admiral Carl Chebi, Commander Naval Air Systems Command (NAVAIRSYSCOM) both stated that if the technology is valuable and "moves the needle," you have to "pull it through the valley of death and not push it through" (NAVAIR, 2023). Critical thinking remains the most important skill set when operating in the technology development space. A clear and objective understanding of not just the technology but also the business elements for its use are cornerstones to crossing the valleys of death. Additional guidance or research into other supporting areas may be required by all involved to achieve success. It is recommended that additional analysis be done on specific trends and root causes of conversion rates across the services, entry points, technology types, and more to extract and highlight areas in need of improvement or further refinement. Lastly, PORs, warfare centers, S&T organizations, and the community at large should define a vision and strategy for what are the capability gaps and needs for different time horizons. This will assist in workforce development and establishing baseline for the current and projected state of technology, and investing resources in the most important things. This will also assist in budgetary planning and flexibility.

References

AcqNotes. (n.d.-a). *PPBE process: Appropriation categories*. Retrieved August 7, 2022, from https://acqnotes.com/acqnote/acquisitions/appropriation-categories

AcqNotes. (n.d.-b) *Technology development: Technology readiness level (TRL).* Retrieved April 14, 2023, from https://acqnotes.com/acqnote/tasks/technology-readiness-level

AcqNotes. (n.d.-c). *Technology Maturation & Risk Reduction (TMRR) phase*. Retrieved May 22, 2022, from https://acqnotes.com/acqnote/acquisitions/technology-development-phase

Commission on PPBE Reform. (n.d.). *Section 1004 FY22 NDAA*. Retrieved April 14, 2023, from https://ppbereform.senate.gov/section1004-fy22-ndaa/

Congressional Research Service. (2022a). *Defense primer: Planning, Programming, Budgeting, and Execution (PPBE) process*. https://crsreports.congress.gov/product/pdf/IF/IF10429

Congressional Research Service. (2022b). *Defense primer: RDT&E*. https://sgp.fas.org/crs/natsec/IF10553.pdf

Congressional Research Service. (2022c). *DOD Planning, Programming, Budgeting, and Execution (PPBE): Overview and selected issues for Congress*. https://crsreports.congress.gov/product/pdf/R/R47178

Defense Acquisition University. (n.d.). *Acquisition community connection: Science and technology management*. Retrieved April 14, 2023, from https://www.dau.edu/cop/stm/Pages/Topics/Technology%20Transition%20and%20Transfer%20Programs.aspx

Defense Acquisition University. (2023, April 06). *Planning, Programming, Budgeting & Execution process (PPBE)*. https://www.dau.edu/acquipedia/pages/ArticleContent.aspx?itemid=154

Greenwalt, W., & Pat, D. (2021, February). *Competing in time: Ensuring capability advantage and mission success through adaptable resource allocation*. Hudson Institute.

Johnson, E., (2023, February 06). *Back to the future: Stop saying the military has an innovation problem*. War on the Rocks. https://warontherocks.com/2023/02/back-from-the-future-stop-saying-the-military-has-an-innovation-problem/

Landreth, J. M. (2022, February 01). Through DoD's valley of death. *Defense Acquisition Magazine*. https://www.dau.edu/library/defense-atl/blog/Valley-of-Death

NAVAIR. (2023, April 4). *Sea, air, space: NAVAIR leadership panel* [Video]. LinkedIn. https://www.linkedin.com/video/live/urn:li:ugcPost:7049017458669547521/

Office of Naval Research. (n.d.-a). *Home*. Retrieved April 14, 2023, from https://www.nre.navy.mil/

Office of Naval Research. (n.d.-b). *Office of Naval Research Reserve Component*. Retrieved April 14, 2023, from https://www.nre.navy.mil/organization/naval-reservist-component

RAND Corporation. (2019). *The Department of Defense posture for artificial intelligence assessment and recommendations*. https://www.rand.org/pubs/research_reports/RR4229.html

SBIR-STTR. (n.d.). *About*. Retrieved April 14, 2023, from https://www.sbir.gov/about

Tropiano, M. (2005, September 1). *The NAVSEA scientist to sea experience*. The Free Library. https://www.thefreelibrary.com/The%20NAVSEA%20Scientist%20to%20Sea%20experience.-a0136077018

Under Secretary of Defense (Comptroller). (2021). *Department of Defense Financial Management Regulation (DoD FMR)* (DoD 7000.14-R).

U.S. Air Force. (n.d.). *Ways to serve: Air Force Reserve*. Retrieved, April 6, 2023, from https://www.airforce.com/ways-to-serve/air-force-reserve

DOD Weapon Systems Acquisition Progress and Challenges on GAO's High Risk List

Anne McDonough—serves as the Assistant Director at the U.S. Government Accountability Office. [mcdonougha@gao.gov]

Abstract

GAO is in the process of updating its High Risk List, coinciding with the start of the 118th Congress in 2023. DOD weapon systems acquisition has been on the High Risk List since 1990, with progress ratings for this area remaining largely unchanged. For the 2023 update of the High Risk List, in recognition of the increasingly complex acquisition environment, GAO divided the overall high-risk area into four segments—acquisition policy and oversight, software and cybersecurity, defense industrial base, and innovation investments—that reflect key areas of risk for DOD weapon systems acquisition. This presentation will focus on DOD's progress in addressing these four segments, while also offering broader observations on DOD's historical progress over the past 33 years on this high-risk area. The presentation will draw on GAO's broad body of work in DOD weapon systems acquisition, including on acquisition policy, emerging technologies, software and cybersecurity, defense industrial base, and drill downs of individual weapon systems. This presentation will cover DOD's accomplishments to date, as well as further efforts needed by DOD and Congress to address GAO's High Risk List criteria.

Why Area Is High Risk

DOD is continually challenged to rapidly deliver capabilities to its warfighters in an increasingly innovative and ever-changing global environment. Further, DOD programs are more software driven than ever before and face global cybersecurity threats. As of December 2021, DOD expected to spend more than $1.9 trillion dollars to acquire weapon systems. It identified the modernization of its weapon systems as critical to the nation's ability to achieve competitive advantage with potential adversaries. Legislation, such as acquisition reforms outlined in the National Defense Authorization Acts for Fiscal Years 2016 and 2017, has prompted DOD to take actions to improve the outcomes of systems that were consistently costing more, taking longer to develop, and performing at lower-than-anticipated levels. We added this area to our High-Risk List in 1990.

Since our 2021 High-Risk Report, our assessment of DOD's performance against our five criteria remains unchanged. For this report, we divided the overall high-risk area into four segments—acquisition policy and oversight, software and cybersecurity, defense industrial base, and innovation investments—that reflect key areas of risk for DOD weapon systems acquisition. Since these are new segments, we will not rate DOD on them separately until our next High-Risk Report in 2025.

Leadership commitment: met. DOD senior leadership continues to demonstrate a strong commitment to improving the management of its weapon systems acquisition. For example, in May 2021, the Deputy Secretary of Defense took action to address portfolio management challenges we identified in August 2015 by establishing Integrated Acquisition Portfolio Reviews. These reviews examine how multiple weapon systems fit into a broader portfolio of capabilities. Additionally, the Office of the Under Secretary of Defense for Acquisition and Sustainment and military department leadership continue to update acquisition policies and develop oversight plans since our last High-Risk Report in 2021.

Capacity: partially met. Since our 2021 report, DOD has taken steps to increase its capacity for addressing risks related to weapon systems acquisition. For example, in

November 2021, DOD established the Software Modernization Senior Steering Group. This group coordinates DOD's software modernization efforts and promotes the adoption of modern software development practices across the department. The Under Secretary of Defense for Acquisition and Sustainment, the Under Secretary of Defense for Research and Engineering, and the DOD Chief Information Officer oversee the group.

However, DOD still needs people with the necessary expertise and sufficient resources to improve weapon systems acquisition. For example, in February 2022, we reported that officials from the Office of the Under Secretary of Defense for Acquisition and Sustainment told us they had no dedicated funding for efforts to improve acquisition reporting. They also said that the office responsible had recently been directed to cut its staffing levels. Further, DOD faced reduced capacity among its leadership while awaiting the confirmation of a new Under Secretary of Defense for Acquisition and Sustainment, which occurred more than a year after the 2021 change in presidential administration.

Action plan: partially met. DOD continues to make progress in developing plans to improve certain aspects of weapon systems acquisition. For example, in February 2022, the Acting Assistant Secretary of Defense for Acquisition approved a plan explaining how DOD would assess the effects of recent acquisition reforms, as we recommended in June 2019. However, the department has yet to develop plans to address other aspects of this high-risk area. We reported in July 2022 that the department had yet to develop a consolidated and comprehensive strategy to mitigate industrial base risks such as reliance on foreign and single-source suppliers for critical materials.

Monitoring: partially met. DOD has made progress in its efforts to conduct data-driven oversight on the effectiveness of defense acquisition system changes. In February 2022, we reported on the Office of the Under Secretary of Defense for Acquisition and Sustainment's multiyear effort to improve acquisition data management. While officials from that office described these efforts as significant, we continue to identify challenges with the data available to DOD for effectively monitoring recent acquisition reforms. For example, in February 2023, we reported that DOD's ability to conduct effective data-driven oversight of its middle tier of acquisition pathway was hindered by a lack of clear reporting guidance and a data framework that obscured key program details. These challenges were compounded by inaccurate data provided by DOD components. An acquisition pathway allows for the rapid prototyping or fielding of capabilities.

Demonstrated progress: partially met. DOD continues to work to implement our past recommendations to help address the high-risk area. For example, in 2021 and 2022, DOD addressed recommendations through actions such as monitoring costs for programs using new acquisition pathways, developing policies and guidance to increase planning for weapon systems sustainment during the acquisition process, and improving software development for its costliest weapon program, the F-35.

However, DOD has yet to address many of our other recommendations that could help improve cost, schedule, and performance outcomes. Additionally, in our June 2022 annual weapon systems assessment, we were unable to assess DOD's progress in reducing unplanned cost growth due to the lack of available data. We noted in our report that DOD still struggled with schedule delays despite congressional legislation and departmental efforts in recent years emphasizing the timely delivery of warfighting capabilities.

The following sections discuss the four segments related to the overall high-risk area of DOD Weapon Systems Acquisition.

Acquisition Policy and Oversight

DOD has yet to implement some of the improvements to its acquisition policies that we have identified. For example, in March 2022, we found that DOD's acquisition policies incorporate some leading principles that private sector companies use to drive innovation and speed in product development. These principles include developing cost, schedule, and performance parameters to define goals before allocating funding. However, DOD missed opportunities for positive outcomes by not addressing others. We recommended—and DOD agreed—that the department update its acquisition policies to fully address leading principles.

Further, DOD has yet to fully determine key program oversight aspects for the Adaptive Acquisition Framework. This framework provides six acquisition pathways that are each tailored for the unique characteristics and risk profile of the capability being acquired. As a result, Congress and senior DOD leadership may lack the information they need to ensure the department's acquisition efforts are on track. For example, in February 2023, we found that DOD components had yet to establish and document processes that DOD directed them to develop to inform execution and oversight of DOD's middle tier of acquisition pathway. Additionally, in February 2022, we reported that many open questions remained about how DOD would track and report on program performance. We made recommendations to strengthen DOD's efforts to improve acquisition program reporting (see figure 1).

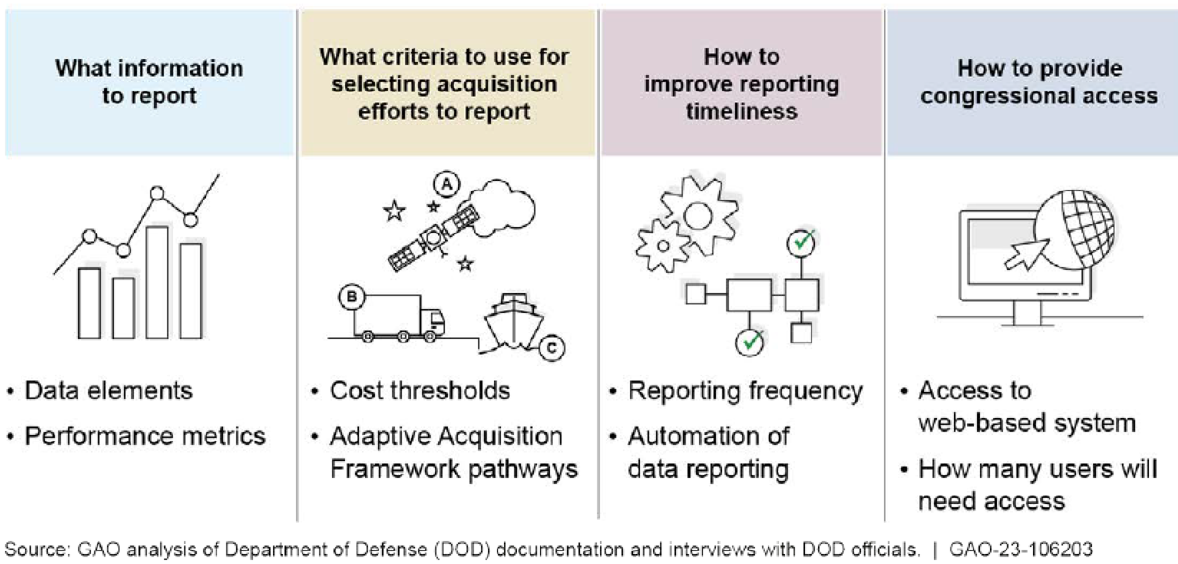


Figure 1. The Department of Defense Has Yet to Address Open Questions Related to Its Proposed Reporting Approach

Software Development and Cyber Cybersecurity

Cyberattacks can target any weapon system that depends on software. Software has become a key component of weapon systems. Yet DOD has been challenged to modernize its software development approach, address workforce shortfalls, and improve cybersecurity—a fact that senior DOD leadership has acknowledged. In June 2022, we reviewed 59 DOD acquisition programs. We found that these programs had made limited progress in implementing software development practices recommended by the Defense Science Board in 2018. Such practices include providing training in modern software development approaches for program managers and staff. These programs also reported continued software development workforce challenges. Nearly half of the programs said it is difficult to find staff with the required expertise. More than one-third reported difficulty hiring staff in time to perform planned work.

Further, the programs we reviewed have not fully implemented recommended cybersecurity practices. For example, they did not consistently complete certain types of testing that assess a system's ability to execute critical missions and defend against cyber threats. In addition, in March 2021, we found that programs did not always include complete cybersecurity requirements in their contracts. We also found that DOD's related guidance was insufficient, increasing the potential for cybersecurity risks.

Defense Industrial Base

DOD recognizes it needs a healthy defense industrial base with secure supply chains, skilled workers, robust competition, and access to innovative, cutting-edge technology to keep pace with strategic competitors. Without these elements, DOD programs could face acquisition cost overruns, schedule delays, and performance issues. For example, we reported in January 2021 that the Navy's submarine programs rely on materials produced by an atrophied supplier base. We also found that risks in the supplier base contributed to schedule and quality challenges for the lead Columbia class submarine.

Congress has recently taken steps that help DOD address these challenges, such as providing funds that the Navy used to expand and develop the submarine supplier base. As of May 2021, the Navy's submarine programs had budgeted nearly $900 million to address suppliers' capacity and workforce risks and to develop additional sources of supply. However, in July 2022, we found that DOD did not have enterprise-wide performance measures to monitor the aggregate effectiveness of its numerous risk mitigation efforts, which cost billions of dollars.

We also reported that DOD's Industrial Base Policy office does not have a consolidated and comprehensive strategy to mitigate industrial base risks. For example, we found that DOD had yet to develop an analytical framework for mitigating risks. Such a framework could support its planning efforts and was required by Congress. We also recommended in June 2022 that DOD update its industrial base assessment instruction. Such a move would ensure that DOD has greater insight into industrial base risks across the department.

Innovation Investments

Responding to threats from strategic competitors, such as China and Russia, requires DOD to invest in innovative technologies for the warfighter. DOD, however, faces challenges in delivering such innovation quickly. The department typically focuses on developing near-term, less risky, incremental innovation at the expense of long-term, disruptive innovation. DOD did not concur with our recommendations and has yet to implement our priority recommendations from June 2017 to (1) define the desired mix of incremental and disruptive innovation investments within military departments, and (2) annually assess whether that mix is achieved to better align with leading commercial companies' approaches to innovative technology development.

In addition, in March 2021 and June 2022, we identified gaps in DOD's leadership and oversight of innovative investments in hypersonic missiles. We also found that DOD lacked the workforce needed to support large-scale production and testing of hypersonic weapons. Further, in April 2022, we found that DOD's prototyping plan for uncrewed maritime systems lacked key strategies to successfully transition the efforts to acquisition programs and help maximize its significant investments.

What Remains to Be Done

As of February 2023, 163 recommendations related to DOD weapon systems acquisition remain open, including that DOD should

- update DOD acquisition policies to fully implement the key product development principles used by leading companies;
- develop and use performance measures to monitor the aggregate effectiveness of mitigation efforts for DOD-wide industrial base risks; and
- define the desired mix of incremental and disruptive innovation investments within military departments and annually assess whether that mix is achieved.

Congressional Actions Needed

There are two open recommendations for congressional consideration. To help DOD improve weapon systems acquisition, Congress should consider

- requiring DOD to report on each major acquisition program's systems engineering status in the department's annual budget request, beginning with the budget requesting funds to start development; and
- revising Section 224(d) of the National Defense Authorization Act for Fiscal Year 2017, Pub. L. No. 114-328, to extend DOD's reporting requirement for Block 4 of the F-35 program until all Block 4 capabilities are fielded to ensure that Congress is aware of cost and schedule growth beyond 2023.

Benefits

Progress in the acquisition of DOD weapon systems has led to more than $250 billion in financial benefits and more than 400 other benefits. For example:

- DOD implemented the Weapons Systems Acquisition Reform Act of 2009, which codified a number of leading acquisition practices we first recommended, to avoid an estimated $36 billion in development costs and $136 billion in procurement costs over 5-year periods.
- DOD established a plan, approved in February 2022, to assess the effects of recent acquisition reform efforts. Our work found that, without such a plan, DOD risked not achieving an effective balance between oversight and accountability and efficient program management.
- In March 2022, the U.S. Army issued guidance for acquisition programs on how to incorporate tailored weapon systems cybersecurity requirements, acceptance criteria, and verification processes into contracts.

DOD updated guidance in July 2022 to provide more useful information about the total cost of warfighting capabilities that use multiple efforts or acquisition pathways.

Improving Defense Acquisition: Insight from Three Decades of RAND Research

Jonathan Wong—is associate director of the Strategy, Doctrine, and Resources Program of the RAND Arroyo Center, a policy researcher at RAND Corporation, and a professor at the Pardee RAND Graduate School. His research focuses on the role of new technologies and operational concepts, and processes in shaping how militaries fight. He also contributes to other force design and development research and RAND's military logistics, manpower, intelligence policy, and strategy portfolios. [jonwong@rand.org]

Obaid Younossi—is director of the Defense and Political Sciences Department and a senior policy researcher at the RAND Corporation. He is responsible for the hiring, professional growth, and support of about 200 regular professional researchers and over 100 adjunct staff located in four major offices and in offsite locations. Since joining RAND in 1998, Younossi has led and worked on a wide range of studies for the U.S. Air Force, the Office of the Secretary of Defense, the U.S. Navy, the UK Ministry of Defence, Government of Qatar, Government of Oman, and the Australian Department of Defence. [obaid@rand.org]

Abstract

Improving the U.S. Department of Defense (DoD) acquisition system—the management and development processes by which the department acquires, develops, and sustains weapon systems, automated information systems, and services—has been an issue of sustained interest to policymakers since the beginning of the military establishment. Numerous actions have been initiated and implemented over decades to rein in the increasing life-cycle costs and to ensure a timely delivery of these systems to meet U.S. security needs. In this report, researchers describe overarching trends that affect the defense acquisition system, outline challenges in the DoD's defense acquisition process, and suggest improvements that might help address those challenges.

Background

Improving the U.S. Department of Defense (DoD) acquisition system—the management and development processes by which the department acquires, develops, and sustains weapon systems, automated information systems, and services—has been of sustained interest to policymakers since the beginning of the military establishment. In 1986, a confluence of trends external and internal to the department prompted Michael Rich, Edmund Dews, and C. L. Batten, Jr., to write *Improving the Military Acquisition Process: Lessons from Rand Research*. In that report, the authors examined years of prior RAND Corporation research and identified the following four trends, which they anticipated would have significant effects on the DoD's acquisition of systems:

- escalating enemy threats
- resource constraints and uncertainties
- longer retention of weapon systems in the operational inventory
- increasing difficulties of producing at an affordable cost.

Our goal with this report is to look broadly at RAND's acquisition research, as Rich et al. did in 1986. Although the context for weapon system acquisition has changed since 1986, the four trends identified in the earlier work remain just as relevant today for system acquisition in the DoD. That said, there have been some additional challenges since 1986 that have affected the DoD's acquisition of weapon systems, and we expect them to continue to do so in the coming years.[1] Moreover, defense acquisition reforms have

[1] These challenges are outlined in further detail later in this report.

remained a major policy issue and continue to be the subject of significant legislative and regulatory efforts—as evidenced by such initiatives as Congress's Weapon Systems Acquisition Reform Act of 2009, the DoD's Better Buying Power initiatives in the early to mid-2010s, a burgeoning set of defense innovation initiatives and organizations since 2014, and the sweeping changes to the DoD acquisition regulation in 2020 that yielded the Adaptive Acquisition Framework (Office of the Under Secretary of Defense for Acquisition and Sustainment [OUSD(A&S)], 2020). Inspired by the approach in Rich et al. (1986), we turned to RAND's research on defense acquisition to understand the current trends and challenges shaping that debate and to identify solutions that might improve weapon system acquisition.

Methodology

Our research approach relied on relevant resources to inform the current trends influencing acquisition decisions and leaned heavily on a sampling of 89 of RAND's publicly available reports on weapon system acquisition practices since 1986 to draw insights and lessons learned.

We examined reports that touched on broad trends, future challenges to acquisition, and comprehensive solutions, similar to that presented in Rich et al. (1986). We did not substantially use (and do not cite) research that was similar to other later work; for instance, RAND conducted periodic assessments of a defense workforce initiative and acquisition reform activities and did cost and schedule evaluations for specific programs. Instead of examining each assessment, we chose the most recent one that captured the results of all previous iterations. In other cases where RAND researchers make similar recommendations to address similar problems across different reports, we chose the report that offered the clearest articulation of the argument.

Using these criteria, we identified 44 relevant RAND reports from the initial list of 89 reports published since 1986. We created a spreadsheet template to qualitatively assess reports based on acquisition issues across all military services, the joint establishment, and all warfighting domains, and organized across 13 topic areas.[2]

Trends and Challenges for System Acquisition in the DoD

We begin by noting four overarching trends that affect the DoD acquisition system—the management and development processes by which the department acquires, develops, and sustains weapon systems, automated information systems, and services. First, geopolitical changes have widened the threat landscape; in addition to a resurgent Russia, growing Chinese economic and military power poses new threats to U.S. interests, while Islamic extremism remains a potent force. Globalization has altered the economic and technological landscape, creating new opportunities, as well as challenges, for the DoD. Furthermore, the United States has changing national priorities: Defense issues remain important, but domestic policy issues compel policymakers to prioritize attention and resources. Lastly, advancing commercial technologies are creating new challenges and opportunities for an acquisition system that was not designed to import and adapt technologies developed outside the traditional defense industrial base.

These trends are in turn linked to the following challenges for the DoD's acquisition of weapon systems:

---

[2] Those areas were defense acquisition policy, program cost, program schedule, risk in acquisition, defense industrial base, defense innovation, acquisition workforce, development and design of weapon systems, lessons learned from acquisition programs, joint acquisition, space and cyber acquisition, data in defense acquisition, and international acquisition.

- **Responding to evolving missions.** A wider range of missions demands a more flexible, responsive, and faster approach to acquisition (see, for example, Ochmanek et al., 2017, p. 100).
- **Leveraging a changing defense industrial base.** The prominence of the commercial technology sector, a consolidating defense industrial base, and a challenging contracting environment demand attention (see Defense Science Board Task Force on Defense Industrial Structure for Transformation, 2008).
- **Accommodating interoperability.** Increased cooperation among U.S. components, allies, and partners requires weapon systems that are more interoperable (see, for instance, Porche et al., 2011, p. 18).
- **Building in cybersecurity.** More-sophisticated cybersecurity threats that can disrupt, damage, degrade, or destroy system capabilities require more attention to securing systems (see Gonzales et al., 2020).
- **Planning for technology refresh and insertion.** Longer service lives of weapon systems may require more attention to designing systems with modular or easily upgradable characteristics (see Drezner & Simpson, 2017, for more information).
- **Rebuilding the acquisition workforce.** Underinvestment in maintaining the acquisition workforce in the 1990s has weakened the workforce's capability to manage an increasingly complex acquisition system (see, for instance, Government Accountability Office [GAO], 2015).
- **Managing the acquisition cost of systems.** Weapon system cost growth continues to be a concern (see Younossi et al., 2007).
- **Aligning incentives, organizations, and processes to acquisition goals.** The complexity of the acquisition landscape has grown, making it essential to reconsider the organizational and procedural norms to ensure alignment.[3]

Potential Actions for Improving the Acquisition Process

Our review of RAND literature highlights many different actions to specifically address these challenges. Most fall within four broad themes, which we discuss in this section. No theme alone can address all of the challenges we have identified from RAND research. However, each has the potential to address numerous challenges, as indicated in Table 1.

Table 1. Action Themes to Address Acquisition Challenges

Challenge	Tailor Acquisition Approaches	Better Engage an Inclusive Industrial Base	Properly Size, Train, and Incentivize the Acquisition Workforce	Track and Analyze Attributes of Acquisition
Responding to evolving missions	✓	✓	✓	✓
Leveraging a changing defense industrial base		✓		✓
Accommodating interoperability	✓			✓
Building in cybersecurity	✓	✓	✓	✓
Planning for technology refresh and insertion	✓	✓	✓	✓
Rebuilding the acquisition workforce		✓	✓	✓
Managing the acquisition cost of systems	✓			✓
Aligning incentives, organizations, and processes to acquisition goals	✓		✓	✓

[3] A good example that outlines this problem is William Greenwalt and Dan Patt (2021, pp. 41–48).

Tailor Acquisition Approaches

A key observation across RAND's acquisition research is that acquisition programs may benefit from management frameworks tailored to the circumstances and characteristics of the system being considered. Attributes that can be tailored include program timelines, contract strategies, oversight structures, and technical risk tolerance. For example, urgent operational needs necessitate quick design and procurement timelines to help field equipment expeditiously. Short obsolescence timelines also drive quick turnarounds in program schedule. On the other hand, complex system developments require large investment and oversight, which makes an expedited timeline less feasible. In these cases, a long-term outlook with careful planning is more appropriate. An effective acquisition system should be sufficiently adaptable that it can respond to urgent and evolving operational needs when necessary and can incorporate deliberate and thoughtful planning when timelines and cost considerations require it.

That said, certain program considerations are more universal. For example, consideration must be given to ensuring the realism of requirements by using relatively mature technologies; maintaining budgetary and program resource stability; and managing interoperable systems, cybersecurity, and obsolescence. Moreover, some measure of accountability and responsiveness to oversight, adjusted to the amount of risk tolerated by stakeholders, is important (Cook et al., 2016, pp. 100–101). Despite arguments by some that oversight is too burdensome and inimical to agility, oversight and accountability are necessary to sustain the political viability for programs and the acquisition enterprise generally (Wong, 2020). These universal considerations never can be fully disregarded in the interest of acquisition agility.

As the DoD reforms the acquisition system to accommodate approaches to reduce schedule and cost slippage *and* become more flexible and agile to contend with evolving threats, it should continue to consider these broad principles as the acquisition workforce learns to use new acquisition pathways and tools. This will be particularly important as acquisition leaders determine which tailored pathways are most appropriate for a given program. One way to synthesize these principles is by categorizing programs into four pathways along two dimensions: program need timeline (short timeline versus long timeline) and technology development risk (evolutionary versus revolutionary).[4]

In some cases, operational circumstances dictate a timeline or level of technology risk. In others, program leaders must choose their timeline and the acceptable level of risk based on external limitations, such as budget. Table 2 summarizes key attributes for programs in each of these four archetypes.[5] We believe that this framework and its underlying principles will continue to be relevant as the program management and oversight landscape in the DoD and Congress evolves.

[4] In the context of this report, evolutionary technology development refers to a gradual development of new capability, as opposed to the development of game-changing capability. The term *evolutionary* should not be confused with evolutionary acquisition, a DoD acquisition approach implemented in the early 2000s that involves *spiral development*, or increasingly detailed incremental system capability development phases (or design spirals) rather than traditional discrete phases.

[5] These summations are adapted from John Birkler et al. (2000). See also Van Atta et al. (2016).

▪ **Table 2: Associated Program Attributes, by Acquisition Program Archetype (Birkler et al., 2000)**

	Technology Development Risk	
Timeline Length	Evolutionary	Revolutionary
Short	Streamlined oversight Increased prototyping Limited changes to requirements	Streamlined oversight Increased prototyping Increased program risk tolerance Flexible contracts Relaxed intellectual property ownership
Long	Limited changes to requirements Longer-term contracts Increased life-cycle planning: operations and support (O&S), interoperability, technology refresh	Increased prototyping Increased program risk tolerance Longer-term contracts Increased life-cycle planning: O&S, interoperability, technology refresh

Challenges to Implementing Tailored Approaches

The tailored acquisition approach described here has not been implemented to the degree that empirical evidence of its effectiveness to improve acquisition outcomes is possible. The DoD has been moving steadily toward emphasizing a tailored approach, including emphasis in the 2013 version of DoD Instruction 5000.02, as well as adoption of the Adaptive Acquisition Framework outlined in the 2020 version of the document.[6]

Nevertheless, RAND research highlights implementation obstacles that are likely to occur. Research by McKernan et al. (2015) on acquisition-tailoring suggests that various bureaucratic characteristics, such as high turnover among senior leaders, weak support for tailoring, and weak incentives and structures, constrain tailoring. Also, education and training are important so that the workforce knows how to tailor acquisition procedures. Tailoring requires a workforce that thinks critically about acquisition issues and understands the acquisition process in great detail (McKernan et al., 2015). Research by Bartels et al. (2020) that wargames elements of the Adaptive Acquisition Framework also suggests that the risks of transitioning programs between pathways (e.g., from middle-tier rapid prototyping and fielding to the more traditional major capability acquisition process) are not well understood by acquisition practitioners (pp. 7–9).

Having adequate training for tailoring, however, is only part of the difficulty with implementing tailored acquisition for weapon system programs. According to case studies of tailored programs documented by McKernan et al. (2015), bureaucratic obstacles are another major challenge. Examples of such obstacles within the DoD include high turnover among senior leadership, limited ground-level support for flexible program approaches, limited holistic understanding of the entire acquisition process within the acquisition workforce, and limited incentives to carry out alternative approaches (McKernan et al., 2015).

However, these challenges to tailored acquisition can be addressed by the DoD's growing understanding of how program context can dictate which tailoring approaches are appropriate for best results in a given situation. Anton et al. (2020) examine 62 potential approaches to more responsive acquisition by identifying 49 contextual program factors that are likely to influence the effectiveness of each approach (pp. 74–82). Such insights as these are likely to be critical to effectively crafting tailored acquisition strategies.

[6] On the 2013 version, see McKernan et al. (2015). On the 2020 version, see OUSD(A&S, 2020).

Better Engage an Inclusive Industrial Base

Industry is the prime source of innovation for the defense acquisition system, and harnessing industry's innovation potential is key to maintaining the United States' warfighting advantage. Toward this end, two major priorities for the defense industrial base are to expand it to include nontraditional suppliers and to implement better long-term planning to ensure that the industrial base remains healthy. RAND research suggests that some tools already exist to enable further expansion of the industrial base and further improve long-term industrial base planning. In this section, we identify RAND research that highlights these existing tools to help enable their use more broadly through defense acquisition.

Expand the Industrial Base to Include Nontraditional Suppliers

Although sustaining members of the present defense industrial base is crucial, further expansion of the industrial base is necessary to better channel the innovation potential of industry. This expansion can be accomplished through improved DoD engagement with industry. The DoD has made recent efforts in this area—for example, by establishing the Defense Innovation Unit in August 2015—but more action can be taken to diversify partnerships with the industrial base.[7]

One possibility is to pursue the further implementation of DoD venture capital funds. Designed to make equity investments in early-stage firms, venture capital funds and their organizational structures are a stimulus for innovation in the technology sector, according to a 2001 RAND study for the U.S. Army (Held & Chang, 2000, p. 2). An example of DoD's limited use of venture capital programs to date is the Army Venture Capital Initiative, chartered by Congress and established in FY 2002. Based within In-Q-Tel (a venture capital firm funded mainly by the Central Intelligence Agency), the venture fund was created (1) to find innovative energy technologies and invest in their development and (2) to realize substantial net return for the investing organizations from commercial and Army markets (Parmentola & Rohde, 2003, p. 29). The Army selected OnPoint Technologies to manage the fund and has invested in firms developing battery electrodes, printing solar cells on flexible substrates, and enhancing battery management devices (Webb et al., 2014, p. 25). An example of the success of the fund is the battery management technology created by PowerPrecise Solutions, which received excellent reviews from deployed soldiers in Iraq and Afghanistan and was estimated to save the Army approximately $375 million over a 5-year period (Steipp, 2013, p. 122). By providing modest funding at the right time, venture capital funds are a conduit to accessing the newest technologies and diversifying partnerships with nontraditional firms. Thus, as mentioned earlier, the DoD should consider employing this venture capital model more widely—for example, in cyber and other technology areas that exhibit promise (Steipp, 2013).

In a similar vein, funding for the DoD Small Business Innovation Research (SBIR) program can be better distributed to already successful small businesses and those that the DoD is already investing in via other avenues. Held et al. (2006) indicate that integrating the resources of the SBIR program with venture capital initiatives can provide a stream of funding throughout the life cycle of a nascent technology, which can be crucial to fielding new capability (p. 92).

An inherent reality of the defense industry is that many systems require significant up-front capital expenditure for production. The infrastructure, materiel, and human capital investments required can be substantial, so both established and emerging markets

[7] The Defense Innovation Unit is a DoD initiative intended to increase agility and innovation in defense acquisition by serving as a bridge between DoD components, the military services, and companies operating at the leading edge of technology.

continually seek ways to reduce such expenditures. This is visible in the established commercial satellite industry, in which operators deploying traditional satellites require up-front capital investment on the order of several hundred million dollars per program. Chang et al. (2016), in a study for the U.S. Army, recommend that the DoD pursue business arrangements and public-private partnerships that defray these capital expenditures for industry (Chang et al., 1999, pp. 55–57). Commercial firms often operate under strict timelines, so there is not always excess capacity for the DoD's needs. Early, up-front investment by the DoD can allow firms to plan their operations more effectively to accommodate both commercial and defense programs.

Lastly, the DoD should continue to reduce the administrative burdens involved in the acquisition process. The DoD is encountering an environment in which nontraditional technology firms are reluctant to conduct business with it, partly because of such barriers as a cumbersome bidding process, unique cost-accounting reporting, and backlogs that create late payments and inconsistent guidance. These barriers add cost and time to the proposal process and can be especially problematic for smaller firms that do not solely rely on defense contracts for revenue. Cox et al. (2014) suggest that, to alleviate these issues, the DoD could streamline the bidding process by standardizing procedures and reducing required paperwork, creating a list of prequalified suppliers, accelerating payment transactions, and using alternative contracting vehicles (p. 24).

On the idea of using alternative contracting vehicles, OT contracts can alleviate administrative burdens by allowing the DoD to contract with firms outside of the standard Federal Acquisition Regulation process. Research on OT usage by Mayer et al. (2020) suggests that OTs allow government contracting officers more flexibility than acquisition through the Federal Acquisition Regulation system, including greater ability to communicate with offerors and greater freedom to tailor solicitations and agreements (pp. 64–65). However, Mayer et al. (2020, pp. 65–67) and Webb et al. (2014, p. 19) note that OTs can limit transparency and require greater efforts by the government to balance flexibility with an appropriate level of discipline. Under certain circumstances, OT agreements can be useful in reducing bureaucratic restrictions.

Improve Long-Term Planning to Sustain the Industrial Base

In addition to broadening the industrial base, the DoD should look to augment the long-term planning of acquisition programs to maintain the health of the defense industrial base. Schank et al. (2011), in a study for the U.S. Navy, found that, to maintain a technology and capability edge, planning is needed to integrate the respective design, production, and maintenance organizations in industry (p. 106). For example, in shipyards, it is important to involve builders, maintainers, operators, and the technical community in the design process of a program. The design engineers should collaborate with and incorporate feedback from these parties to ensure that the designed system can be produced and maintained in an efficient manner. This is often achieved through implementing a single integrated design and production contract with the prime contractor. For certain classes of weapon systems that are complex and high cost, such as aircraft or large ships, the infrequency of new acquisition programs endangers certain critical skills in the industrial base. For example, historically, there have been large time intervals between new aircraft carrier design programs, which put critical skills, such as design engineering, at risk of erosion. Some of these design engineering skills may be retained by employing some number of the low-workload engineers for a related program (e.g., for a new submarine) that shares some design features (e.g., pumps, instrumentation systems, power generation or distribution equipment) during these periods.

Another method of sustaining industry's technological capability during a fiscally constrained period is by maintaining several active design or prototyping programs. Birkler et al. (2003) show that a reduction in acquisition funding can cause gaps in innovative design efforts, particularly for niche technologies, and developing a long-term plan to mitigate this is vital (p. 89). In an environment of limited major development and production programs, an option could be to fund some design projects, such as through the Advanced Technology Demonstration program or the Advanced Concept Technology Demonstration (ACTD) program. Drezner and Leonard (2002, pp. 25–30) and Thirtle et al. (1997) observe that, during the fiscally constrained 1990s, the Predator and Global Hawk ACTD programs, respectively, enabled the continued development of key unmanned aerial vehicle development efforts. This is a way of channeling R&D investment so that specific technological capability is developed, retained, and ready to be used when production resumes.

Long-term acquisition program planning could also enable longer-term contracts with industry, which has multiple benefits under the right circumstances, according to RAND research by Birkler et al. (2000) for the Office of the Secretary of Defense. Because of uncertain future funding, the employment of annual contracts is not conducive to industry making significant investment in facility modernization and training. Long-term agreements ensure a steady flow of capital and encourage firms to revitalize infrastructure and human capital training, among other cost-reduction initiatives. Longer-term contracts are also helpful in alleviating the effect of unexpected price increases during market volatility, as noted earlier. Seong et al. (2009) conclude that, when structured properly, long-term contracts for titanium could provide stability to the DoD and industry amid unpredictability in global markets; this may be the case in other contexts as well (p. 102).

The challenge of maintaining a capable defense industrial base is likely to intensify. Efforts to broaden the industrial base to adapt commercial technologies for military use are necessary but may deflect attention away from the parts of the defense industrial base that do not contribute to commercial markets. One can look to the United Kingdom and Australia to see examples of the challenge of modernizing military capabilities absent a robust domestic industrial base (see, for example, Bassford et al., 2010, and Birkler et al., 2015). RAND research has helped these countries make difficult decisions about developing military ships and aircraft, but these options do not fully address the risks.

Properly Size, Train, and Incentivize the Acquisition Workforce

Since 1986, concerns over the size, mix, and quality of the acquisition workforce have driven numerous investigations and policy changes aimed at reshaping it. However, as many studies have shown, acquisition outcomes have not improved noticeably. To be sure, confounding factors unrelated to the acquisition workforce—for example, churn in broader acquisition policy and unstable acquisition program budgets—may challenge the establishment of a link between workforce characteristics and acquisition outcomes. Nevertheless, basic information needed to begin to assess the impact of acquisition workforce characteristics on acquisition outcomes is lacking. Establishing this link would support acquisition workforce planning because it would highlight current or expected gaps in the workforce and inform initiatives aimed at reshaping the acquisition workforce to address these gaps. Thus, drawing on RAND research, we argue in this section that the DoD should expend efforts to establish a link between acquisition workforce characteristics and acquisition outcomes (Gates et al., 2008; Gates, 2009). However, to improve acquisition outcomes, more effective acquisition workforce planning must be supported by better understanding of how workforce composition affects outcomes and must be complemented by incentives that are aligned with acquisition goals, as we discuss next.

Map Workforce Characteristics to Acquisition Activities and Their Outcomes

To identify the impact of workforce attributes on acquisition outcomes, improvements must be made to both acquisition workforce data collection and appropriate acquisition outcome metrics.

As noted by Gates et al. (2008), data on the acquisition workforce are lacking for a few reasons. First, the definition of the organic acquisition workforce (military and civilian) has varied over the years and across DoD organizations, thereby precluding reliable trend analyses from before 2008. The DoD should work to revise data collection policy guidance to improve consistency of workforce data over time and across organizations. Second, to address the common criticism that the acquisition workforce lacks the skills to accomplish its workload, the DoD should improve workforce metrics that capture the competencies necessary to do its work. Third, there is poor DoD-wide information on the number of support contractors in the acquisition workforce. Because support contractors constitute an important segment of the acquisition workforce, the DoD cannot hope to manage the acquisition workforce from a total workforce perspective if its insight into this segment of the workforce is severely limited (Gates et al., 2008). Thus, the DoD should collect the same kind of data on contractors that we recommend for the organic workforce.

As mentioned earlier, to enable acquisition workforce planning, workforce characteristics must be linked to appropriate acquisition outcome metrics (Gates et al., 2008). Accomplishing this goal would require managers to develop metrics appropriate to the program, organization, or activity in question that plausibly inform the quality of the work being done; that is, they should develop metrics based on the things that the workforce could influence and that would ultimately be expected to affect outcomes. For example, if managers agree that providing timely systems engineering to support investment decision-making is a critical process indicator, they could track whether such activities are occurring and possibly assess the quality of those activities.[8]

Information could then be linked with data on that program's workforce to assess the relationship between workforce characteristics and these outcomes. Similarly, the tenure of program managers has been highlighted as a plausible factor influencing outcomes. This workforce characteristic could be tracked at the program level and related to program outcomes to determine whether there is a relationship between tenure and outcomes.

Align Incentives With Desired Acquisition Outcomes

In some respects, the challenge of shaping acquisition workforce behavior so that it is aligned with acquisition goals is similar to the challenge of other segments of the DoD workforce—or even the broader government workforce. For example, the manner in which the acquisition workforce is compensated may not optimally encourage effective work from the workforce. Asch and Warner (1994) indicate that the active-duty compensation structure could be revised to induce the workforce to supply more effort through increased intergrade pay spreads and by tying part of compensation to performance. Presumably, similar lessons hold for the civilian and contractor segments of the acquisition workforce. Indeed, this hypothesis regarding the civilian General Schedule personnel system motivated the DoD Civilian Acquisition Workforce Personnel Demonstration Project (AcqDemo), which is an initiative beginning in 1999 to reengineer the civilian personnel systems with greater flexibility (e.g., tying a greater portion of pay to performance) to meet the needs of the acquisition workforce. Lewis et al. (2016) indicate that, within AcqDemo, higher levels of contribution to the organizational mission were associated with higher salaries, more rapid

[8] Additional RAND research on the implementation of performance-based accountability systems in various service industries identifies circumstance-specific considerations that must be made when implementing workforce incentive systems. See Stecher et al. (2010).

salary growth, more promotions, and a greater likelihood of retention, but the perceived complexity of the project's evaluation system has been a long-standing concern (Werber et al., 2012). Guo et al. (2014), in another RAND assessment of the acquisition workforce, illustrate that people who were in the AcqDemo project, or any demonstration pay plan, were retained longer than those in the General Schedule.

We recommend that the DoD continue implementing and evaluating compensation schemes that provide greater flexibility in rewarding performance that aligns with desired acquisition outcomes. In that vein, Savych (2005) examines how different compensation models in the labor economics literature may be adapted to help create greater flexibility in managing personnel and inducing desired performance in the DoD (see also Klitgaard & Light, 2005, Chapter 11). As with our previous recommendation on workforce planning, the key to compensation schemes that employ performance incentives is defining metric-based dimensions (e.g., problem-solving, teamwork and cooperation, customer relations, leadership and supervision, communication, and resource management) that the workforce could influence and that would ultimately be expected to affect acquisition outcomes.[9] Consistent with our earlier theme of tailoring, Asch (2005) suggests that the most effective pay incentives will likely be highly dependent on situational factors, such as occupation, organizational mission, and costs of monitoring.

In addition to revisiting personnel compensation, the DoD should also reconsider policies that may create incentives for program managers or other decision-makers that run counter to desired acquisition outcomes. For example, seeking efficiencies that generate savings for programs may not be encouraged if all of the savings are subsequently removed from the program's budget. In a similar vein, programs are incentivized to execute funds in accordance with generic benchmarks from the Office of the Secretary of Defense, even if it is premature for the program to do so, because under-execution of funds can be punished by cutting current or later program funding. As a result, incentives may exist to prematurely award contracts or to spend funds unnecessarily, and those incentives are contrary to desired acquisition outcomes. Program manager tenure is another area that may merit attention; tenures that are much shorter than the length of acquisition programs may incentivize short-term decision-making.[10] Assuming that program manager tenure is a driver of acquisition outcomes, the DoD should consider resolving these conflicting incentives so that lengthy tenure in a program can be advantageous for promotion.

Track and Analyze Attributes of Acquisition

Finally, because most reforms require several years for their full effects to be realized, the DoD must be patient in letting acquisition reforms play out before implementing additional changes. Indeed, since its inception, the DoD's acquisition system has been subjected to a constant stream of reform initiatives, many of which harken to earlier efforts whose effects may not have been fully assessed. Thus, it is only through a patient, data-driven evaluation of reform initiatives that the DoD can tell what worked, what did not, and where the DoD should go to improve acquisition outcomes.

Conclusion

The themes of recommendations that this body of research makes is remarkably consistent since 1986. Indeed, some themes and specific recommendations were present in

---

[9] These performance dimensions were articulated as part of the AcqDemo project. See Werber et al. (2012, pp. 19–20).

[10] Better data in support of acquisition workforce planning could shed light on the strength of the correlation between program manager tenure and acquisition outcomes.

Rich et al. (1986) as well. This begs a question: Why has the DoD continued to struggle with weapon system acquisition?

It might be possible that these recommendations are not effective or the DoD is incapable of implementing them. This might be true to some extent, but it is far more likely that the needs that the acquisition system is meant to serve and the imperatives that it operates under have changed over time. Weapon system acquisition must balance the tension between delivering maximum performance while minimizing cost overruns and schedule delays. This tension has shifted repeatedly over the decades. Performance, particularly for the burgeoning aerospace domain, was the preeminent concern in the 1950s (see, for example, Loftin, 1985). This gave way to the imperative of controlling costs in the 1960s (Enthoven & Smith, 2005). Reducing schedule delays was critical during the post-9/11 era to meet operational needs (Wong, 2016). Once those conflicts subsided, reducing cost overruns and increasing buying power became the priority.

Since this research was conducted in 2022, the imperative for fast, responsive acquisition has returned. This is driven by current Ukrainian operational needs as they consume considerable stocks of munitions and utilize new and untested emerging technologies on the battlefield ("Ukraine's Tech Entrepreneurs," 2023). Speed also motivates the DoD as it competes with China in the realm of shipbuilding, long range missiles, integrated command and control systems, and others. The recommendations highlighted in RAND research therefore represent sets of choices that that the DoD must make to respond to the operational and strategic needs at hand.

References

Anton, P. S., Tannehill, B., McKeon, J., Goirigolzarri, B., Holliday, M. A., Lorell, M. A, & Younossi, O. (2020). *Strategies for acquisition agility: Approaches for speeding delivery of defense capabilities* (Report No. RR-4193-AF). RAND.

Asch, B. J. (2005). The economic complexities of incentive reforms. In R. Klitgaard & P. C. Light (Eds.), *High-performance government: Structure, leadership, incentives* (Report No. MG-256-PRGS, pp. 309–342). RAND.

Asch, B. J., & Warner, J. T. (1994). *A theory of military compensation and personnel policy* (Report No. MR-439-OSD). RAND.

Bartels, E. M., Drezner, J. A., & Predd, J. B. (2020). *Building a broader evidence base for defense acquisition policymaking* (Report No. RR-A202-1). RAND.

Bassford, M., Pung, H., Edgington, N., Thompson-Starkey, T. G., Weed, K., Arena, M. V., Kallimani, J. G., Lee, G. T., & Younossi, O. (2010). *Sustaining key skills in the UK military aircraft industry* (Report No. MG-1023-MOD). RAND.

Birkler, J., Schank, J. F., Arena, M. V., Keating, E. O., Predd, J. B., Black, J., Danescu, I., Jenkins, D., Kallimani, J. G., Lee, G. T., Lough, R., Murphy, R., Nicholls, D., Persi Paoli, G., Peetz, D., Perkinson, B., Sollinger, J. M., Tierney, S., & Younossi, O. (2015). *Australia's naval shipbuilding enterprise: Preparing for the 21st century* (Report No. RR-1093-AUS). RAND.

Birkler, J., Smith, G., Kent, G. A., & Johnson, R. V. (2000). *An acquisition strategy, process, and organization for innovative systems* (Report No. MR-1098-OSD). RAND.

Chang, I., Galing, S., Wong, C., Yee, H., Axelband, E., Onesi, M., & Horn, K. (1999). *Use of public-private partnerships to meet future Army needs* (Report No. MR-997-A). RAND.

Cook, C. R., Westerman, E., McKernan, M., Ahtchi, B., Lee, G. T., Oberholtzer, J., Shontz, D., & Sollinger, J. M. (2016). *Contestability frameworks: An international horizon scan* (Report No. RR-1372-AUS). RAND.

Cox, A. G., Moore, N. Y., & Grammich, C. A. (2014). *Identifying and eliminating barriers faced by nontraditional Department of Defense suppliers* (Report No. RR-267-OSD). RAND.

Defense Science Board Task Force on Defense Industrial Structure for Transformation. (2008, July). *Creating an effective national security industrial base for the 21st century: An action plan to* *address the coming crisis.* Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics.

Drezner, J. A., & Leonard, R. S. (2002). *Innovative development: Global Hawk and DarkStar—Transitions within and out of the HAE UAV ACTD Program* (Report No. MR-1476-AF). RAND.

Drezner, J. A., & Simpson, M. (2017). *Exploring parallel development in the context of Agile acquisition: Analytical support to the Air Superiority 2030 Enterprise Capability Collaboration Team* (Report No. RR-1808-AF). RAND.

Enthoven, A. C., & Smith, K. W. (2005). *How much is enough? Shaping the defense program, 1961-1969* (Report No. CB-403). RAND.

Gates, S. M. (2009). *Shining a spotlight on the defense acquisition workforce—Again* (Report No. OP-266-OSD). RAND.

Gates, S. M., Keating, E., Jewell, A., Daugherty, L., Tysinger, B., Robbert, A. A., & Masi, R. (2008). *The defense acquisition workforce: An analysis of personnel trends relevant to policy, 1993–2006* (Report No. TR-572-OSD). RAND.

Greenwalt, W., & Patt, D. (2021, February). *Competing in time: Ensuring capability advantage and mission success through adaptable resource allocation.* Hudson Institute.

Gonzales, D., Harting, S., Adgie, M. K., Brackup, J., Polley, L., & Stanley, K. D. (2020). *Unclassified and secure: A defense industrial base cyber protection program for unclassified defense networks* (Report No. RR-4227-RC). RAND.

Guo, C., Hall-Partyka, P., & Gates, S. M. (2014). *Retention and promotion of high-quality civil service workers in the Department of Defense acquisition workforce* (Report No. RR-748-OSD). RAND.

Held, B., & Chang, I. (2000). *Using venture capital to improve Army research and development* (Report No. IP-199). RAND.

Klitgaard, R., & Light, P. C. (Eds.). (2005). *High-performance government: Structure, leadership, incentives* (Report No. MG-256-PRGS). RAND.

Lewis, J. L., Werber, L., Wright, C., Danescu, I., Hwang, J., & Daugherty, L. (2016). *2016 assessment of the Civilian Acquisition Workforce Personnel Demonstration Project* (Report No. RR-1783-OSD). RAND.

Loftin, L. K., Jr. (1985). *Quest for performance: The evolution of modern aircraft.* National Aeronautics and Space Administration.

McKernan, M. P., Drezner, J. A., & Sollinger, J. M. (2015). *Tailoring the acquisition process in the U.S. Department of Defense* (Report No. RR-966-OSD). RAND.

Ochmanek, D., Wilson, P. A., Allen, B., Speed Meyers, J., & Price, C. C. (2017). *U.S. military capabilities and forces for a dangerous world: Rethinking the U.S. approach to force planning* (Report No. RR-1782-1-RC). RAND.

Office of the Under Secretary of Defense for Acquisition and Sustainment. (2020, January 23). *Operation of the adaptive acquisition framework* (DoD Instruction 5000.02).

Parmentola, J. A., & Rohde, R. S. (2003, November–December). Army venture capital initiative. *Army AL&T*.

Porche, I. R., III, Dryden, J., Connor, K., Wilson, B., McKay, S., Giglio, K., & Montelibano, J. (2011). *Finding services for an open architecture: A review of existing applications and programs in PEO C4I* (Report No. MG-1071-NAVY). RAND.

Rich, M., Dews, E., & Batten, C. L., Jr. (1986). *Improving the military acquisition process: Lessons from Rand Research* (Report No. R-3373-AF/RC). RAND.

Savych, B. (2005). *Toward incentives for military transformation: A review of economic models of compensation* (Report No. TR-194-OSD). RAND.

Schank, J. F., Ip, C., Lacroix, F. W., Murphy, R. E., Arena, M. V., Kamarck, K. N., & Lee, G. T. (2011). *Learning from experience, volume II: Lessons from the U.S. Navy's* Ohio*,* Seawolf*, and* Virginia *submarine programs* (Report No. MG-1128/2-NAVY). RAND.

Stecher, B. M., Camm, F., Damberg, C. L., Hamilton, L. S., Mullen, K. J., Nelson, C., Sorensen, P., Wachs, M., Yoh, A., Zellman, G., & Leuschner, K. J. (2010). *Toward a culture of consequences: Performance-based accountability systems for public services* (Report No. MG-1019/1). RAND.

Steipp, C. M. (2013, July–August). Funding cyberspace: The case for an Air Force venture capital initiative. *Air and Space Power Journal*, *27*(4), 119–128.

Thirtle, M. R., Johnson, R. V., & Birkler, J. L. (1997). *The Predator ACTD: A case study for transition planning to the formal acquisition process* (Report No. MR-899-OSD). RAND.
Ukraine's tech entrepreneurs turn to military matters. (2023, February 23). *The Economist*.
GAO. (2015, December). *Defense acquisition workforce: Actions needed to guide planning efforts and improve workforce capability* (GAO-16-80).
Van Atta, R. H., Kneece, R. R., Jr., & Lippitz, M. J. (2016, September). *Assessment of accelerated acquisition of defense programs.* Institute for Defense Analyses.
Werber, L., Daugherty, L., Keating, E. G., & Hoover, M. (2012). *An assessment of the Civilian Acquisition Workforce Personnel Demonstration Project* (Report No. TR-1286-OSD). RAND.
Wong, J. P. (2016). *Balancing immediate and long-term defense investments* (Report No. RGSD-378). RAND.
Wong, J. P. (2020, July 2). Why you can't call in an air strike with an iPhone. *War on the Rocks*.
Younossi, O., Arena, M. V., Leonard, R. S., Roll, C. R., Jr., Jain, A., & Sollinger, J. M. (2007). *Is weapon system cost growth increasing? A quantitative assessment of completed and ongoing programs* (Report No. MG-588-AF). RAND.

Acquisition Research Program
Department of Defense Management
Naval Postgraduate School
555 Dyer Road, Ingersoll Hall
Monterey, CA 93943

www.acquisitionresearch.net