SYM-AM-16-019

PROCEEDINGS
OF THE
THIRTEENTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

WEDNESDAY SESSIONS
VOLUME I

Acquisition Research:
Creating Synergy for Informed Change

May 4–5, 2016

Published April 30, 2016

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ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL

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Keynote: The Honorable Sean Stackley, Assistant Secretary of the Navy for Research, Development, & Acquisition

The Honorable Sean J. Stackley—assumed the duties of assistant secretary of the Navy (ASN), Research, Development, & Acquisition (RDA) following his confirmation by the Senate in July 2008. As the Navy's acquisition executive, Stackley is responsible for the research, development, and acquisition of Navy and Marine Corps platforms and warfare systems, which include oversight of more than 100,000 people and an annual budget in excess of $50 billion.

Prior to his appointment to ASN (RDA), Stackley served as a professional staff member of the Senate Armed Services Committee. During his tenure with the Committee, he was responsible for overseeing Navy and Marine Corps programs, U.S. Transportation Command matters, and related policy for the Seapower Subcommittee. He also advised on Navy and Marine Corps operations and maintenance, science and technology, and acquisition policy.

Stackley began his career as a Navy surface warfare officer, serving in engineering and combat systems assignments aboard USS *John Young* (DD 973). Upon completing his warfare qualifications, he was designated as an engineering duty officer and served in a series of industrial, fleet, program office, and headquarters assignments in ship design and construction, maintenance, logistics, and acquisition policy.

From 2001 to 2005, Stackley served as the Navy's LPD 17 program manager, with responsibility for all aspects of procurement for this major ship program. Having served earlier in his career as production officer for the USS *Arleigh Burke* (DDG 51) and project naval architect overseeing structural design for the Canadian Patrol Frigate HMCS *Halifax* (FFH 330), he has the unique experience of having performed a principal role in the design, construction, test, and delivery of three first-of-class warships.

Stackley was commissioned and graduated with distinction from the U.S. Naval Academy in 1979 with a Bachelor of Science degree in mechanical engineering. He holds the degrees of Ocean Engineer and Master of Science in mechanical engineering from the Massachusetts Institute of Technology. Stackley earned certification as a Commonwealth of Virginia professional engineer in 1994.

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Plenary Panel: Weapon Acquisition Program Outcomes and Efforts to Reform DoD's Acquisition Process

Wednesday, May 4, 2016	
9:30 a.m. – 11:00 a.m.	**Chair: Michael Sullivan,** Director, GAO Acquisition and Sourcing Management **Panelists:** **Kris Keener,** Assistant Director, GAO Acquisition and Sourcing Management **Travis Masters,** Assistant Director, GAO Acquisition and Sourcing Management **Cheryl Andrew,** Assistant Director, GAO Acquisition and Sourcing Management

Michael Sullivan—is the Director, Acquisition and Sourcing Management, U.S. Government Accountability Office. This group has responsibility for examining the effectiveness of the DoD's acquisition and procurement practices in meeting its mission performance objectives and requirements. In addition to directing reviews of major weapon system acquisitions such as the Joint Strike Fighter, F-22, Global Hawk, and various other major weapon acquisition programs, Sullivan has developed and directs a body of work examining how the DoD can apply best practices to the nation's largest and most technically advanced weapon systems acquisition system. This work has spanned a broad range of issues critical to the successful delivery of systems, including technology development, product development, transition to production, software development, program management, requirement-setting, cost estimating, and strategic portfolio management. The findings and recommendations from this work have played a major role in the department's recent acquisition policy revisions. Most recently, he has directed the GAO's annual assessment of major weapon systems programs for Congress and the GAO's work with Congress in establishing acquisition policy reforms. His team also provides Congress with early warning on technical and management challenges facing these investments. Sullivan has been with the GAO for 24 years. He received a bachelor's degree in political science from Indiana University and a master's degree in public administration from the School of Public and Environmental Affairs, Indiana University. [sullivanm@gao.gov]

Kris Keener—Assistant Director, GAO Acquisition and Sourcing Management

Travis Masters—Assistant Director, GAO Acquisition and Sourcing Management

Cheryl Andrew—Assistant Director, GAO Acquisition and Sourcing Management

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Panel 2. Applications of Real Options Analysis in Defense Acquisition

Wednesday, May 4, 2016	
11:15 a.m. – 12:45 p.m.	**Chair: James E. Thomsen,** Former Principal Civilian Deputy, Assistant Secretary of the Navy for Research, Development, & Acquisition ***Acquiring Technical Data With Renewable Real Options*** Michael McGrath, ANSER Christopher Prather, Senior Associate Analyst, ANSER ***Incorporation of Outcome-Based Contract Requirements in a Real Options Approach for Maintenance Planning*** Xin Lei, Research Assistant, University of Maryland Navid Goudarzi, Postdoctoral Researcher, University of Maryland Amir Reza Kashani Pour, Research Assistant, University of Maryland Peter Sandborn, Professor, University of Maryland ***Measuring the Return on Investment and Real Option Value of Weather Sensor Bundles for Air Force Unmanned Aerial Vehicles*** Thomas Housel, Professor, NPS Johnathan Mun, Research Professor, NPS David Ford, Research Associate Professor, NPS Sandra Hom, Research Associate, NPS Dave Harris, NPS Matt Cornachio, NPS

James E. Thomsen—former principal civilian deputy, assistant secretary of the navy (ASN) research, development and acquisition (RDA). As the principal civilian deputy to the Honorable Sean Stackley, Thomsen's responsibilities included oversight and policy for Navy and Marine Corps research, development, and acquisition programs for Shipbuilding, Aviation, Space, and Weapons systems. In his capacity, Thomsen was responsible for more than $100 billion annually; hundreds of technical development and procurement programs for the Department of the Navy; and the department's Senior Executive Acquisition Corps. Thomsen also served as co-executive director for the Under Secretary's Better Buying Power initiative for defense acquisition from 2010 to 2015.

Thomsen also served as the Program Executive Officer (PEO) for Littoral and Mine Warfare (LMW), as well as Executive Director of the PEO (LMW). As the PEO, Thomsen was responsible for the execution of more than $3 billion annually on technical programs that included Counter-IED Electronic Warfare Systems in response to Operation Iraqi Freedom and Operation Enduring Freedom; ASW, SuW, and MIW; Mission Modules for the Littoral Combat Ship; Special Warfare Operations Systems; Anti-Terrorism Naval Ship Systems; and all Naval Undersea Surveillance Systems.

Thomsen has held several technical and management positions within the Navy's Engineering Commands—Department Head of Naval Weapons Systems at Dahlgren, VA; Department Head of Coastal Warfare Systems at Panama City, FL; and Program Manager of Undersea Weapons at the Naval Sea Systems Command in Washington, DC.

Thomsen received his bachelor's degree in ocean engineering in 1981 from Florida Atlantic University and his master's degree from Florida State University.

Thomsen has received numerous career awards for his work in Defense and R&D programs. For his career achievements in the Department's Senior Executive Corps, Thomsen was awarded the Presidential Rank Award (Distinguished) in 2010, as well as the Secretary of Defense Distinguished Performance Medal in 2012.

Acquiring Technical Data With Renewable Real Options

Michael McGrath—holds a BS in space science and applied physics and an MS in aerospace engineering from Catholic University, and a doctorate in operations research from George Washington University. As a former Vice President at ANSER, he led business operations in systems and operations analysis. He previously served as Deputy Assistant Secretary of the Navy for Research, Development, Test, and Evaluation, and is a strong proponent for improvements in technology transition, modeling and simulation, and test and evaluation. His research interests are in cybersecurity for manufacturing and procurement and use of digital technical data. [michael.mcgrath@anser.org]

Chris Prather—holds a BA in sociology from the University of Washington and a dual-title MA in sociology and demography from Pennsylvania State University. He is currently working as an analyst in the Threat & Risk Analysis Division at the Homeland Security Studies & Analysis Institute, a federally funded research and development center operated by ANSER on behalf of DHS. At ANSER, he has worked on a variety of projects involving demographic methodology and advanced statistics, with a particular focus on quantitative methodology. His interests include policy analysis, methodology development, and forecasting. [christopher.prather@hsi.dhs.gov]

Abstract

This paper investigates the use of real options as a strategy to hedge risks in situations where the need for contract deliverables is uncertain over a long life cycle. It focuses on the case of contracting for technical data to support competitive spares procurement, and it proposes a data maintenance contract with renewable options to deliver technical data at a pre-negotiated price at the time of need and the required level of data rights. A business case analysis tool is developed using dynamic programming to calculate the value of the technical data options to the government. This tool is applied in an example using available cost data to support a series of annual decisions on whether to continue the option, and to determine the optimal timing to exercise the option to rent or buy the technical data based on the expected cost avoidance to the government. This options-based approach helps the government avoid the costly acquisition of technical data that may never be used while ensuring data are available when a need arises. Industry also benefits from the data maintenance contract as a business opportunity that provides more accurate data for system support and better insight into government uses of the data.

Introduction

Acquisition program managers are expected to acquire technical data needed for life cycle sustainment functions such as maintenance or competitive spare parts procurement, but this expectation is more complicated than it seems (DoD, 2015). The needs and timing for competitive spare parts procurement are uncertain, and changes in system configuration or sustainment strategy can alter the need for technical data. Additionally, price negotiation for the technical data package (TDP) often occurs in a sole source environment, with conflicting assertions by the contractor and government over rights in data, an issue that is compounded by inadequate business case evaluations of the value of the data to the government (DoD, 1993). In some instances, prices in excess of $1 billion have been quoted for the acquisition of TDPs (GAO, 2011). Consequently, TDPs that are needed are often not acquired, TDPs that are acquired are often not properly priced, and TDPs that are delivered may never be used. Program managers need better ways to hedge uncertainty in technical data needs and better business case analysis tools for the procurement of TDPs.

This research investigates a new method for acquiring technical data with flexible options to be exercised at the time of need during the product life cycle. The option would allow the government the right, but not the obligation, to rent or purchase the technical data and technical data deliverables at the time the data are needed. Purchasing an option preserves the opportunity to acquire technical data deliverables at a set price while hedging the risk that the technical data ultimately may not be needed. Because the data are not acquired until the time of need, this helps to ensure that the associated data rights are acquired at the appropriate level for the intended technical data use. This allows program managers the ability to continuously reassess needs and mitigate changes in supply chain, system configuration, or sustainment strategy.

To calculate the value of an option to the government for the purchase of technical data rights and deliverables, we use real options theory, which accounts for the costs or savings associated with various alternative outcomes. Real options theory originated from the valuation of options in the financial market. Instead of valuing the option to purchase a stock, however, real options theory extends this valuation to the purchase of “real” things such as technical data packages, which we explore in detail. We use dynamic programming to value the real option, and package the valuation algorithm in a user-friendly Excel-based business case analysis tool that is freely available. We present a proposed business model for how to use this business case analysis tool in a real-world scenario.

Although there are many government needs for technical data (engineering investigations, depot maintenance, spares procurement, etc.) we limit our focus in this research to TDPs and associated data rights used in competitive procurement of spares and repair parts. A complete TDP will cover all the parts in a system or subsystem. Although spares (repairable items) and repair parts (consumable items) are managed differently in the DoD supply system, there is no difference from the standpoint of TDP data deliverables needed to support competitive procurement. So, for simplicity, we will use the term spare parts to include both categories. To illustrate the decision support tool proposed for the new acquisition approach, we use a scenario involving the data deliverables and data rights needed for competitive procurement of a single part numbered item.

Current Acquisition Policy and Practice

DoD acquisition policy requires the acquisition program manager to consider procuring technical data and associated data rights during acquisition. Implicitly underlying this policy is an expectation that the acquisition cost of technical data will be more than offset by the downstream benefits of competition and other benefits of DoD use of the data. DoD Instruction (DoDI) 5000.02 (DoD, 2015) requires that

> program management must establish and maintain an IP [Intellectual Property] Strategy to identify and manage the full spectrum of IP and related issues (e.g., technical data and computer software deliverables, patented technologies, and appropriate license rights) from the inception of a program and throughout the life cycle.

This requirement was strongly re-emphasized in the DoD’s Better Buying Power 2.0 (BBP 2.0) initiative as a means to ensure that the DoD is positioned for competitive sourcing of materials needed for sustainment and upgrades to the system (OUSD[AT&L], 2012). As a result of BBP 2.0, the DoD published a Data Rights brochure, updated DoDI 5010.12M on Procedures for the Acquisition and Management of Technical Data, and developed an Intellectual Property Strategy Guidance brochure to support data rights planning. Army, Navy, and Air Force documents provide further guidance on the acquisition of the data deliverables that comprise a TDP. Technical data is a significant area of emphasis in DoD acquisition policy; Federal Acquisition Regulations provide standard contract requirements for acquisition of technical data and associated IP rights. MIL STD 31000a prescribes the content of TDPs and TDP data management products, and the DoD acquisition workforce is trained in assessing technical data needs, conducting business case analyses on technical data acquisition strategies, and contracting for data and data rights.

In practice, however, it is difficult to determine life cycle data needs, evaluate the business case, negotiate and contract for priced data rights and deliverables, validate deliverables, maintain technical data, and make the data accessible for use over an extended period. Additionally, industry is reluctant to release technical data that may be used by potential competitors. There may also be circumstances, such as contractor maintenance of the system under a Performance Based Logistics (PBL) arrangement, where the government may not need the data during a specified period, but may need the data later to maintain a competitive market. Given the uncertainty of needs and the difficulty and expense of procurement, technical data are often deferred or put in a contract option that is never exercised. The Government Accountability Office (GAO) has published several reports critiquing the Department's handling of technical data acquisition. In 2004, the GAO reported that "program managers often opt to spend limited acquisition dollars on increased weapon system capability rather than on acquiring rights to the technical data—thus limiting their flexibility to perform maintenance work in house or to support alternative source development should contractual arrangements fail." In 2010, the GAO reported "For 27 of the 47 noncompetitive DoD contracts we reviewed, the government was unable to complete requirements due to a lack of access to proprietary technical data." More recently, the GAO (2011) reported that, although DoD policies have been updated to require determination of data needs, business case analysis and inclusion of technical data and data rights in the acquisition strategy, these policies are sparsely implemented in the acquisition programs they reviewed. The disconnect between technical data acquisition policy and practice has been a longstanding issue in the DoD.

In the section titled A New Acquisition Strategy for Technical Data, we propose a new acquisition approach designed to address these pragmatic difficulties by creating and preserving competitively priced options for deferred delivery of, or access to, technical data at the time of need throughout the life cycle. This approach is motivated not only by the need to reconcile policy and practice, but also by the opportunity to take advantage of technology trends affecting technical data.

Technology Trends Affecting Technical Data

Two important industry trends are changing DoD practices for acquiring and using TDPs: 3-dimensional (3D) digital product models and product life cycle management (PLM) systems.

3D digital product models have revolutionized industry engineering practices, and are now affecting DoD practices. When DoD policies and standards for TDPs were originally developed, hard copy 2D engineering drawings produced by draftsmen were the norm. These drawings required interpretation by skilled machinists to produce a part. The broad adoption in the 1980s of computer aided design (CAD), computer aided engineering (CAE), and computer aided manufacturing (CAM) systems shifted this paradigm. Today, the aerospace and defense industries use CAD/CAE systems to generate engineering data in digital form, often called the "digital thread" or "digital tapestry" that drives modeling, analysis, and automated processes throughout the manufacturing enterprise (Model Based Enterprise, 2016). The DoD is gradually equipping itself to acquire and use 3D digital data in engineering, maintenance, and supply applications. The advantages of a 3D TDP for spares procurement were demonstrated in a recent Manufacturing Technology program (U.S. Army Armament Research, Development, and Engineering Center, 2009). Faced with diminishing sources for M2 .50 caliber machine gun parts, an Army engineering center entered the old

2D drawings into a CAD system, generated a 3D TDP, and prototyped the part to capture the manufacturing recipe. When the validated 3D TDP and manufacturing process data files were released, bids were received from new suppliers who said they would not have bid without the digital files. The parts were ultimately delivered with a 70% savings in manufacturing run time and a 45% savings in cost compared to prior procurements. The conclusion is that the value to the government of a TDP used for spares procurement increases when the TDP is available in a 3D format. Other government users of TDPs in engineering and maintenance organizations have similarly concluded that 3D TDPs add considerable value. Recognizing the value of 3D TDPs, the DoD has issued a new standard practice for acquiring either 2D or 3D TDPs (DoD, 2013). For the technical data acquisition approach proposed in this research, we assume the government will prefer delivery of 3D TDPs.

PLM systems are a more recent development in industry, but have grown rapidly, reaching $40 billion in global sales in 2014. An article in PR Newswire recognized this rapid growth, noting that

> aerospace and defense was the largest end-use segment of the PLM market in 2014. This segment has a significantly long product development cycle and in order to manage this, the companies in this sector started adopting PLM solutions in wide manner. (Wood, 2015)

The primary function of a PLM system is to manage product information of all types used in engineering, manufacturing, product support, and business processes throughout the life cycle. Product information starting in the conceptual phase is developed in a distributed collaborative environment, linked, configuration-managed, and made accessible to downstream users for re-use without duplicating the data or allowing it to get out of synch. The value to industry stems from the ability of PLM systems to reduce time and errors associated with locating complex data sets and reconciling version control issues. Government organizations see potential value in using PLM systems to archive and manage technical data delivered to the government. Naval Air Systems Command, for example, is reviewing the capabilities of systems offered by major PLM vendors with a view toward procuring such a system (Owens & Gordon, 2014). Some PLM systems enable trusted partners to share access to a PLM database and associated CAD systems, to export data sets from one PLM system for ingestion into another PLM system, or to create digital files (e.g., a 3D TDP) for transmission to users who have no PLM access (Doyle & Grossman, 2014). Such systems typically include strong digital rights management features that are suitable for protecting intellectual property in both commercial and government uses. The technical data acquisition approach in the next section assumes that in the future, contractor and government organizations will use PLM systems to manage technical data for speed and accuracy in the generation of a bill of materials, 2D drawings and 3D product models, supporting engineering analysis data, manufacturing process and tooling data, and numerous other types of data.

A New Acquisition Strategy for Technical Data

As described by the GAO (2011), the current acquisition approach includes the following four phases:

1. **Requirements, strategies, and plans phase**—the government determines needs for technical data and data rights and includes those requirements in the acquisition strategy and plan.

2. **Contracting phase**—the government specifies data requirements in the solicitation, evaluates competitive contractor proposals, negotiates, and awards a contract.
3. **Contract performance and delivery phase**—the contractor develops and delivers (or provides access to) technical data per the contract. Delivery may be deferred at the government's option for up to three years after the end of the contract (DFARS 227.71). Ultimately, the government accepts delivery of the data into a government storage and distribution system.
4. **Post-performance and sustainment phase**—the government uses the technical data in engineering, maintenance, supply support, and other life cycle functions.

The proposed new method uses the same four phases, but adds flexibility by using a subscription to the contractor PLM system for online access and options for deliverables to hedge risks and uncertainties in life cycle needs for technical data. Key differences include the following:

- Needs determination is essentially the same in Phase 1, but a new business case analysis tool (described in the following section) is used in developing an options-based acquisition strategy. This tool considers the value to the government of having the option, at any point in the life cycle, to access technical data maintained by the contractor, rent TDPs for one-time use, or deliver TDPs to a government system.
- In Phase 2, the solicitation requires online access through a subscription to the contractor's PLM system (with appropriate data rights) during the contract period, and competitively priced options for delivery or one-time use (rental) of TDPs that may be exercised up to three years after the end of the contract using a standard DoD contract clause (FAR Parts 204, 212, and 252).
- In Phase 3, the government has the option to accept delivery of data, but relies primarily on access to the contractor PLM system. For data deliverables this is similar to the deferred ordering clause in DoD 5010.12-M, which "ensures the availability of the raw data while avoiding the cost of buying the data, if the need never arises." The proposed framework differs in that all data deliverables are priced during Phases 2 and 3 at the appropriate level of rights. In contrast, the deferred ordering clause pertains only to items developed at government expense, in which case "the contractor is compensated only for the cost of converting the technical data or software into the required format and for reproduction and delivery." Also in Phase 3, the government plans and negotiates a sole source follow-on data maintenance contract for award before the base contract data options expire. This sole source negotiation is bounded by the fact that the government can exercise the prior competitively priced option for delivery of all the data if the proposed price of follow-on data maintenance is too high. The data maintenance contract also includes a subscription to the contractor PLM system that may be renewed as needed throughout the life cycle.
- Finally, in Phase 4 the government meets life cycle needs either by using data already delivered into a government system or by making case by case decisions at the time of need on whether to exercise an option for data delivery or one-time use (rental), with pricing based on the level of data rights needed. Figure 1 illustrates the data flow between contractor and government systems in Phases 3 and 4.

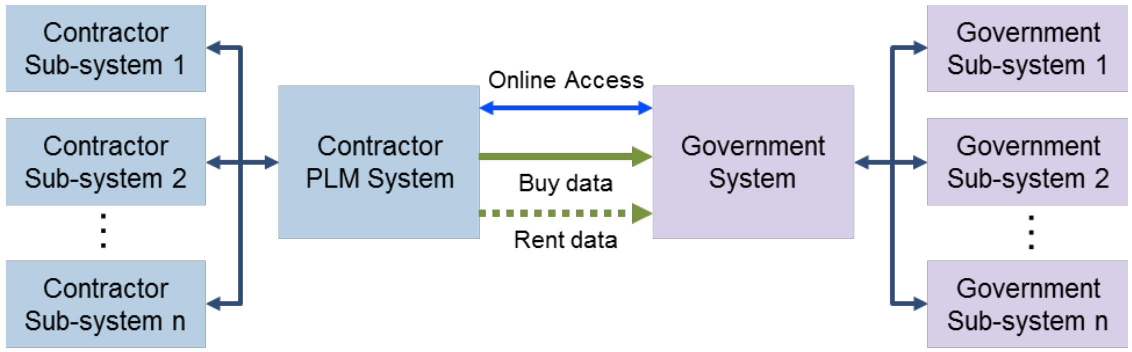

Figure 1. Modes of Data Flow Between Contractor and Government Systems

The major effect of this new acquisition approach is that it allows the government to acquire only the technical data needed, with the data rights needed, at the time of need rather than acquiring all the data during acquisition with the highest level of data rights. In current practice, data not procured during acquisition may later have to be priced and procured in a sole source environment. The new approach preserves option prices that are competitively priced in the acquisition phase.

An excellent example of using competition for leverage on pricing is the Request for Proposals (RFP) for the Joint Logistics Tactical Vehicle Family of Vehicles (JLTV FOV; U.S. Army Contracting Command, 2014). The RFP required that the contractor develop and maintain the TDP for the life of the contract, that the government have the option for purchase and delivery of the TDP at a firm fixed price, and that the contractor warrant the correctness of the TDP. The government required that the 3D product model be the design master record, and that delivery under the contract option use a government PLM system:

> The Contractor shall perform all work under this contract using the Government Windchill PDMLink, beginning with the date the Government exercises the TDP Option and shall provide models and CAD files which successfully pass the quality checks and Windchill PDMLink release process defined in these modeling standards.

To incentivize delivery of a complete TDP, the RFP included a novel provision that gave the offerors credit for a TDP Adjustment in the Total Evaluated Cost/Price factor in source selection (U.S. Army Contracting Command, 2014). The TDP Adjustment was based on a government estimate of $511 million in expected life cycle savings if the TDP supported future full and open competitive acquisitions. Credit was given for the difference between the offeror's TDP price and government savings estimate, adjusted by completeness of the offered TDP and data rights. The three offerors responding to the RFP were incentivized to get maximum credit by offering TDPs with no restrictions on use for competitive re-procurement, thereby allowing the government to avoid the cost of reverse engineering and qualification testing for secondary sources.

According to current government users of technical data, past practice in exercising TDP purchase options has often encountered problems in the timeliness of delivery, completeness, and accuracy of technical data deliverables. Contractor and government PLM systems will be helpful in avoiding past problems in delivery times, in review of data rights markings, and in configuration accuracy and completeness of TDPs. A continued contractual relationship during the sustainment phase would allow the government to enforce contract requirements more easily. In the new acquisition method, provisions of the data maintenance contract could include requirements for timeliness of delivery, accuracy, and completeness of the TDP for use in competitive re-procurements, and specified formats for deliverables suitable for government repositories or PLM systems.

From the contractor point of view, the subscription to the contractor PLM system presents a new business opportunity over the life cycle. Making accurate, up-to-date data available for government purposes can avoid problems for the contractor as well as the government. Perhaps the greatest benefit, however, is the ability to avoid potential delays in production decisions by agreeing on options rather than relying on the government to find full funding for technical data acquisition to meet acquisition milestone decision requirements.

A Decision Framework Based on Real Options Theory

The options-based method for acquiring technical data requires government decisions on whether to contract for options, whether to extend options by renewing the data maintenance contract, and whether/when to exercise options to rent or buy the data at the appropriate level of data rights. The nature and timing of a government need for technical data is uncertain. Therefore, we use a real options theory approach to calculate the expected value of the option to acquire the TDP and determine the optimal time to exercise this option.

Real Options Theory

Real options theory grows out of the valuation of options in the financial market. There, the purchase of an option allows the purchaser the right, but not the obligation, to buy or sell a stock at a fixed price. The decision of whether to purchase the option is based on the calculation of the option's value relative to the cost of the option (Goudarzi & Sandborn, 2015). As an example, imagine a stock that is currently trading at $80, where the cost of an option is $15 for a one-year option to purchase the stock at the exercise price of $70. If you purchase the option, and exercise it on the same day, the payoff would be $10 for the stock, but the cost of the option is higher than this payoff, meaning you would end up losing $5. If you waited, however, and the value of the stock increased to $100, you could then exercise the option at the $70 exercise price, and will make $15 ($100 current trading value - $70 exercise price - $15 option; Leslie & Michaels, 1997).

Real options theory extends this logic to real assets, such as factories, real estate, mines, and intellectual property (Sick & Gamba, 2005). In real options terms for technical data, the purchase of an option allows the purchaser the right, but not the obligation, to acquire the TDP and deliverables at a fixed price. In addition to addressing the question of "What should I pay to buy the option?" real options theory also assists in determining when the option should be exercised (Goudarzi & Sandborn, 2015). For the case of technical data, we use real options theory to account for the uncertainty in need associated with spare parts as well as the variability in costs of acquiring the parts. Calculating the value of the option at various stages in the program life cycle provides the program manager the information necessary to purchase only the technical data that is needed at the time that it is needed, and at the appropriate level of rights, avoiding the costly acquisition of technical data that may never be used, or the acquisition of technical data at a level of rights that is not necessary.

The traditional method to value stock options is the Black-Scholes model, proposed by Black & Scholes in 1973. Variations of the Black-Scholes model are still widely used, but the basic assumptions of the model generally do not hold for the valuation of real options. The Black-Scholes model makes assumptions about constant volatility in price, normal distribution of returns and lognormal distribution of underlying asset value—assumptions that do not fit many real option scenarios. More importantly, the Black-Scholes model was developed to value a European-style option, which is an option that must be exercised at a fixed point in time. Real options, on the other hand, are usually better conceptualized as American-style options, which can be exercised at any point in time over the life of the option (Gilbert, 2004).

To calculate the value of our real options for the purchase of technical data and data rights, we structure the problem as an American-style option that can be exercised at the time of need, but must be renewed on a scheduled basis. We calculate the value of the option to the government based on the year by year probability of need (Bayesian prior probability) and an evaluation of expected cost avoidance. Essentially, we are valuing the benefit of avoiding the expenses of working around the lack of technical data that would be necessary had the TDP not been available. For example, lack of technical data might necessitate sole source procurement of a spare part from the original supplier. If there is a 25% savings associated with competitive procurement of the part, this savings would be a source of cost avoidance to the government.

Decision Tree for Technical Data Options

In Phases 3 and 4 of our technical data acquisition method, there are two recurring decisions to be evaluated. The first considers whether to pay to keep the option open or allow it to lapse. The second considers whether to exercise the option (buy or rent the technical data) at the time a need occurs. Both decisions are based on the expected net cost avoidance associated with various government uses, summed across the remaining years of the life cycle. We can represent this as a decision tree, as shown in Figure 2, that decides each year (labeled stage s) whether to renew the data maintenance contract and data delivery options, and then decides during the year whether to exercise an option based on operational needs.

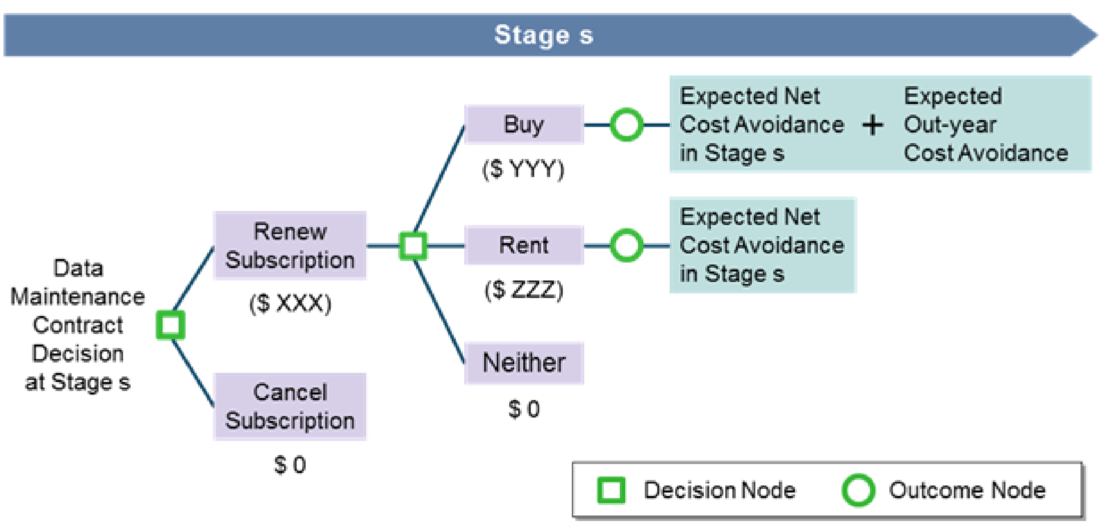

Figure 2. Iterative Decision Tree

Decision trees are evaluated by working backward, from right to left. For simplicity, assume that this subscription only contains one technical data deliverable, and consider just decisions that occur during one year (stage s). For the buy option (top branch of the decision tree), if the government buys the technical data, there is a cost avoidance in the current stage (expected net cost avoidance in stage s), and in all subsequent stages in the future (expected out-year cost avoidance), since the technical data are now available in a government system for future use. For the rent option, because the technical data are rented for a limited time, the cost avoidance accrues to the government only during the rental period (expected net cost avoidance in stage s). If the technical data are neither bought nor rented during stage s, there is no cost avoidance. The value of renewing the subscription, then, depends on which decision is chosen (buy, rent, neither) and on the inherent value of online access to the contractor system for data that has not yet been delivered.

Since we are working backward, and this is a multi-stage (i.e., multi-year) problem, we set stage s to be s = N-1 where N is the last year of the life cycle, and work backward from there. If a need occurs with only one year of life remaining, only one year of cost avoidance is possible. Assuming it is less expensive to rent the data than to buy it, the decision would be to rent the data or to do without, whichever generates the larger expected net cost avoidance. If we know the probability of need for spare parts in the last year of the life cycle, the difference in cost between meeting that need with and without delivered technical data, and the cost of renting the technical data, we can compute the expected net cost avoidance and choose the optimal path for that year.

In similar fashion we can back up another year (s = N-2) and evaluate expected net cost avoidance for each branch in the decision tree. We compute the current year expected cost avoidance for the buy and rent options, and for the buy option also add in the out-year cost avoidance calculated in the previous step. We continue to work backward to the current year, always choosing the decision for each year that maximizes cost avoidance, and recognizing that once the “buy” decision is chosen, all remaining out-years benefit from the availability of technical data. This results in an optimal path through the many branches of the multi-stage decision tree shown in Figure 3. The example scenario discussed below will illustrate one such optimal path.

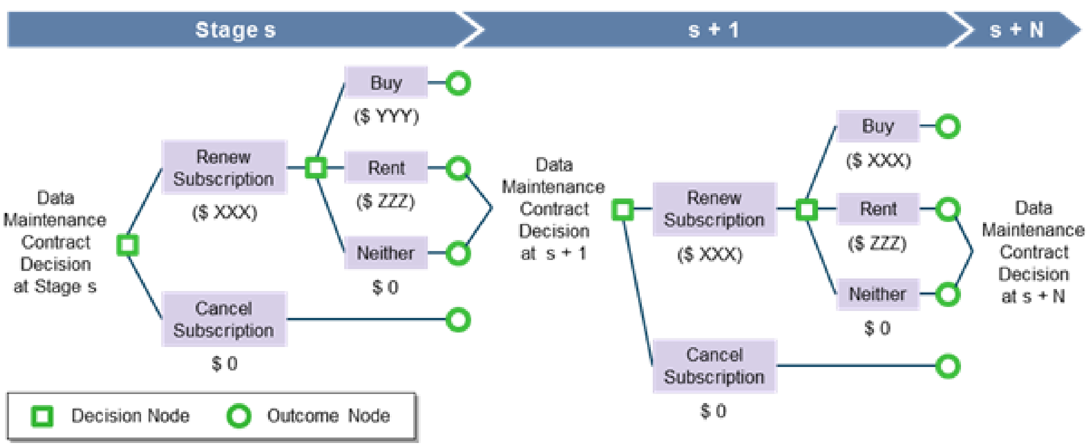

Figure 3. Multi-Stage Decision Tree

Formulation as a Dynamic Programming Problem

We recognize this multi-stage decision problem as belonging to the class of dynamic programming problems first addressed in the 1950s (Bellman, 1954). To find the series of decisions that will maximize cost avoidance, we define the following variables:

$$\boldsymbol{stage\ s} = [0,1,2 \ldots \boldsymbol{N}], where\ \boldsymbol{N}\ is\ the\ last\ year\ of\ the\ life\ cycle$$

$$\boldsymbol{decision\ variable\ x_j} = [Buy, Rent, Neither]\ for\ \boldsymbol{j} = [1,2,3]$$

$$\boldsymbol{C_{sx_j}} = Expected\ net\ cost\ avoidance\ in\ stage\ \boldsymbol{s}\ if\ \boldsymbol{x_j}\ is\ chosen\ (net\ of\ option\ cost)$$

$$C_s^* = \max[j]\, C_{sx_j}$$

$$\boldsymbol{CG_{sx_j}} = \textit{Expected gross cost avoidance in stage } \boldsymbol{s} \textit{ if } \boldsymbol{x_j} \textit{ is chosen}$$

$$\boldsymbol{f}(\boldsymbol{s}, \boldsymbol{x_j}) = \textit{total cost avoidance of best policy (sequence of choices)}$$

$$\textit{for the remaining stages given we are in stage } \boldsymbol{s} \textit{ and choose } \boldsymbol{x_j}$$

We maximize total cost avoidance by starting at stage N-1 and working backward, choosing $\boldsymbol{x_j}$ in stage s that maximizes:

$$\boldsymbol{f}(\boldsymbol{s}, \boldsymbol{x_j}) = C_s^* + (1 - \delta_s) \sum_{i=s+1}^{N} C_i^* + \delta_s \sum_{i=s+1}^{N} CG_{ix_1}$$

$$\textit{where } \boldsymbol{\delta_s} = 1 \textit{ if } \boldsymbol{C_s^*} = \boldsymbol{C_{sx_1}} \textit{ and } \boldsymbol{\delta_s} = 0 \textit{ otherwise}$$

$$\textit{since "buy" avoids subsequent gross costs}$$

This can be visualized as the decision tree shown in Figure 4.

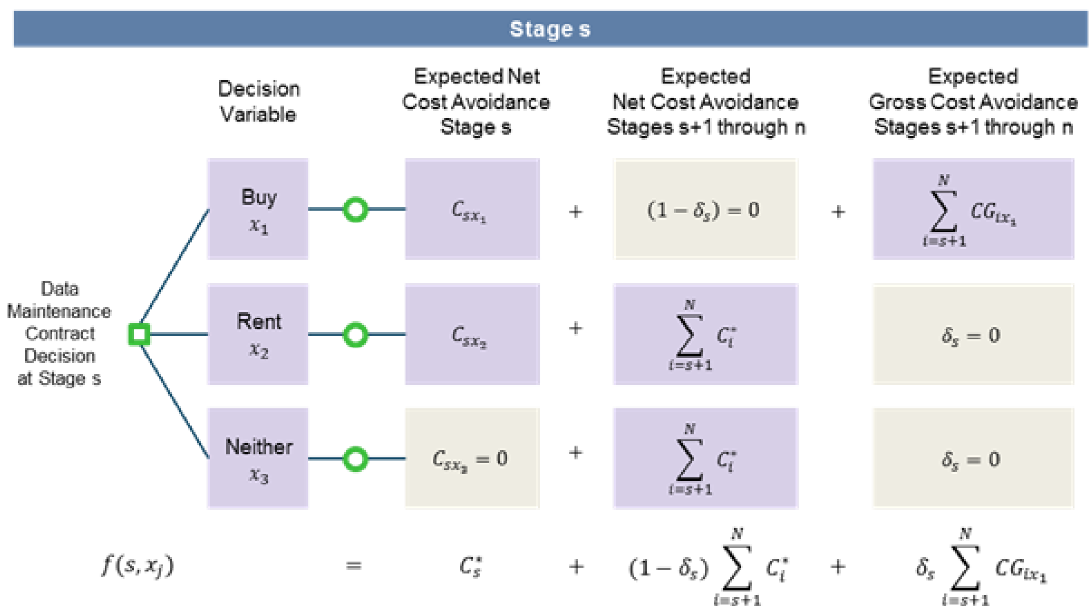

Figure 4. Decision Tree Showing Dynamic Programming Equation to Calculate Value of TDP Option

For ease of computation, we developed a recursive algorithm to evaluate ***f(s,x$_j$)*** for each year of the life cycle, starting from the final year:

$$\textit{Let } \boldsymbol{OY_{sx_1}} = \textit{outyear gross savings if } x_1 \textit{ is chosen in period } s$$

$$\boldsymbol{OY_{sx_1}} = \sum_{i=s+1}^{N} CG_{ix_1}$$

$$\textit{Then } \boldsymbol{f}(\boldsymbol{s}, \boldsymbol{x_j}) = C_s^* + (1 - \delta_s) \sum_{i=s+1}^{N} C_i^* + \delta_s OY_{sx_1}$$

Starting at ***s=N-1*** and working backward,

$$\boldsymbol{f}(\boldsymbol{N-1}, \boldsymbol{x_j}) = C^*_{N-1} + (1 - \delta_{N-1})C^*_N + \delta_{N-1} OY_{(N-1)x_1}$$

$$\boldsymbol{f}(\boldsymbol{N-2}, \boldsymbol{x_j}) = C^*_{N-2} + f(N-1, x_j)$$

$$\boldsymbol{f}(\boldsymbol{s}, \boldsymbol{x_j}) = C^*_s + f(N-s+1, x_j) \text{ (This is a recursive algorithm)}$$

This algorithm has been implemented in an Excel spreadsheet model that is freely available.[1] The required inputs for this model are: the year-by-year probability of being in a buy position for spare parts, the forecasted buy quantity of parts to be procured, projected cost resolution data if TDP is not available, the purchase price of the TDP, the rental price of the TDP, the sole source price of a single spare part unit, the life cycle duration for which spare parts are required, and the discount rate, if any, to be applied for net present value calculations.

With this business case analysis tool, for any given spare parts acquisition scenario, the total cost avoidance can be calculated to determine the initial benefit and support the decision to include the data maintenance and data delivery option line items during initial acquisition. The decision of whether to continue the data maintenance and delivery options in follow-on contracts can be evaluated with the same tool. Finally, the tool can be used as needs arise during the life cycle to decide whether to buy or rent the technical data or to meet the need without delivery of technical data.

Example Scenario

This example shows how the calculations might apply to decisions on a TDP to support spare parts procurement. The scenario assumes the following:

- The probability of being in a spare parts buy position (p(spares)) in any given year is as shown in Table 1.[2] When spare parts are procured, the buy quantity is always a lot of 100.
- The system life cycle is 20 stages, or years. A contractor PBL program is in force for the first three years of operation (to illustrate how options-based acquisition of data could complement other acquisition practices).
- The cost of the subscription is zero. In practice, the cost of the subscription would be significant and would be amortized across multiple data

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[1] Full text available at
http://anser.org/docs/reports/Acquiring_Technical_Data_with_Renewable_Real_Options.pdf; spreadsheet model available at
http://anser.org/docs/reports/Tech_Data_with_Real_Options_Spreadsheet_Model.xlsx

[2] Note that in practice, when the need arises for spare parts procurement, the probability of being in a spare parts buy position becomes 1. The probability of need for each year should be regularly re-evaluated based on changes in the projected forecast for spare parts procurement. For example, being in a buy position in one year might increase the probability of being in a buy position for spare parts in subsequent years. The probabilities are not intended to remain static over the entire life cycle.

deliverables. Since this scenario looks at a single data deliverable and focuses on cost avoidance calculations, we omit the cost.

- The TDP data deliverables and associated rights can be purchased for $50,000[3] or rented for one year for $5,000.
- Two courses of action are available when the TDP is not delivered to the government: sole source procurement from the original supplier, or workarounds to enable procurement from other sources without a TDP.
    - If spare parts are purchased in a sole-source environment, the unit cost is $1,000. If they are sourced competitively, there is a cost savings of 25%, for a unit cost of $750 (Office of the Inspector General, 1995).
    - Workarounds include procuring approved substitutes, qualifying a new substitute, repair/refurbishment/reclamation, reverse engineering, and redesign. The average cost of these workarounds is $159,179 for our scenario.[4] This estimate is based on surveyed cost metric data from the resolution of parts obsolescence problems (Defense Standardization Program Office, 2015). These costs can be avoided if the TDP is available for spares procurement. If a work-around is implemented for a particular application, the out-year costs for that application become zero.

Table 1. Probability of Being in a Buy Position for Spare Parts Procurement

Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
p(spares)	0	0	0	.5	.5	.5	.5	.5	.4	.4	.4	.4	.3	.3	.3	.3	.2	.2	.1	.01

Using these assumptions, the recursive algorithm calculates the expected cost avoidance for each decision at each time point, starting at year 20, and working backwards to year 1. At each time point, the algorithm selects the optimal decision (buy, rent or neither). This results in the optimal decision path shown in Table 2.

Table 2. Expected Cost Avoidance for Example Scenario

	Expected Cost Avoidance (thousands of dollars)																			
Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Buy	0	0	0	209	192	174	156	138	120	104	88	72	55	41	27	12	5	-18	-34	-45
Rent	0	0	0	174	162	149	136	123	110	99	88	77	65	57	47	37	25	17	6	0
Neither	0	0	0	-259	-242	-224	-206	-188	-170	-154	-138	-122	-105	-92	-77	-62	-45	-32	-16	-5

[3] In order to present results that are intuitively clear, we set the discount rate to zero for net present value calculations.
[4] The $159,179 value is a weighted average based on the average cost of each workaround, weighted by the probability of each workaround being selected. The average costs for each workaround were calculated by the Defense Standardization Program Office based on responses collected from the 2014 Defense Industrial Base Assessment: Diminishing Manufacturing Sources and Material Shortages Cost Resolution Values Survey conducted by the Department of Commerce's Bureau of Industry and Security.

In the first three years, since contractor PBL is used, the probability of being in a buy position for spare parts is zero. As a result, in these years, there is no benefit to purchasing or renting a TDP for spares procurement.

In year 4, if the government were to exercise the option to buy the technical data, it would accrue $209,000 in cost savings over the rest of the life cycle, including the benefits in the current year and all expected benefits in the out-years. Buying the TDP continues to be the optimal decision in years 5 through 10. In year 11, however, the expected cost avoidance for buying or renting the technical data is equal. At this point, the combination of low probability of need and limited remaining years of benefit make it equally attractive to meet a need, if one occurs, by either buying or renting the TDP. In year 12 and beyond, renting the technical data becomes the optimal decision.

Monte Carlo Simulation

The business case analysis tool uses expected values as the basis for decisions. In order to evaluate the sensitivity of decisions to the probability of being in a buy position and variability in the cost metrics, we performed two separate Monte Carlo simulations. The first used a uniform distribution to vary the probability of being in a spares buy position between plus or minus .05 of the values reported in Table 1. The results of 1,000 runs are presented in Figure 5.

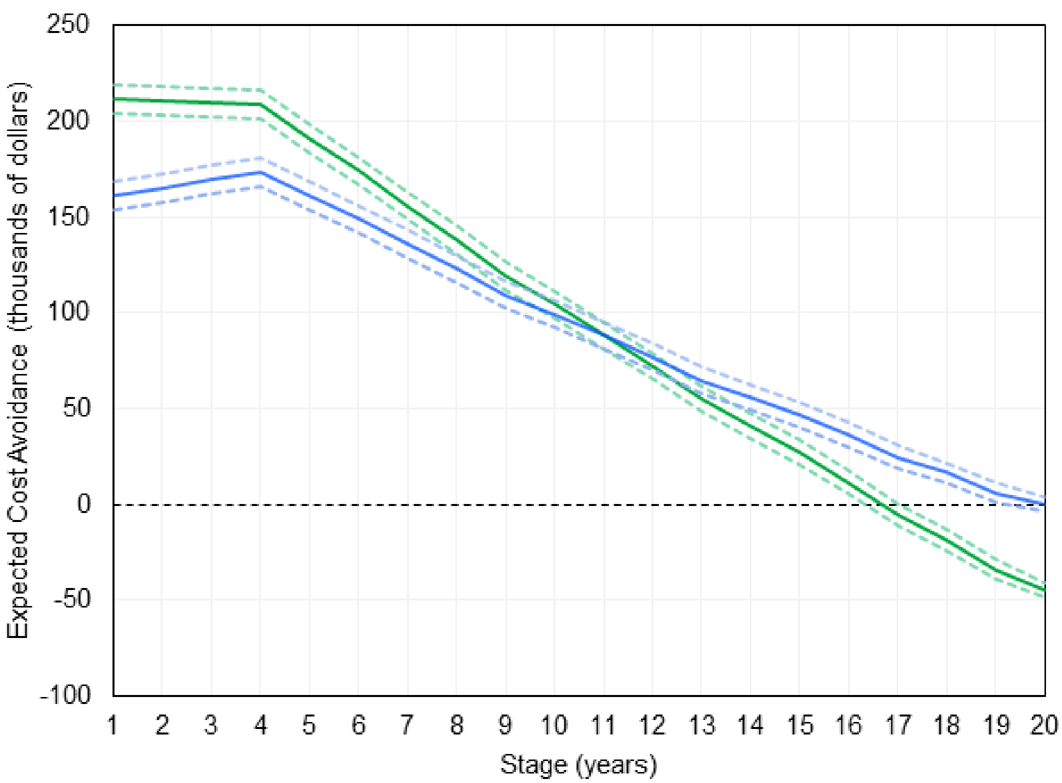

Figure 5. Monte Carlo Results for Varying Probability of Buy Position for Spares

Figure 5 shows the expected cost avoidance associated with buying the technical data at each stage, represented by the green lines, and renting the technical data, represented by the blue lines. The solid lines show the mean expected cost avoidance at each stage. The dashed lines of each color above their mean represent the expected value if the probability of being in a buy position were up to one standard deviation higher than the mean, and dashed lines of each color below their mean represent the expected value if the probability of being in a buy position were up to one standard deviation lower than the mean. The resultant bands show that at the beginning of the life cycle and at the end of the life cycle, as the expected cost avoidance values diverge, the decision to rent or buy is less sensitive to variation in the probability of being in a buy position. Near the middle of the life cycle, however, as the expected cost avoidance values for buying and renting the TDP converge, the decision to rent or buy is more sensitive to variation in the probability of being in a buy position. This shows that as the expected value for renting or buying the TDP becomes more equal, it is especially important to have an accurate assessment of the probability of being in a buy position.

The second Monte Carlo simulation allowed the resolution cost metrics to randomly vary around the mean according to a normal distribution bounded by the 95% confidence interval reported in the Diminishing Manufacturing and Material Shortages report (Defense Standardization Program Office, 2015). Similar results to Figure 5 were obtained. As the expected cost avoidance for buying versus renting the technical data converges in the middle years of the life cycle, the decision is more sensitive to the variation in the resolution cost metrics. These two Monte Carlo simulations show that in the middle of the life cycle, accurate data on the probability of being in a buy position for spares and cost metrics are essential in order to reduce the variation in the estimates and make a more accurate decision to buy or rent the TDP. In the beginning and end stages of the life cycle, an accurate decision can be made even with a higher variance in both the probability of being in a buy position and cost metrics for various resolution alternatives.

Conclusion

We have proposed a new method of contracting for technical data using options, and a business case analysis tool for decision support in acquisition and sustainment phases. In addition, we have identified the contracting issues to be addressed in both acquisition and sustainment phases, the opportunities to take advantage of technology trends in industry, and the potential for cost avoidance in situations where government needs are uncertain. Finally, building upon the basic underlying decision tree that is present in most real options settings, we have developed and demonstrated a business case analysis tool using a dynamic programming solution algorithm. The business case analysis tool fits cases where the timing of need is uncertain, thereby avoiding the restrictive assumptions of the traditional Black-Scholes model. The Monte Carlo analysis available in the tool can be used to test sensitivity to assumptions and interactions among variables.

While the new acquisition method is applicable for technical data and data rights acquisition to meet the full range of government needs for technical data, we have illustrated its application in only a single scenario—TDPs for competitive procurement of spares and repair parts. Further research could extend the business case analysis to other government application areas, such as engineering analysis, weapon system upgrades, and depot maintenance. The underlying decision support process would be the same for other application areas, but the probability of need and cost avoidance data sources would differ.

Our research was limited by the lack of publically available data. Discussions with DoD practitioners during the course of the research indicated that the year-by-year probability of need could be estimated through a combination of reliability data, parts usage data, and expert opinion. Cost data associated with courses of action with and without availability of technical data are also available within the DoD, as reflected in the JLTV example cited where a government estimate of $511 million was given for expected life cycle savings if the TDP supported future full and open competitive acquisitions. We were told by both government and industry representatives that the proposed acquisition method has real potential for use and may merit demonstration in a pilot program.

Ideally, a pilot program would have an established baseline for comparison of the new method to prior methods, and it would be executed on a time scale of tens of months rather than tens of years. A weapon system upgrade program might be suitable as a candidate pilot in follow-on research. Key elements to be developed or investigated in such a pilot program might include the following:

- Solicitation and contract language to incentivize competitive pricing of technical data options
- Identification of data sources for the business case analysis in application areas of interest
- Provisions for government online access to contractor PLM systems, and for maintaining and synchronizing technical data held in separate government and industry systems
- Documentation of costs and savings compared to prior costs for data deliverables and data rights on the system being upgraded
- Evolution of the business case analysis tool, its connection to data sources and its user interface

Finally, we note that real options are widely used as a hedging strategy in the investment sector, but are rarely used in government procurements at federal, state, or local levels. The methods and models developed in this NPS-sponsored research are now freely available (http://anser.org/docs/reports/Tech_Data_with_Real_Options_Spreadsheet_Model.xlsx) and applicable to other procurement settings where the public has a long-term interest in sustainment of a capability and a need to mitigate the cost and risk of being dependent on a sole source for the life of the system.

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Incorporation of Outcome-Based Contract Requirements in a Real Options Approach for Maintenance Planning

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Abstract

Performance-based logistics (PBL) is growing in popularity for both governmental and non-governmental acquisitions of critical systems. These contracts allow the customer to buy the performance of the system rather than purchase the system and/or to buy the availability of the system rather than pay for maintenance. Outcome-based contracts, which include PBL, are highly quantified "satisfaction guaranteed" contracts where "satisfaction" is defined by the outcomes received from the system (i.e., the specified performance level or availability).

Maintenance planning seeks to predict and optimize when maintenance for a system is performed. Condition-monitoring technologies such as Condition-Based Maintenance (CBM) and Prognostics and Health Management (PHM) provide Remaining Useful Life (RUL) estimates that can be used to plan maintenance. The challenge is how to use the predicted RULs (with their associated uncertainties) and the performance requirements imposed by the outcome-based contracts to optimally plan future maintenance.

This research addresses the incorporation of outcome-based contract requirements within a real options approach used to optimize maintenance planning. A simulation-based real options analysis (ROA) approach is used to determine the optimum predictive maintenance opportunity for a system managed via an outcome-based contract.

Introduction

Background and Motivation

While researchers have studied planning and decision making for outcome-based contracting in different areas (e.g., supply chain, logistics, and inventory management) and for different applications (e.g., defense, avionics, railroads, infrastructure, and energy), there is little formal work dedicated to contractual design and requirements optimization (Kashani-Pour & Sandborn, 2016).

The impact of contract oriented design processes on original equipment manufacturer (OEM) decision making for optimizing reliability in the post-production purchase period led to the development of integrated schemes with dynamic interdependencies of product and service, called product-service systems (PSSs; Meier, Roy, & Seliger, 2010). Procurement and system acquisition process efficiency and success across a system's life cycle requires the development and implementation of best-value, long-term, performance-based product support strategies that leverage performance-based agreements with both industry and government product support providers (Datta & Roy, 2010). Hence, an effective combination of technical and monetary approaches that includes the inventory, maintenance, and operational decisions together to form a unified model that provides visibility into the effect of different parameters is required (Arora, Chan, & Tiwari, 2010). PBL contracting is designed to incentivize this integration towards reducing life-cycle cost and improving design.

System-level PBL contracts were developed to connect system acquisition and logistics with a focus on acquiring a measurable performance outcome (such as the availability of a system), and they seek to optimize system readiness through logistics. Compared with contractor logistics support (CLS), where a contractor, rather than the government, is responsible for the integration of logistics support functions, an effective PBL requires a balanced contribution from both public- and private-sector providers. PBL contracts, as a group of strategies for system support, are intended to improve system performance at a cost similar to that previously achieved under a non-PBL approach or obtain the current system performance at a lower cost. The contract structure (defining the desired outcomes), performance measurements, and pricing (payment models) are key parameters in achieving performance-based contract goals throughout the complex legacy system support domain. System-level PBL contracts should address the operational availability time window, reliability, maintainability, supportability, operation and inventory cost, logistics footprint, total cost of ownership, and logistics response time for making program decisions.

An alternative outcome-based contract mechanism called public–private partnerships (PPPs) has been used to fund and support civil infrastructure projects. Availability payment models for civil infrastructure PPPs require the private sector to take responsibility for designing, building, financing, operating, and maintaining an asset. Under the "availability payment" concept, once the asset is available for use, the private sector begins receiving an annual payment for a contracted number of years based on meeting performance requirements (Sharma & Cui, 2012). The challenge in PPPs is to determine a payment plan (cost and timeline) that protects the public interest (i.e., does not overpay the private sector, but also minimizes the risk that the asset will become unsupported; Gajurel, 2014).

Discrete-event simulation (DES) techniques have been previously used in an integrated model to optimize the *payment* and *contract duration* by incorporating the effects of condition changes, uncertainties, and required availability of infrastructure for PPPs (Sharma, Cui, Chen & Lindly, 2010). This work resulted in obtaining an improved procurement and system acquisition model in which the system availability was chosen as the objective to meet contract requirements (Sandborn, Kashani-Pour, Zhu, & Cui, 2014). However, making decisions for specific future actions during pre-project planning (as DES, which is simply an implementation of discounted cash flow analysis, does) does not accurately address how uncertain conditions evolve because it does not model management flexibility. Real options analysis (ROA) is one means of organizing and valuing flexible strategies to address uncertainties throughout the life cycle of systems. ROA could be used to accommodate management flexibility and uncertainties in both design and monetary aspects of an outcome-based contract.

System Health Management

The maintenance planning that this paper focuses on is contingent on the presence and use of system health management technologies. System health management technologies such as Condition-Based Maintenance (CBM) seek to perform predictive maintenance based on the condition of the system. Prognostics and Health Management (PHM) uses the condition of the system coupled with the expected future environmental conditions (temperature, vibration, etc.) to forecast a Remaining Useful Life (RUL). The system management challenge is how to perform an accurate system risk allocation using the predicted RULs (with their associated uncertainties) to optimally plan when to perform maintenance and allocate maintenance resources. The optimal maintenance planning is modified by performance requirements imposed by the outcome-based contracts.

Maintenance Planning Using Real Options

ROA has been previously applied to maintenance modeling problems. An ROA model for offshore platform life-cycle cost-benefit analysis is developed by treating maintenance and decommissioning as real options (Heredia-Zavoni & Santa-Cruz, 2004; Santa-Cruz & Heredia-Zavoni, 2011). Jin, Li, and Ni (2009) presented an analytical ROA cost model to schedule joint production and preventive maintenance under uncertain demands. In the study by Koide, Kaito, and Abe (2001), the maintenance and management cost of an existing bridge for 30 years is analyzed and minimized using ROA. Goossens, Blokland, and Curran (2011) developed a model to assess the differences in performance between different aircraft maintenance operations.

Haddad, Sandborn, and Pecht (2014) applied ROA to estimate the values of maintenance options created by the implementation of PHM in wind turbines. When an RUL is predicted for a subsystem, there are multiple choices for the decision-maker, including performing predictive maintenance at the first maintenance opportunity, waiting until closer to the end of the RUL to perform maintenance, or doing nothing (i.e., letting the system run to failure). Haddad et al. (2014) demonstrated that the fundamental tradeoff in predictive maintenance problems with PHM is finding the point in time to perform predictive maintenance that minimizes the risk of expensive corrective maintenance (which increases as the RUL is used up), while maximizing the revenue earned during the RUL (which increases as the RUL is used up).

A Real Options Approach to Maintenance Planning describes a real options approach to maintenance planning when RULs are predicted for the system. The section titled Example—Wind Turbine With an Outcome-Based Contract presents a case study for a PHM enabled wind turbine with and without an outcome-based contract. In the Generalization of Predictive Maintenance Options With Outcome-Based Contracts (Non-Production Earning Systems) section, we discuss the generalization of the approach developed and demonstrated in the following two sections to systems subject to other types of outcome-based contracts.

A Real Options Approach to Maintenance Planning

This section starts with presenting the concept of PHM-enabled maintenance options. Then, it describes how the requirements from an outcome-based contract are incorporated into the option valuation process.

A real option is the right, but not the obligation, to undertake certain business initiatives, such as deferring, abandoning, expanding, staging, or contracting. For example, the opportunity to invest in an asset is a real “call” option. Real options differ from financial options in that they are not typically traded as securities and do not usually involve decisions on an underlying asset that is traded as a financial security. Unlike conventional net present value analysis (discounted cash flow analysis) and decision tree analysis, real options offer the flexibility to alter the course of action in a real asset decision, depending on future developments. Predictive maintenance options are created when in situ health management (i.e., PHM) is added to systems. In this case, the health management approach generates a remaining useful life (RUL) estimate that can be used to take proactive actions prior to the failure of a system. The maintenance option when PHM is used is defined by Haddad et al. (2014) as

- Buying the option = paying to add PHM to the system
- Exercising the option = performing predictive maintenance prior to system failure after an RUL indication
- Exercise price = predictive maintenance cost
- Letting the option expire = doing nothing and running the system to failure, then performing corrective maintenance

The value from exercising the option is the sum of the cumulative revenue loss and the avoided corrective maintenance cost.

The cumulative revenue loss is what the system would earn between the predictive maintenance event and the end of the RUL (if no predictive maintenance was done). Restated, this is the portion of the system's RUL that is thrown away when predictive maintenance is done prior to the end of the RUL. In reality, this cumulative revenue takes the form of loss in spare part inventory life (i.e., the revenue earning time for the system will be shorter because some inventory life has been disposed of).

Avoided corrective maintenance cost includes[1] the avoided corrective maintenance parts, service and labor cost, the revenue loss associated with corrective maintenance downtime, and the avoided under-delivery penalty due to corrective maintenance (if any).

Figure 1 illustrates the construction of the maintenance value. The cumulative revenue[2] loss is the largest on day 0 (the day the RUL is forecasted). This is because the most remaining life in the system is disposed of if predictive mainenance is performed the day that the RUL is predicted. As time advances, less RUL is thrown away (and less revenue is lost). The avoided corrective maintenance cost is assumed to be constant.

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[1] This is not the difference between the predictive and corrective maintenance actions, but rather the cost of just a corrective maintenance event. The predictive maintenance event cost is subtracted later when the real option value is determined (i.e., in Equation 1).

[2] The value construction in this section assumes that the system is revenue earning (e.g., a wind turbine or an airplane used by an airline). In Generalization of Predictive Maintenance Options With Outcome-Based Contracts (Non-Production Earning Systems), a generalization of the model that applies to non-production systems is discussed.

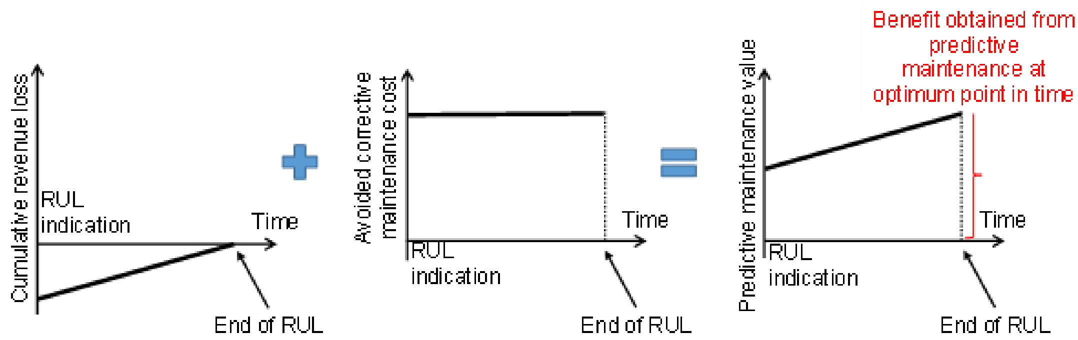

Figure 1. Predictive Maintenance Value Construction
(Lei, Sandborn, Goudarzi, & Bruck, 2015)

The predictive maintanance value is the summation of the cumulative revenue loss and the avoided corrective maintanance cost (Figure 1). If there were no uncertainties, the optimum point in time to perform maintenance would be at the peak value point (at the RUL), which is the last moment before the system fails. Unfortunately, everything is uncertain.

The primary uncertainty is in the RUL prediction. The RUL is uncertain due to inexact prediction capabilities and uncertainties in the environmental stresses that drive the rate at which the RUL is used up. A "path" represents one possible way that the future could occur starting at the RUL indication (Day 0). The cumulative revenue loss paths have variations due to uncertainties in the system's availability or uncertainties in how compensation is received for the system's outcome.[3] The avoided corrective maintenance cost paths represent how the RUL is used up and vary due to uncertainties in the predicted RUL. Each path is a single member of a population of paths representing a set of possible ways the future of the system could play out.

Due to the uncertainties described above, there are many paths that the system can follow after an RUL indication, as shown in Figure 2. Real options analysis lets us evaluate the set of possible paths to determine the optimum action to take.

Consider the case where predictive maintenance can only be performed on specific dates.[4]

[3] For example, if the system is a wind turbine, path uncertainties could be due to variations in the wind over time.
[4] This could be due to the limited availability of maintenance resources.

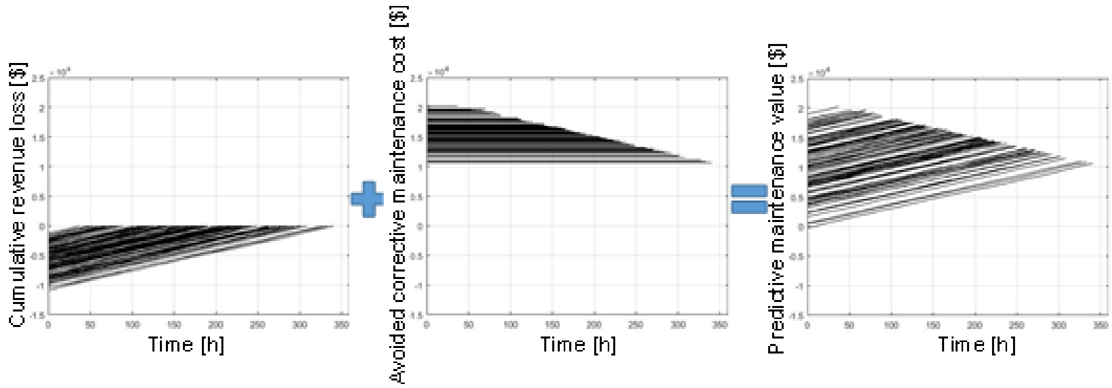

Figure 2. Example of the Simulated Paths After an RUL Indication

On each possible maintenance date, the decision-maker has the flexibility to determine whether to implement the predictive maintenance (exercise the option) or not (let the system run to failure [i.e., let the option expire[5]]). This makes the option a sequence of "European" options that can only be exercised at specific points in time in the future. The left side of Figure 3 shows two example predictive maintenance paths (diagonal lines) and the predictive maintenance cost (the cost of performing the predictive maintenance). Real Option Analysis (ROA) is performed to valuate the option where the predictive maintenance option value is given by

$$O_{PM} = Max(V_{PM} - C_{PM}, 0) \quad (1)$$

where V_{PM} is the value of the path (right most graph in Figure 2 and the diagonal lines in Figure 3) and C_{PM} is the predictive maintenance cost. The values of O_{PM} calculated for the two example paths shown on the left side of Figure 3 are shown on the right side of Figure 3. Note that there are only values of O_{PM} plotted at the maintenance opportunities (not in between the maintenance opportunities). Equation 1 only produces a non-zero value if the path is above the predictive maintenance cost (i.e., the path is "in the money").

Each separate maintenance opportunity date is treated as a European option. The results at each separate maintenance opportunity are averaged to get the expected predictive maintenance option value of a European option expiring on that date. This process is repeated for all maintenance opportunity dates. The optimum predictive maintenance date is determined as the one with the maximum expected option value. The detailed mathematical formulation of the solution can be found in Lei et al. (2015).

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[5] The decision-maker may also have the flexibility not to implement the predictive maintenance on a particular date but to wait until the next possible date to decide, which makes the problem an American option style as has been demonstrated and solved by Haddad et al. (2014). The Haddad et al. (2014) solution is correct for the assumption that an optimal decision will be made on or before some maximum waiting duration and the solution delivered is the maximum "wait to date." Unfortunately, in reality, maintenance decision-makers for critical systems face a somewhat different problem: given that the maintenance opportunity calendar is known when the RUL indication is obtained, on what date should the predictive maintenance be done to get the maximum option value. This makes the problem a European option style.

Incorporating Outcome-Based Contract Requirements Into the Predictive Maintenance Option

The "paths" described in Figures 1 and 2 are based on a non-outcome-based contract (e.g., an "as-delivered" energy delivery contract for a wind farm that defines a single fixed price for each unit of the energy delivered). When a system is managed via an outcome-based contract (like a PBL), the paths will be impacted. The outcome-based contract influences the combined predictive maintenance value paths due to changes in the cumulative revenue loss and the avoided corrective maintenance cost paths. These cost paths will be influenced by the outcome target, prices before and after that target is reached (generally the latter is lower than the former), penalization mechanisms, the outcome already produced, and the operational state of the other systems in the population. For example, assume that the cumulative outcome produced by a population of systems is close to the outcome target. All systems are operational while some are indicating RULs. The population of systems can meet the outcome target without the members indicating RULs. Then the cumulative revenue loss of the systems with RULs will be lower than when they are managed under a non-outcome-based contract, since the cumulative revenue loss will be lower (because the price paid for the outcome is lower after the outcome target is met). Assume a different scenario where the cumulative outcome from the population of systems is far from the outcome target and many systems are non-operational. In this case, running the systems with RULs to failure and performing corrective maintenance causing long downtimes may result in the population of the systems not reaching the outcome target. In this case, the under-delivery penalty will occur, and the avoided corrective maintenance cost will be higher than the non-outcome-based contract (as delivered) case that doesn't have any penalization mechanisms.

Under an outcome-based contract, the optimum predictive maintenance opportunity for individual systems in a population (e.g., a fleet) is generally different than for an individual system managed in isolation. These two cases would have the same optimum if an as-delivered contract was used.

Example—Wind Turbine With an Outcome-Based Contract

In this section, the predictive maintenance option model is implemented on a single turbine, and then a wind farm with multiple turbines is managed via an outcome-based contract. A Vestas V-112 3.0 MW offshore wind turbine (Vestas, 2013) was used for this study.

Maintaining offshore wind turbines requires resources that are not continuously available. These resources include ships with cranes, helicopters, and trained maintenance personnel. These resources are often onshore-based (which may be as much as 100 miles from the wind farm) and may be maintaining more than one wind farm. Therefore, maintenance is only available on scheduled dates (maintenance opportunities) that may be weeks apart. The availability of maintenance is also dependent on weather and ocean conditions, making the timing of future maintenance visits uncertain.

Figure 4 shows an example result for a single wind turbine. In this example, the ROA approach is not trying to avoid corrective maintenance, but rather to maximize the predictive maintenance option value. In this example, at the determined optimum maintenance date, the predictive maintenance will be implemented on only 65.3% of the paths (the paths that are "in the money"). Thirty-two percent of the paths, which are "out of money," will choose not to implement predictive maintenance, and in 2.7% of the paths, the turbine has already failed prior to that date.

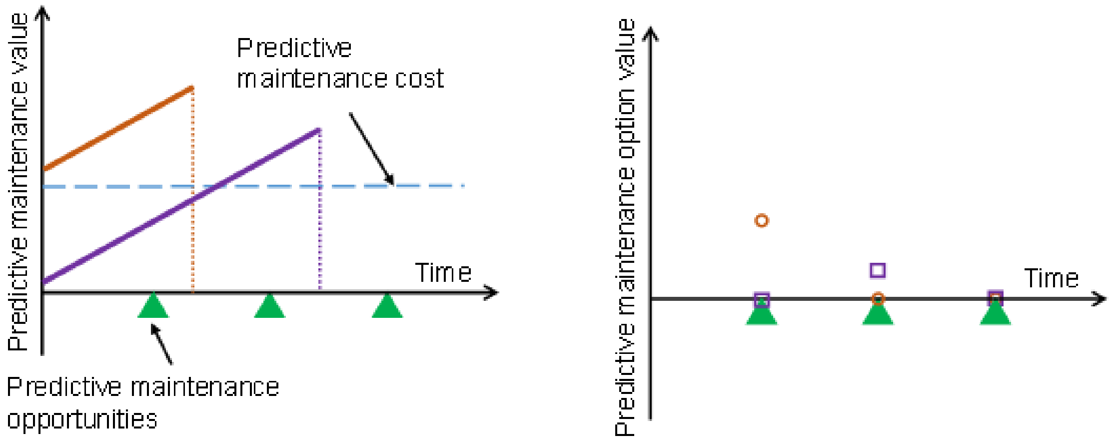

Figure 3. Real Options Analysis (ROA) Valuation Approach
Note. In the right graph, circles correspond to the upper path and the squares correspond to the lower path in the left graph.

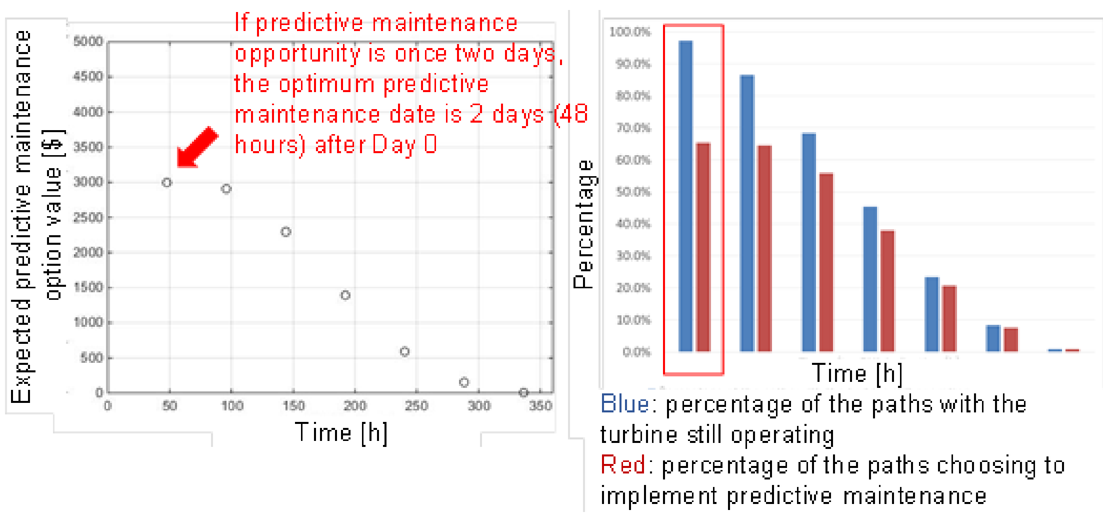

Figure 4. Optimum Maintenance Date After an RUL Indication for a Single Wind Turbine

The result in Figure 4 assumes that all the power generated by the turbine can be sold at a fixed price. There are many wind farms (and other renewable energy power production facilities) that are managed under outcome-based contracts called power purchase agreements (PPAs). A PPA defines the energy delivery targets, purchasing prices, output guarantees, etc. Wind farms are typically managed via PPAs for several reasons (Bruck, Goudarzi, & Sandborn, 2016). First, though wind power can be sold into the local market, the average local market prices tend to be lower than long-term PPA contract prices. Second, lenders are not willing to finance wind projects without a signed PPA that secures a future revenue stream. Third, wind energy buyers prefer simply purchasing power to building and operating wind farms by themselves.

PPA terms are typically 20 years for wind energy, with either a constant or escalating contract price defined through the whole term. At the beginning of each year, a PPA often requires the seller to estimate how much energy they expect to generate during the whole year, based on which an annual energy delivery target may be defined. For each year, a maximum annual energy delivery limit can be set, beyond which a lower excess price may apply. The buyer may also have the right not to accept the excess amount of energy or adjust the annual target of the next contract year downward based on how much has been over-delivered. A minimum annual energy delivery limit or output guarantee may also be set, together with a mechanism to determine the liquidated damages. For example, the seller must compensate the buyer for the output shortfall that the buyer is contracted to receive, multiplied by the difference between the replacement energy price, the price of the energy from sources other than wind paid by the buyers to fulfill their demands, and the contract price. The buyer may also adjust the annual target of the next contract year upward to compensate for how much has been under-delivered.

Assume a 5-turbine-farm managed via a PPA, turbines 1 and 2 indicate RULs on Day 0, turbine 3 operates normally, and turbines 4 and 5 are non-operational. Predictive maintenance value paths of all turbines with RULs need to be combined together because maintenance will be performed on multiple turbines on each visit (see Xin et al. [2015] for details on how the paths are combined for multiple turbines). Cumulative revenue loss, avoided corrective maintenance cost, and predictive maintenance value paths for turbines 1 and 2 are shown in Figure 5.

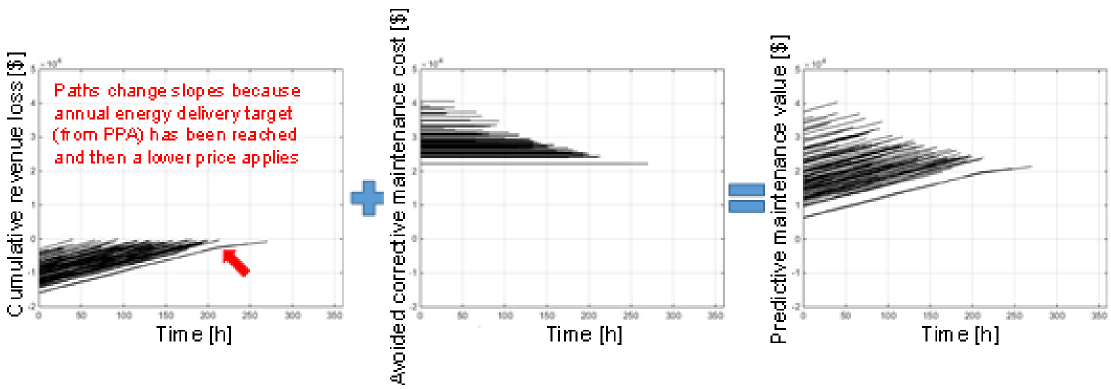

Figure 5. Combined Value Paths for Turbines 1 and 2 in a 5 Turbine Farm Managed by a PPA

Note. Some paths (as indicated by the arrow) change slopes because the annual energy delivery target defined by the PPA has been reached, after which a lower price for the power applies.

Real options analysis run on the wind farm with a PPA demonstrates that the maximum maintenance value varies with the number of turbines that are down (non-operational). Figure 6 shows the results. The result that corresponds to Figure 5 is the right most result in Figure 6.

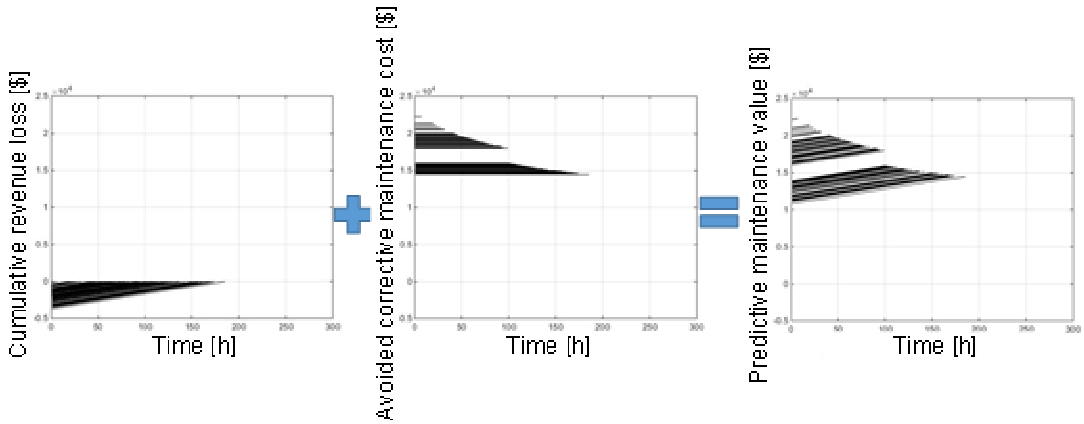

Figure 6. Example of the Simulated Paths After an RUL Indication for a Single Non-Production System Managed Under an Outcome-Based Contract

Generalization of Predictive Maintenance Options With Outcome-Based Contracts (Non-Production Earning Systems)

The real options approach for the predictive maintenance planning described in the sections A Real Options Approach to Maintenance Planning and Example—Wind Turbine With an Outcome-Based Contract assumes that the system is revenue earning (e.g., a wind turbine or aircraft engine). In this section, a generalization of the model is developed and applied to the non-production systems. For example, the hourly rate (e.g., per available hour) in PBL contracts is a fixed number. Hence, it creates a different challenge than selling the energy, which produces a variable amount of revenue.

To start with, we assume a single system (e.g., an aircraft engine) with PHM embedded. This system is managed under an outcome-based contract between a contractor (e.g., the OEM of the engine) and a customer (e.g., an airline), in which the availability is the contracted-for measurable performance outcome. The customer pays a fixed contract price to the contractor for each unit of time the system is operating; the contractor compensates the customer for each unit of time the system is down (non-operational). The contractor is responsible for all the maintenance activities. On Day 0, an RUL is predicted by the PHM, and the contractor needs to decide if and when to implement the predictive maintenance; alternatively, the system will be operated until failure, at which point corrective maintenance will be performed (we assume that safety is not compromised). It is reasonable to assume the predictive maintenance will cause a lower cost (part, service, labor, etc.) and shorter downtime than a corrective maintenance.

Integrated PHM and Inventory Management

The decision to act on PHM indications (RUL predictions) will be influenced by the inventory of spares (for the system) that are available. An integrated model to address both PHM and inventory is described here. This integration clarifies how PHM should be used to make maintenance and logistics decisions and how it impacts inventory management. Here, the primary focus is on individual component prognosis (e.g., an aircraft engine in considered to be an individual component for the purpose of this discussion) and the system-level maintenance support and management decision.

Inventory modeling is an important part of the integration of PHM and inventory management. For example, Fang Tu et al. (2007) have used a multi-state Markov network to model different levels of inventory. However, this model does not consider the best time to perform maintenance (it only considers the inventory size). The model discussed here addresses the best time to perform maintenance. The goal of this model is “when-to-act” rather than “how many spare parts to order.” This assumption allows this model to be extended to the case of multiple systems using a single shared inventory (e.g., a fleet of aircraft all drawing engines from the same inventory).

This model simulates the case where upon RUL indication, the spare part is not available and it takes some time t_s for it to become available. If the maintenance starts at a time point before the spare part arrives, a penalty on the contractor will occur (e.g., to expedite the spare order). In practice, t_s is coming from a probability distribution that models the arrival of the spare part.

The cumulative revenue loss, the avoided corrective maintenance cost, and the predictive maintenance value paths can be simulated as shown in Figure 6. The avoided corrective maintenance cost in the middle plot and the predictive maintenance value paths in the right plot separate into two groups where the penalty for implementing corrective maintenance before ts occurs to the upper group of paths and not in the lower.

By applying the ROA approach, the optimum predictive maintenance date can be determined, as shown in Figure 7. Similar to a wind farm managed under a PPA, when we consider a fleet of systems under an outcome-based contract, both the cumulative revenue loss and the avoided corrective maintenance cost paths for the systems with RULs are influenced by the contract price, availability requirement, penalization mechanisms, and the operational state of the other systems in the fleet.

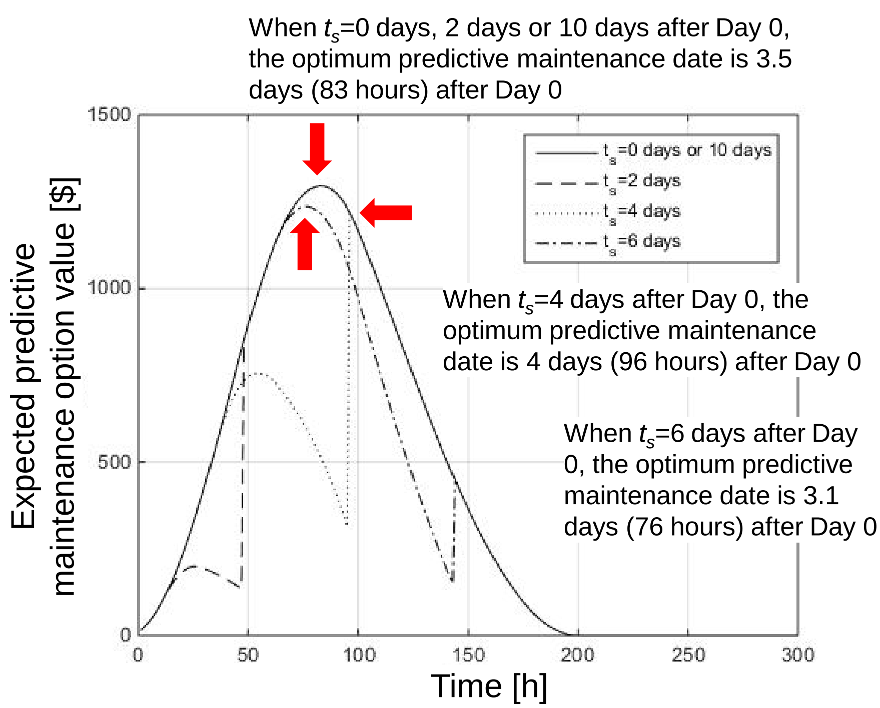

Figure 7. Optimum Maintenance Date Determined by the ROA Approach (Pointed to by the Arrows)

Note. When t_s changes, the optimum date may also change.

Conclusions

The objective of this work is to find the optimum predictive maintenance opportunity for systems managed under outcome-based contracts. Uncertainties in the RUL predictions from PHM and other sources are considered. This work demonstrates that the optimum action to take when a system presents an RUL depends on whether the system is an individual or is part of a larger population of systems managed via an outcome-based contract.

When considering non-production systems, the availability of a required spare part in the inventory is added to the model, and both the inventory and PHM are taken into account when making the decision on best time to perform maintenance.

Our vision is to develop a multidisciplinary outcome-based real options pricing model for supply chain and logistics design to determine the optimum performance metrics and an optimum payment plan (amount, term, incentive fees, and penalties) during the total life cycle of critical systems in PBL contracts. The proposed integrated PBL contract would address public policy and management in the field of government acquisition as well as have applicability to many types of non-governmental performance-based contracts. It includes economics, financial management, risk management, marketing, contracting, logistics, test and evaluation, and systems engineering management.

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Measuring the Return on Investment and Real Option Value of Weather Sensor Bundles for Air Force Unmanned Aerial Vehicles

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Measuring the Return on Investment and Real Options Valuation of a Weather Sensor Bundle in Mission Execution Processes

Weather-related losses of remotely piloted aircraft (RPA) have exceeded $100 million over the past 20 years (Preisser & Stutzreim, 2015). The growing ubiquity of RPAs in routine combat operations is driving fundamental changes to the nature of support for these unmanned aircraft. Support requirements such as bandwidth availability, data transmission capabilities, digital interoperability, and weather forecasting are being pushed to unprecedented limits to ensure they enhance RPA performance without imposing superfluous constraints. A persistent trend plaguing RPA operators has been poor environmental situational awareness degrading overall operational effectiveness.

The impact of suboptimal weather forecasting, especially regarding adverse weather conditions, on RPAs is significant, and it is driving an increasing need for fundamental changes to a system that has matured over several decades of proven operational success with manned aircraft. Without humans in the cockpit, the nature and frequency of weather forecasting processes and supporting technologies must evolve to enable optimized RPA operational performance by providing weather products that achieve high levels of resolution, accuracy, and timeliness.

This research supports Air Force A2I leadership by providing a comprehensive business case analysis that estimates the overall value of investing in, acquiring, and implementing WeatherNow technology. It provides a risk-based assessment for technology portfolio optimization. The WeatherNow technology in this research refers to an advanced weather forecasting software suite and an onboard weather sensor. The software suite collects, decodes, and processes space-based, airborne, and surface observations used in conjunction with numerical weather prediction models. Using advanced algorithms, data fusion techniques, and rapid update capability, it provides comprehensive environmental intelligence products, improved asset protection, and decreased operational risk. The onboard weather sensor provides real-time weather information about icing, humidity, and cloud top heights directly to RPA aircraft operators. The sensor also provides continuous weather data in otherwise data-deprived areas. The software suite and sensor were built to be integrated to provide timely, relevant, and mission-specific environmental intelligence, early threat detection for icing or instrument meteorological conditions (IMC), and overall enhanced ISR collection capability.

The study estimates the value of WeatherNow technology in terms of return on investment (ROI) and uses integrated risk management (IRM) to provide a way to value implementation options; both are indispensable tools that support informed decision-making for technology investment. The analysis and conclusions from this study will support development of effective policy and strategic investment decisions in the effort to transform the existing weather forecasting processes to meet modern demand for near real-time weather information to RPA operators.

To represent a typical mission execution process, this study focused on an RQ-4B Global Hawk squadron based at Beale Air Force Base (AFB). The mission execution process model (MEPM) describes how an RQ-4B squadron plans and executes a typical intelligence, surveillance, and reconnaissance (ISR) mission. The MEPM consists of five subprocesses that are further broken down into tasks. Each subprocess takes an input and changes it in some way to produce an output, which becomes the input for the next subprocess. This process flow continues until the final output is produced, the RPA mission itself. The MEPM in this study was verified by a number of SMEs to be an accurate representation while remaining generic enough to be extensible to a wide range of platforms and scenarios throughout the Air Force and the DoD at large. To ensure extensibility while conserving accuracy in the model, this study is driven by key assumptions that are explained in further detail in the study.

The quantitative framework for this research is known as ROI-IRM (return on investment with integrated risk management). This methodology measures the value added by the WeatherNow technology and by intangibles such as the people executing the process. Since traditional ROI calculation is inadequate for assessing the value of intangible assets such as embedded knowledge, this study uses the knowledge value added (KVA) methodology to estimate ROI. The benefit of using KVA is that a traditional metric such as ROI can be estimated without revenue, by using a surrogate by describing process outputs in common units of output (CUO). Another benefit of KVA is its ability to allocate value across the subprocesses and even down to the task level, a much improved granularity compared to traditional investment finance ROI estimates. To measure the intangible benefits, KVA uses a metric called return on knowledge (ROK). To determine ROI and ROK, KVA compares the As-Is MPEM, the current process, to the To-Be MPEM, the process with the WeatherNow technology included. ROI and ROK estimates are precisely comparable with regard to value for cost return estimates.

Integrated risk management (IRM) uses the KVA results to further develop the business case by forecasting the future value of technology options. IRM uses a methodology known as real options valuation (ROV) to provide leaders with a robust decision support tool to enable informed technology portfolio investment and implementation decisions based on future value estimates. ROI-IRM is an essential tool for supporting decisions on high level strategy and policy concerning new technology and its effective implementation and integration. KVA and IRM used together form a powerful and defensible analytical tool set for decision-making for technology investments.

KVA Analysis and Results

KVA produces two key metrics, ROI and ROK, both expressed as ratios. KVA takes the traditional ROI calculation used in finance and adapts it to non-revenue generating organizations such as the DoD. As in investment finance, a higher ROI indicates a better return for the money invested. For DoD applications, a surrogate value for revenue must be used to monetize the outputs for purposes of an ROI estimate that typically comes from a market comparable analysis. This research used a very conservative, putative value of $1 per unit of output. ROK is calculated as number of outputs (in common units) divided by the cost to produce the outputs. A higher ROK indicates a better use of knowledge assets, and therefore a better investment.

Overall, the results of the KVA analysis show that the use of WeatherNow technology in the RPA mission execution process will generate significantly higher returns and far better use of the WeatherNow technology over the current As-Is process. By comparing the As-Is MPEM to the To-Be MPEM, KVA not only reveals that the WeatherNow technology will add value, but exposes which tasks benefit the most and which benefit the least. Figure 1 displays the differences in returns between both models. With the WeatherNow technology included in the process, ROI increased by 69% and ROK is more than 2.8 times larger than the As-Is ROK. These gains are attributable to the large improvement within the Flight Brief/Outbrief/Weather Update subprocess, specifically the Weather Update task. The WeatherNow technology greatly improves the frequency at which RPA operators receive weather updates, from every four hours in the As-Is process, to every 15 minutes in the To-Be process. This increase means an ROK almost 300 times larger and an ROI over 1000 times larger than the As-Is model. These enormous improvements are due to the process recognizing the added value of the new technology many more times compared to the As-Is without WeatherNow.

	----- As-Is -----		----- To-Be -----			
Mission Execution Process Description (RQ-4B) Items in red are WX-related	**Return on Knowledge**	**Return on Investment**	**Return on Knowledge**	**Return on Investment**	**Change in Return on Knowledge as Ratios**	**Change in Return on Investment as Ratios**
TOTAL	**38%**	**-62%**	**107%**	**7%**	**2.8**	**1.1**
DAY PRIOR TO FLIGHT						
Data Extraction (mission study)	**35%**	**-65%**	35%	-65%	**1.0**	**1.0**
Confirm which mission you are flying (i.e. which COCOM, route, etc)	101%	1%	101%	1%	1.0	1.0
Confirm currency to fly in that theater and other currency items required for flight	169%	69%	169%	69%	1.0	1.0
Confirm aircraft assignment and status with maintenance	31%	-69%	31%	-69%	1.0	1.0
Review SPINS and classified regulations that pertain to your mission	23%	-77%	23%	-77%	1.0	1.0
Review en route procedures built by COCOM Flight Commander	31%	-69%	31%	-69%	1.0	1.0
File flight plan (DD-175 or 1801)	310%	210%	310%	210%	1.0	1.0
Disseminate products	62%	-38%	62%	-38%	1.0	1.0
Review Terminal Area Procedure brief (if doing TO/LDG and unfamiliar with local operations)	31%	-69%	31%	-69%	1.0	1.0
DAY OF FLIGHT						
Identify Showstoppers (determine and decide)	**78%**	**-22%**	**251%**	**151%**	**3.2**	**8.0**
Does the weather forecast support flight safety and tactical execution of the mission?	61%	-39%	434%	334%	7.1	9.6
Are appropriate aircraft available for the mission?	21%	-79%	21%	-79%	1.0	1.0
No prohibitive interference (GPS degraded/denied, SAM threat, red air, etc)	103%	3%	103%	3%	1.0	1.0
Can we mitigate expected threats en route and in the target area to an acceptable risk level?	123%	23%	434%	334%	3.5	14.7
Do we have satisfactory LOS comm/data link conditions?	62%	-38%	62%	-38%	1.0	1.0
Have the appropriate supporting agencies been assigned?	62%	-38%	62%	-38%	1.0	1.0
Simultaneous detailed mission planning (based on individual assignments and responsibilities)	**10%**	**-90%**	**10%**	**-90%**	**1.0**	**1.0**
All mission materials and products complete for mission commander review	10%	-90%	10%	-90%	1.0	1.0
Formal Intelligence update (receive intelligence analysis of the following considerations)	**124%**	**24%**	**124%**	**24%**	**1.0**	**1.0**
METT-TSL, EN tactics, EMLCOA, EMDCOA, Threats, Friendly situation	124%	24%	124%	24%	1.0	1.0
Flight Brief/Outbrief/Weather Update Brief	**79%**	**-21%**	**22659%**	**22559%**	**287.6**	**1064.7**
All mission participants understand the plan and their role in support	41%	-59%	41%	-59%	1.0	1.0
Outbrief with Operations Duty Officer (receive latest updates)	45%	-55%	45%	-55%	1.0	1.0
Weather update (icing, convection, lightning, IMC, threat mitigation, etc)	82%	-18%	41616%	41516%	506.7	2324.9
Safety brief/ORM considerations prior to execution	62%	-38%	62%	-38%	1.0	1.0

Figure 1. Impacts of WeatherNow Technology Use on Mission Execution (Differences in Returns as Ratios)

IRM Analysis and Results

The IRM portion of this research incorporates raw data and KVA results from a concurrent study concerned specifically with the weather forecasting process. Both studies use the ROI-IRM methodologies and serve as complementary works. Three deployment options were evaluated using IRM Analysis of Alternatives. The first option, Strategy A, is a phased implementation in which the WeatherNow technology is implemented incrementally over time. The second option, Strategy B, is a higher risk option in terms of capital investment and involves immediate implementation and quick returns. The third option, Strategy C, is to proceed with the existing plan of implementing the new technology on 50 Global Hawk aircraft and no more. Figure 2 displays the results from the ROV analysis. Based on IRM economic valuation forecasting, the highest value option is to deploy the WeatherNow technology immediately.

AS-IS Strategy	
Asset Value	$ 270,707
Implementation Cost	$ 1,342,045
Maturity	0
Risk-Free Rate (Annualized %)	0.00%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	9.85%
ROI %	-79.83%
Net Present Value	$ (1,071,338)
Option Value	$ -
Total Strategic Value	**$ (1,071,338)**

TO-BE Strategy: Sequential Implementation	
Asset Value	$ 1,993,268,707
Implementation Cost: Phase I	$ 519,802
Implementation Cost: Phase II	$ 1,039,605
Implementation Cost: Phase III	$ 1,039,605
Maturity: Phase I	2
Maturity: Phase II	4
Maturity: Phase III	6
Risk-Free Rate (Annualized %)	1.56%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	30.56%
Total Strategic Value	**$ 1,990,841,590**
Incremental Value-Added	**$ 1,991,912,928**

TO-BE Strategy: Immediate Implementation	
Asset Value	$3,986,537,414
Implementation Cost	$ 5,198,024
Maturity	3
Risk-Free Rate (Annualized %)	0.92%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	30.56%
Total Strategic Value	**$3,981,480,893**
Incremental Value-Added	**$3,982,552,231**

Real Options Valuation	
Strategy A Phased Implementation	$ 1,990,841,590
Strategy B Immediate Execution	$ 3,981,480,893
Strategy C As-Is Base Case	$ (1,071,338)

Figure 2. ROV Results

Insights

Although enormous improvements in ROI and ROK were realized, there are still more unrealized benefits of using WeatherNow technology. These benefits include the improvement in the richness of information that RPA operators receive and the implications of this richness on the level of confidence that operators have in making critical go/no-go decisions during mission execution.

Recommendations

Based on the results of this analysis, the following recommendations are submitted. To reduce uncertainty and mitigate risks, leaders should consider total strategic value through sophisticated analytical techniques, such as those used in this study, to inform critical decision-making. Once selected, investments should be tracked and monitored over time and then adjusted as necessary based on observed performance. This study was designed around a mature analytical framework and is extensible to a wide range of services, technologies, and platforms. Similar economic valuation analyses should be performed on other aviation platforms that may benefit from the WeatherNow technology, particularly lower flying RPA platforms that are more limited by adverse weather than the high-flying Global Hawk.

Conclusion

This quantitative analysis has proven that implementation of WeatherNow technology will improve the current mission execution process and has provided risk-based decision support tools to assist with critical decisions. This research did not examine the socio-technical implications of implementing such sophisticated technology in the mature weather forecasting system. Thus, there is opportunity for further research to conduct a detailed examination of potential acceptance issues with WeatherNow and how policy should evolve to support the optimal integration and sustained success of WeatherNow technology. This is an important area for continued research, investment, and innovation, toward modernizing the weather forecasting system to complement the unique needs of RPAs, improving their operational effectiveness, and reducing their susceptibility to adverse weather conditions.

Measuring the Return on Investment and Real Options Value of a Weather Sensor Bundle in Weather Forecasting Processes

Remotely Piloted Aircraft (RPA) usage has grown exponentially both in ubiquity and utility over the past decade and a half. From their initial use as a purely tactical-level asset in providing ground troops with aerial reconnaissance and surveillance, RPAs have become a strategic-level asset with the precision strike capability to take out high-level targets anywhere in the world. Currently, the greatest threat to RPAs is not surface-to-air missiles, but rather their susceptibility to severe weather conditions (Preisser & Stutzreim, 2015). When Unmanned Aerial Vehicles (UAVs) conduct missions in austere and remote environments where little or no infrastructure exists, timely and accurate weather forecasts have become difficult and in some cases almost impossible to produce. Losses in the hundreds of millions of dollars can be attributed to UAV crashes caused by high winds, icing, lightning, and heavy turbulence (Preisser & Stutzreim, 2015). Unfortunately during the development and acquisition of many UAVs in use today, very little testing and analysis of environmental situational awareness was conducted in order to prepare for this threat. Furthermore, without a human present on the platform itself, it becomes even more difficult to determine current weather conditions throughout the mission, exacerbating the threat that severe weather creates. It is for these reasons that a need for increased weather situational awareness has arisen among the UAV community.

The current weather forecasting process for UAV missions reflects a high degree of uncertainty and is often based on hours-old and sometimes inaccurate information. WeatherNow technology will attempt to mitigate the risks presented by the current weather forecasting process by providing significantly improved environmental awareness to maximize mission effectiveness and platform survivability. The program consists of an on-board weather sensor referred to as an Atmospheric Sensing and Prediction System (ASAPS) as well as a software suite, called Nowcasting, that fuses together data from the sensor as well as from existing weather nodes (such as satellite imagery and ground-based radar) to create weather updates that are accurate, timely, and relevant to the RPA crew.

Unique to the WeatherNow technology is the method in which the sensor and software suite are able to interoperate and integrate with current RPA tactics, tools, and procedures (Preisser & Stutzreim, 2015). The WeatherNow program consists of three separate phases that together produce actionable, real time, and much improved environmental awareness. Part one, Mission Area Sensor Streaming (MASS) retrieves environmental data from several sources, both typical and atypical (such as overhead persistent infrared) for the area of interest. Part two, Dynamic Rapid Update Module (DRUM), fuses together the data from the MASS phase (as well as data retrieved from the ASAPS sensor) to create a 4-D view of the environmental situation in the targeted area. As the name suggests, updates are conducted at a high rate, but the system is able to maintain a low level of latency while still producing a high-resolution view. The third portion of the Nowcasting program is Fused, Integrated Representation of the Environment (FIRE). The goal of FIRE is to provide the RPA crew with near-real-time products that give them enhanced environmental awareness of the area of interest. The WeatherNow program has the potential to significantly enhance the weather intelligence gathered in support of unmanned platform missions, but more broadly, it could radically improve the weather forecasting process as it exists in the Air Force today.

In order to estimate the value added by purchasing and implementing the WeatherNow technology, it is necessary to conduct a thorough analysis of the costs and benefits of using both the ASAPS sensor and Nowcasting software suite. This research uses the Knowledge Value Added (KVA) methodology to quantify the benefits of introducing the Nowcasting program into the Air Force weather forecasting process, specifically for the RQ-4B Global Hawk UAV community. This study quantifies value in terms of a Return on Investment (ROI), as well as provides implementation options through the use of Integrated Risk Management (IRM) and Real Options Valuation (ROV) portfolio optimization strategy.

This research documents a process model of the current “as-is” weather forecasting procedures based on input from Subject Matter Experts (SMEs) in the 9th Reconnaissance Wing aboard Beale Air Force Base (AFB). The process model describes how a weather forecast is created for use by an RQ-4B Global Hawk squadron while remaining generic enough to be applied to any Air Force squadron in which weather forecasts are produced. The process is broken down into six main subprocesses, which are further disaggregated to capture the complex nature of weather forecasting. Each subprocess takes a given input and produces an output, which becomes the input to the subsequent subprocess. The final output of the process is an actionable weather forecast brief to be used by the Global Hawk aircrew.

KVA methodology estimates the productivity embedded in an organization by measuring the value of knowledge contained in its people, technology, and processes (Housel & Bell, 2001). In this study, KVA quantifies the value of each subprocess of weather forecasting in terms of a common unit of output. In a non-profit organization like the DoD, estimating the ROI of a technology investment in dollars is not possible in the traditional sense. KVA produces a measure known as Return on Knowledge (ROK) based on the knowledge that is embedded within the organization’s people, technology, and processes. This study uses KVA to assess the value added to the weather forecasting process by implementing WeatherNow technology.

The IRM and ROV portions of this study determine the different pathways for the implementation of WeatherNow into the weather forecasting process. Due to the inherent volatility within the DoD acquisition of technology, Air Force leadership needs to have the flexibility to make changes to their adoption strategy. IRM and ROV provides those decision-makers with a tool that helps optimize the value of strategic decisions.

Knowledge Value Added Results

As in traditional financial investment return calculations, ROK is determined by dividing total output by total input. In this study the same ratio is applied to calculate the return on knowledge for each subprocess of weather forecasting and weather forecasting as a whole for both the as-is model and the to-be model (process with WeatherNow technology included). The numerator is calculated by multiplying the total learning time (time required to learn how to do that specific task) by the number of times that task is executed (“fired”) per year, and the value of one hour’s worth of learning time. In this case a value of $1.00 was used as a very conservative estimate (this is done in both the as-is and to-be models). The denominator is calculated by multiplying the labor cost by the number of people performing the task, the number of times the task is fired in one year, and the time required to perform the task. ROK values allow management to determine which subprocesses within their organization add more value to the process as a whole. Ultimately a higher ROK value for the to-be subprocesses (as well as the overall ROK value) would indicate that investing in WeatherNow technology adds value.

The results of the KVA analysis overwhelmingly support the adoption of WeatherNow technology into the Air Force weather forecasting process. The mission-watching subprocess received the greatest increase in return on knowledge from the as-is to the to-be scenario, as seen in Figure 3. The reason for this is because of the increase in the number of times the tasks within that sub-process are fired in one year. The Nowcasting software suite increases the number of weather updates by almost 20 times per Global Hawk flight mission. The knowledge embedded within the WeatherNow technology is another factor that contributes to the increase in ROK. The Nowcasting software and ASAPS sensor take thousands of hours of learning time and are able to fire at much higher rates than humans are capable. It is this central principle that explains the enormous increases in ROK and ROI. The return on knowledge in the to-be scenario is over 3,000 times greater than the as-is return on knowledge.

RQ-4 Weather Forecasting Process: Comparison of As-Is and To-Be ScenarioResults	As-Is Return on Knowledge	As-Is Return on Investment	To-Be Return on Knowledge	To-Be Return on Investment	Change in Return on Knowledgeas Ratio	Change in Return on Investment as Ratio
TOTAL	20%	-80%	76693%	76593%	3,802.1	612.1
Conduct Annual Cross Talk Between Forecasters and RPA Operators	276%	176%	276%	176%	1.0	1.0
Data Collection	322%	222%	3213%	3113%	10.0	14.0
sensitivities to determine mission-critical weather information	1084%	984%	148349%	148249%	136.9	150.7
Assemble the weather brief, tailoring the collected data to suit the specific mission set	274%	174%	274%	174%	1.0	1.0
Conduct mssion-watching	16%	-84%	366054%	365954%	23,386.8	3,087.5
Conduct debrief	45%	-55%	45%	-55%	1.0	1.0

Figure 3. Changes in Return on Knowledge and Return on Investment Due to WeatherNow Sensor (Differences in Returns as Ratios)

Integrated Risk Management and Real Options Valuation Analysis and Results

The IRM and ROV portions of this study evaluated three different strategies for adopting the WeatherNow Technology. Strategy A implements both the Nowcasting software and the ASAPS sensors over time in a phased approach. This is done with the intent to limit potential risks of failure early in adoption, as technology and software acquisition programs are prone to do. Phase I will outfit 10 Global Hawks with the ASAPS sensor within two years, Phase II will outfit another 20 Global Hawks in the next two years, and Phase III will outfit another 20 aircraft within the last two years. Strategy B is an approach that incurs very high capital investments early in order to reap the returns as quickly as possible. It calls for the implementation of the ASAPS sensor on 100 Global Hawks within three years. Strategy C adopts the technology to only 50 Global Hawks to be outfitted with the sensors, with no specific time constraint. The strategic option strategies are seen in Figure 4. As a result of the ROV calculations, the most optimal solution is Strategy B, immediate execution. It produces a total strategic value of just under $4 billion, as compared to a negative strategic value of $1.07 million for the as-is strategy. These results are seen in Figure 5.

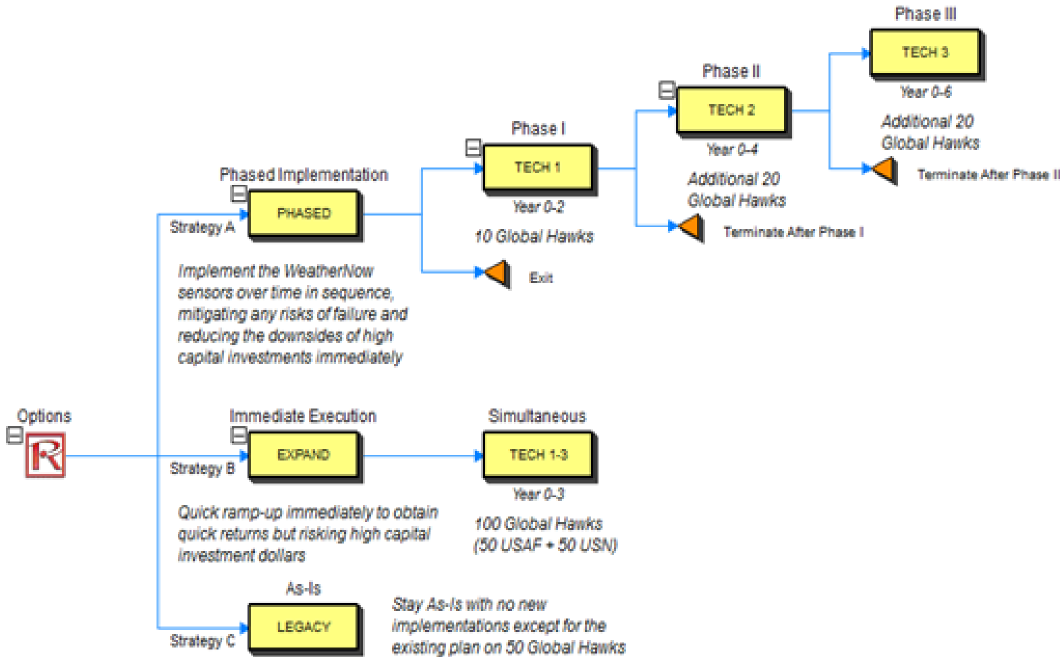

Figure 4. Adoption Strategies for WeatherNow

AS-IS Strategy

Asset Value	$ 270,707
Implementation Cost	$ 1,342,045
Maturity	0
Risk-Free Rate (Annualized %)	0.00%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	9.85%
ROI %	-79.83%
Net Present Value	$ (1,071,338)
Option Value	$ -
Total Strategic Value	**$ (1,071,338)**

TO-BE Strategy: Sequential Implementation

Asset Value	$ 1,993,268,707
Implementation Cost: Phase I	$ 519,802
Implementation Cost: Phase II	$ 1,039,605
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Maturity: Phase I	2
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Risk-Free Rate (Annualized %)	1.56%
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Incremental Value-Added	**$ 1,991,912,928**

TO-BE Strategy: Immediate Implementation

Asset Value	$3,986,537,414
Implementation Cost	$ 5,198,024
Maturity	3
Risk-Free Rate (Annualized %)	0.92%
Dividend Rate (Annualized %)	0.00%
Volatility (Annualized %)	30.56%
Total Strategic Value	**$3,981,480,893**
Incremental Value-Added	**$3,982,552,231**

Real Options Valuation

Strategy A Phased Implementation	$ 1,990,841,590
Strategy B Immediate Execution	$ 3,981,480,893
Strategy C As-Is Base Case	$ (1,071,338)

Figure 5. Real Options Valuation Results

Insights, Recommendations, and Conclusions

The KVA analysis conducted in this research indicates a favorable return should the DoD decide to invest in WeatherNow technology. Return on knowledge and cost savings aside, WeatherNow has potential benefits in several other areas as well. This study has only looked at implementation on the Global Hawk platform. Today there are over 10 different RPA platforms in use by the DoD, all of which are susceptible to adverse weather conditions. This study is generic enough to be extensible to not just Air Force weather forecasting in support of Air Force only RPA platforms. Army, Navy, and Marine Corps forces are potential benefactors of WeatherNow technology as well. Furthermore, the accurate weather forecasts produced by the Nowcasting software suite are not necessarily for use by RPA aircrews only. Manned aircraft have the potential to benefit from the increased environmental awareness afforded by WeatherNow. Additionally, ground units, specifically those that fire long-range rockets like the High Mobility Artillery Rocket System (HIMARS) and Guided Multiple Launch Rocket System (GMLRS) rely on timely and accurate weather forecasts. Improved weather intelligence would help those units improve the accuracy and lethality of their strike missions. As with most technological innovations that may disrupt current practices, however, appropriate care and time must be taken to train personnel in the operations and implications of WeatherNow technology. The relevant publications and doctrine would also have to reflect the use of WeatherNow as well. It is the recommendation of this study, however, that Air Force leadership adopts this technology and implements it rapidly.

Conclusion

This quantitative analysis supports the conclusion that implementation of the WeatherNow technology that was examined for this study will improve the current mission execution process and real time weather forecasting process. The results also have provided a risk-based decision support framework and supporting tool set to assist with future investment in technology decisions by treating such decisions as a portfolio of options with varying future quantitative values and risks.

The focus of this research precluded examining the socio-technical implications of implementing such sophisticated weather forecasting technology in the current weather forecasting system. Thus, there is opportunity for further research to conduct a detailed examination of potential acceptance issues with WeatherNow and how policy should evolve to support the optimal integration and sustained success of WeatherNow technology. This is an important area for continued research, investment, and innovation, all in the course of modernizing the weather forecasting system to complement the unique needs of RPA pilots. By improving their operational effectiveness and reducing their susceptibility to adverse weather conditions, the number of successful missions will increase over time.

Recommendations

The results clearly indicate that the immediate option to deploy the WeatherNow technology RAP fleet-wide are warranted. Delays in acquiring and implementing this technology will likely result in reduced value added and lower than possible mission success. The effect of this technology on mission success should be tracked over time so that options, risks, and ROIs can be adjusted to reflect real usage of the technology.

The performance analytical framework used in this study is extensible to a wide range of services, technologies, and platforms beyond its use in evaluating the potential value added of the WeatherNow technology. Similar economic valuation analyses should be performed on other aviation platforms that may benefit from the WeatherNow technology, particularly lower flying RPA platforms that are more limited by adverse weather than the high-flying Global Hawk.

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Panel 3. Systems Engineering: New Thinking for a New Age

Wednesday, May 4, 2016	
11:15 a.m. – 12:45 p.m.	**Chair: John D. Burrow,** Deputy Assistant Secretary of the Navy for Research, Development, Test, & Evaluation (DASN RDT&E) ***Rethinking the Systems Engineering Process in Light of Design Thinking*** Ronald Giachetti, Chair and Professor, NPS Clifford Whitcomb, Professor, NPS ***Content Analysis in Systems Engineering Acquisition Activities*** Karen Holness, Assistant Professor, NPS ***Update on the Department of the Navy Systems Engineering Career Competency Model*** Clifford Whitcomb, Systems Engineering Professor, NPS Corina White, Systems Engineering Research Associate, NPS Rabia Khan, Research Associate, NPS Dana Grambow, Research Psychologist, OPM Jessica Delgado, Technical Workforce Strategy Lead, DASN (RDT&E) José Vélez, Technical Workforce Lead, DASN (RDT&E)

John D. Burrow—serves as Deputy Assistant Secretary of the Navy, Research, Development, Test, and Evaluation (DASN RDT&E) under the Assistant Secretary of the Navy for Research, Development, and Acquisition (ASN [RD&A]). Dr. Burrow is responsible for executive oversight of all matters related to RDT&E Budget Activities, Science and Engineering, Advanced Research and Development, Prototyping and Experimentation, and Test and Evaluation. He is also responsible for oversight and stewardship of the Department of Navy Research and Development Establishment including naval laboratories, warfare centers, and systems centers.

Dr. Burrow has more than 30 years of federal service as an acquisition professional, systems engineer, and technical leader. He has held numerous senior leadership positions including Executive Director, Marine Corps Systems Command (MCSC); Deputy Commander (MCSC), Systems Engineering, Interoperability, Architectures, and Technology; Head, Naval Surface Warfare Center, Force Warfare Systems Department; Systems Engineering Director, Program Executive Office, Integrated Warfare Systems; Director, Marine Corps Amphibious Combat Vehicle Assessment Team; and Director, Navy Small Surface Combatant Task Force.

Dr. Burrow was appointed to the Senior Executive Service in December 2004. He is a Certified Level III Acquisition Professional in the Advanced Systems Planning, Research, Development, and Engineering (SPRDE) and Program Management (PM) acquisition career fields. Dr. Burrow holds a Bachelor of Science in mathematics from the University of Mississippi (1983), a Master of Public Administration from Virginia Polytechnic Institute and State University (1997), and a Doctorate of Management from the University of Maryland University College (2009).

Rethinking the Systems Engineering Process in Light of Design Thinking

Ronald E. Giachetti—is the Chair and Professor of the Systems Engineering Department at the Naval Postgraduate School (NPS) in Monterey, CA. He teaches and conducts research in the design of enterprise systems, systems modeling, and system architecture. He has published over 50 technical articles on these topics, including a textbook, *Design of Enterprise Systems: Theory, Methods, and Architecture*. Prior to joining NPS, he was at Florida International University in Miami, FL. He earned his BS in mechanical engineering from Rensselaer Polytechnic Institute, MS in manufacturing engineering from Polytechnic University (at NYU), and PhD in industrial engineering from North Carolina State University. [regiache@nps.edu]

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Abstract

The systems engineering process to design and develop new systems is based on a technical rationalization of the design process. This paper contrasts the technical rational approach with the design thinking approach, which describes the principles and methods based on how experienced designers approach design problems. We assert the structure of the design problem changes during development, and one contributor to the challenges that defense programs face in meeting budget, schedule, and performance requirements is the mismatch between the nature of the design problem and the engineering approach. Our position is a variant of contingency theory, contending there is no single best way to approach a problem, and an approach effective in one situation may not be effective in another. This paper reviews the technical rational and design thinking perspectives. The paper then examines the systems engineering process in light of design thinking principles and methods, and the paper makes recommendations to partition development into architecting and engineering, increase the variety and frequency of prototyping, explicitly show iteration in process models, and practice delayed commitment.

Introduction

The defense acquisition system implements systems engineering through standards, codification of policies and procedures, and extensive documentation. The systems engineering vee is the process model and serves as the de facto standard process model for Department of Defense (DoD) programs. The vee process model is a top-down approach of analyzing stakeholder needs to arrive at technical system requirements and finally a system design. The top-down approach is evidence in the extensive decomposition from the system-level design to subsystem design and component design. The vee model then shows synthesis by building and integrating the system from a bottom-up perspective. This is followed by component level, subsystem level, and finally system-level test and evaluation. The vee model makes feedback explicit in verification and validation information flows from test and evaluation to the analysis and design activities.

The systems engineering vee model adheres to the technical rational perspective. In this paper, we review the technical rational design approach and the assumptions underlying its methods. We then introduce design thinking and its assumptions. The technical rational design approach and the design thinking approach start with different worldviews and lead to two very different design approaches. We then analyze the systems engineering process in order to make recommendations to improve the process. We make recommendations and draw final conclusions.

Technical Rational Design

The Technical Rational Design approach is a structured approach to design based on a problem-solving perspective in which the designer's task is to solve a design problem. Simon (1996) was among the first to present the problem-solving perspective of design, which separates design into a problem formulation phase and problem solution phase. Simon and the artificial research community at the time sought computer algorithms to do the design process. The technical rational design approach assumes a positivist perspective that a single objective truth exists and can be observed and discovered through scientific methods (Neuman, 2005).

Pahl and Beitz (2013) wrote an influential German text defining a systematic approach to engineering design, which illustrates the assumptions and perspective of technical rational design. They partition the design process into four phases of clarifying the task, conceptual design, embodiment design, and detail design. The design process starts with the definition of requirements followed by successful refinement of a design concept through the last three phases. Each step of the way, the designer is making rational decisions in a pre-determined manner to arrive at the final design.

The technical rational design approach makes two key and interrelated assumptions. First, technical rational design approach assumes problem formulation can be separated from problem solution. We see evidence of this mindset in many texts with the advice to separate the "what" described by the functional architecture from the "how" described by the physical architecture (see Blanchard & Fabrycky, 1990). Second, the technical rational design approach assumes we can know and present the stakeholder objectives and system requirements without embarking on any design activities. The designer would then be able to search the design space to determine the set of Pareto optimal designs.

Given these two assumptions, design can progress in an orderly fashion through each step with minimal feedback and iteration. Moreover, adopting these assumptions makes the design problem amenable to formulation as a mathematical problem, which can then be subjected to algorithms to find the best designs. Here we formulate the design problem.

Design variables are the controllable dimensions, characteristics, and attributes of a system design specification. Initially, the value for each design variable is unknown, and through the process of design, the designer will specify values for the design variable until all design variables are specified. Let d_i denote the i^{th} design variable which can take any value in Δ_i, in other words $d_i \in \Delta_i$. The set Δ_i can be the set of integers, real numbers, or discrete options available for that design parameter (e.g., if d_i is the design parameter for battery type, then the domain Δ_i = {lithium-ion, nickel-cadmium, lead-acid}). If there are n design parameters, then the *design space* is an n-dimensional hyperspace that contains all the possible designs. It is defined by the Cartesian product

$$DS = \Delta_1 \times \Delta_2 \times \ldots \times \Delta_n$$

A design denoted by $\mathbf{D^k}$ is a vector of length n that specifies a value for each of the design variables, i.e., $\mathbf{D^k} = \left(d_1^k, \ldots, d_n^k\right)$. The superscript denotes the k^{th} design and distinguishes between the many designs in a design space. Every point in the design space is a design. However, not every design in *DS* will satisfy stakeholder requirements or even be technically feasible.

Requirements either describe function relationships between multiple design variables or requirements place restrictions on the admissible values of a design variable. The j^{th} function requirement is given by

$$r_j\left(\mathbf{D^k}\right) \leq 0 \quad j = 1 \ldots m$$

and requirement restrictions are expressed by lower limits Δ_i^{ll} and upper limits Δ_i^{ul} on the admission values as $\Delta_i^{ll} \leq d_i \leq \Delta_i^{ul}$.

The j^{th} system requirement partitions the design space into a region that satisfies the requirement, DS_j^S and a region that does not satisfy the requirement, DS_j^N. A design $\mathbf{D^k}$ satisfies a system requirement if it is in the satisfactory region of the requirement defined by $DS_j^S \subseteq DS$. The intersection of all m requirements defines the *satisfactory region* within which each design satisfies all the system requirements, and is given by

$$DS^S = \bigcap_{j=1}^{m} DS_j^S .$$

A design team will seek the best design, in other words the design that delivers the most value to the stakeholders, within the satisfactory region. Almost all designs will have multiple objectives from which stakeholders derive value. The value of a design with respect to a single objective is given by a *value function*. Value is a function of the design parameters and noise parameters. The value of the k^{th} design with respect to the l^{th} objective is given by the *value function*

$$V_l^k = f\left(d_1^k, \ldots, d_n^k, n_1, \ldots, n_p\right).$$

The set of noise parameters, denoted by $n_1, \ldots, n_p$, represents uncontrollable influences on performance such as environmental factors.

The vector $\mathbf{V^k} = \left(V_1^k, \ldots, V_n^k\right)$ denotes the values of the k^{th} design across all objectives. A design with a value of $\mathbf{V}^a = \left(V_1^a, \ldots, V_n^a\right)$ is said to dominate a design with a value of $\mathbf{V}^b = \left(V_1^b, \ldots, V_n^b\right)$ if and only if $\mathbf{V}^a$ is partially less than $\mathbf{V}^b$, which is when $\forall l \in L\, V_l^a \geq V_l^b \wedge \exists l \in L, V_l^a > V_l^b$.

The set of dominate designs is called the Pareto frontier. We speak of designers trading off objectives, and they would do this between designs in the Pareto frontier.

In summary, the design problem is formulated as finding the design(s) that maximize value while satisfying all the system requirements. It is expressed by the optimization model

$$\begin{aligned} \underset{\mathbf{D^k}}{\arg\max} \quad & \mathbf{V^k} = \left(V_1^k, \ldots, V_n^k\right) \\ & r_j\left(\mathbf{D^k}\right) \le 0 \qquad j = 1 \ldots m \\ & \Delta_i^{ll} \le d_i \le \Delta_i^{ul} \qquad i = 1 \ldots n \end{aligned}$$

The design optimization model is possible in technical rational design because the problem structure is assumed to be well-defined, it is assumed we can express value mathematically, and it is assumed we can express all requirements as mathematical functions. The design problem then becomes a matter of searching the design space to find the Pareto optimal designs.

The concepts and assumptions of the technical rational design approach form the basis upon which systems engineering process models (Blanchard & Fabrycky, 1990) and the majority of engineering design education (Dym et al., 2005). The waterfall model was an early example, largely developed in reaction to the poor experience of development software without any process.

There are many benefits to the technical rational design approach embodied by these methods. The systemization of design leads to manageable projects and the ability to define milestones and deliverables, and it standardizes the process which facilitates communication and makes the process repeatable. These benefits have enhanced government's and industry's ability to design and develop complex weapon systems.

Design Thinking

Design thinking is a term to describe the creative thinking process exhibited by designers and now used in many non-traditional design domains such as strategy formulation, business, and social sciences (Brown, 2008; Plattner et al., 2010). It has also influenced the Navy, as seen in ADM Richardson's eight-page "A Design for Maintaining Maritime Superiority" strategic document.

Dorst (2010) differentiates design thinking from other thought processes through the logical process of abduction, whereby we know the end value we want and have to discover the means to achieve it. The study and conceptualization of design thinking is conducted primarily according to an interpretivism approach after Schön's (1983) reflection-in-action research, in which he examined how professionals actually work. Interpretivism accepts multiple different realities based on the observer's perspective. It is in contrast to the positivist's claim that there is a single objective reality and we can only acquire knowledge through the scientific method, which is the technical rational approach (Neuman, 2005).

A process for design thinking identifies five activities (after Stanford University Institute of Design, 2016):

1. Empathize—Understand what the stakeholders desire through open-ended questions and related techniques to better understand the problem from many different perspectives.
2. Define—Combine and synthesize all the acquired information and perspectives to arrive at a group consensus on the problem structure.
3. Ideate—Generate ideas in a typical brainstorming fashion with the goal to generate as many ideas as possible.

4. Prototype—Create a mock-up of the design solution and use it for evaluation.
5. Test—Test the prototype, preferably with stakeholders and end-users.

Completion of a single iteration leads to a greater understanding of the problem as well as a potential design solution. Design thinking is based on the observation that designers work simultaneously on both problem structuring and problem solving (Dorst & Cross, 2001). Problem structuring involves the discovery of needs, requirements, and feasibility so that the designer can understand the problem. Problem structuring is achieved partially by proposing solutions because having a solution provides something concrete for stakeholders to react to and better understand their needs.

Design thinking is also referred to as human-centric design because of the importance placed on empathizing with the human users (Patnaik, 2009). During the empathize step, designers frame and re-frame the problem by adopting the user's perspective to arrive at different problem structures. Framing the problem from multiple perspectives implies the imposition of an interpretation of the problem, and each interpretation allows for additional insights and potentially different and more fruitful solutions (Paton & Dorst, 2011).

Unlike technical rational design, design thinking seeks to preserve ambiguity as long as possible because too quickly converging on a solution is seen to stifle creativity. Design thinking also promotes the early and frequent creation of prototypes to serve multiple purposes from problem understanding, solution evaluation, and communication.

Analysis and Recommendations

This section is organized according to the main recommendations on how design thinking can be incorporated into the systems engineering process.

Architecting vs. Engineering

The design problem changes in character from an ill-structured problem in the early phases to a well-structured problem in the later phases. Consequently, it makes sense to approach the different design problems differently. The concept of tailoring is based on contingency theory, which claims the best approach depends on the fit between the process and contextual factors (Drazin & Van de Ven, 1985). In the systems engineering process, a major contextual factor is the nature of the design problem: ill-structured or well-structured.

DoD Instruction (DoDI) 5000.02 (*Operation of the Defense Acquisition System*) allows for tailoring and says, "The structure of a DoD acquisition program and the procedures used should be tailored as much as possible to the characteristics of the product being acquired, and to the totality of circumstances associated with the program including operational urgency and risk factors." The instruction provides four baseline acquisition models to serve as starting points for tailoring. What is lacking in the systems engineering community is guidance on how to make the tailoring decisions.

The design process should be partitioned between two distinct phases of architecture design and system design. The architecture phase should be managed according to a design thinking approach, and the system design phase according to the technical rational design approach. Architecting is the activity comprising the generation, evaluation, and selection of alternative solutions. The architect works in both the problem space and the design space. Understanding the problem and conceiving of a design solution are directly related to each other. Consequently, architects iterate between problem structuring and problem solving and in the process they reveal new understandings of the problem space and the solution space.

The output of the architecture design phase is a system architecture defining the structure of the system in terms of the design variables, set of system technical requirements, and the measures of effectiveness, which in the DoD define value. Consequently, we have a well-defined problem amenable to the technical rational design approach. Designers would search the design space using algorithms and computational tools when available and appropriate to find the set of Pareto optimal design solutions.

We note the systems engineering community has been moving to this dichotomy between system architecting and system engineering, as evidenced by the earliest book on system architecture (Rechtin & Maier, 2010), to more recent works and emphasis (Dickerson & Mavris, 2009).

Requirements

Both technical rational design and design thinking suggests we need to think of systems requirements as being of two types: value statements and technical system requirements. Value statements express what stakeholders value in a system, can be measured on a continuous scale, and are negotiable. Requirements are the constraints a system must have and are non-negotiable. In the design optimization model, the value statements are part of the objective function and the requirements define the edges of the design space. When we state stakeholder value as a requirement rather than a value statement, we shackle the hands of our designers by unnecessarily restricting the design space. The value statements more closely match attainment of value as defined by stakeholders. Barry Boehm came to a similar conclusion and suggested we need to modify our terminology in order to effect the cultural change within the acquisition and systems engineering communities (Mavor & Pew, 2007).

Since the set of requirements define the edges of the design space, it is easily shown that adding requirements makes the design space smaller or at best the same size. If the design space is made smaller, then it is possible good designs are excluded. Given this insight, it is important to keep to a minimum the number of technical system requirements because they limit, perhaps unnecessarily in some cases, the design space.

Prototyping

Prototyping during the early architecting phase is as important as during the later phases (Kimbell, 2011). It seems many programs illogically think a prototype is an almost fully-functional copy of the intended system. Prototyping in the design thinking community is much more inclusive. Prototyping during the architecting phase is important for reasons of discovery, developing a deeper understanding of stakeholder value, communication, and to support problem structuring. A prototype as discussed by the design thinking community is any physical model that stakeholders and the designers can interact with. Design thinking promotes the building and usage of many low fidelity prototypes to aid the designers during problem structuring. An overemphasis by many programs on high fidelity prototypes with much of the functionality of the expected production system is counterproductive because they overlook the value of prototyping in the early architecting phase. Programs need to expand their prototyping capability in terms of both the diversity and fidelity of prototypes.

Incremental and Iterative

Design thinking research has demonstrably revealed that higher performing designers iterate between problem structuring and problem solving (Dorst & Cross, 2011). Top-down, sequential process models such as the vee model do not show this important aspect of system design and development. Moreover, the systems engineering vee and the Joint Capability Integrated Development (JCIDS) process suggest it is possible for the government to generate a solution agnostic specification of capability needs and system requirements. Design thinking says such a separation is not possible. In fact, designers need to think about solutions in order to better understand needs and system requirements. The systems engineering models should incorporate documentation to stress the importance of both incremental and iterative development. Larman and Basili (2003) discuss the history of incremental and iterative development and why within the software domain these methods are usually superior to sequential and document-intensive methods.

The number of iterations in iterative approaches is limited by either time or budget. Consequently, it is impossible to exhaustively search the entire design space before running out of time or money. All iterative approaches are local searches confined by the starting point and consequently, if you have a poor starting point, you will likely finish at an inferior design. One strategy is the multi-start whereby instead of using a single starting design to iterate upon, the designers consider multiple alternative designs preferably representative of the entire design space. Indeed, a GAO (2009) report analyzed 32 major defense programs that started after the year 2003. The GAO found the programs with a broad scope of alternatives had lower cost and schedule growth than programs with a narrow scope of alternatives. Each alternative is essentially a starting design for a multi-start strategy to explore the design space. A broader AoA is more likely to fully explore the design space and lead to better program outcomes. A narrow AoA is less likely to fully explore the design space; hence the problems.

Deferment and Delayed Commitment

The architecting phase is characterized by high uncertainty, yet it is well established that early design decisions can have an enormous impact on committed cost (Blanchard & Fabrycky, 1990). Deferring decisions until more information can be gained is a good strategy (Loch & Terwiesch, 2005). Set-based design, based upon American understanding of Toyota’s design process, is when instead of iterating from a starting design, a set of designs is propagated and progressively pruned until a final design is found (Sobek et al., 1999). Set-based design is one approach to tackling the mismatch between the amount of information available and the timing of decisions. It delays decisions until more information is available. This is a form of progression refinement since as the development process progresses, the uncertainty (measured as the size of the set) is gradually decreased until a precise value is arrived at. Giachetti et al. (1999) did something similar with fuzzy sets; Finch and Ward (1995) with intervals; HP with delayed differentiation; and Boehm and Lane (2007) with delayed commitment. More recently, the set-based approach has been applied to naval ship design (Singer et al., 2009; Mebane et al., 2011).

Conclusions

Design thinking starts out with a very different worldview from the technical rational design approach. While technical rational design is based on a positivist perspective of knowledge, design thinking is based on an interpretative perspective. The result is very different assumptions about how to conduct design, and consequently very different approaches. Using contingency theory, we propose to partition the system design and development process to achieve a better match between the problem space and the solution approach. Broadly, this means separating design and development into two phases of architecting and engineering design. The architecting phase is guided primarily by the design thinking perspective, and the engineering design phase is guided primarily by the technical rational design perspective. Additionally, we make recommendations for adoption of a broader set of prototyping capabilities, rethinking many requirements as value statements, and for greater recognition of iteration and incremental development in the systems engineering process model. The Systems Engineering Department at the Naval

Postgraduate School (NPS) is working towards educating the younger cohort of naval engineers in design thinking and how it can be beneficially incorporated into the systems engineering process.

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Content Analysis in Systems Engineering Acquisition Activities

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Abstract

This paper examines the role of content analysis in systems engineering technical evaluation processes. Content analysis is a qualitative data analysis methodology used to discover consistencies, inconsistencies, themes, and trends within datasets. This methodology is particularly useful when evaluating Contract Data Requirements List documents, as well as deficiency reports from test and evaluation activities; examples of such analyses are provided. Factors that can impact a systems engineer's ability to effectively and efficiently use this analysis method are also discussed. Research into the development of valid, relevant, and repeatable analysis criteria promises to define (1) how content analysis can be used consistently across different system baselines and (2) how content analysis results generated during the "Production and Deployment" and the "Operations and Support" acquisition lifecycle phases can be used to shape requirements definitions for system upgrade or modification contracts and new baseline contracts. Finally, content analysis training and skill development for systems engineers in the acquisition workforce is discussed.

Introduction

During the different phases of a system's lifecycle, systems engineers evaluate a lot of data from a variety of sources. A key part of analyzing this data is discovering patterns and using those patterns to support additional analyses. As stated in the *International Council on Systems Engineering* (INCOSE) *Handbook,*

> Systems thinking captures and exploits what is common in a set of problems and corresponding solutions in the form of patterns of various types … Systems engineers use the general information provided by patterns to understand a specific system problem and to develop a specific system solution. (INCOSE, 2015)

A variety of quantitative and qualitative methods exist to (1) capture or generate data needed for a particular analysis, (2) reduce the data, (3) evaluate the data to find patterns, and (4) draw conclusions about the System Of Interest (SOI). This paper focuses on content analysis, a qualitative method that is well suited for datasets that contain primarily text-based data.

What Is Content Analysis?

Patton (2015) describes content analysis as "any qualitative data reduction and sense-making efforts that takes a volume of qualitative material and attempts to identify core consistencies and meanings. … The core meanings found through content analysis are patterns and themes." As defined by Krippendorff (2004), content analysis is used to make "replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" and is most successful when evaluating attributions, social relationships, public behaviors and institutional realities. The basic steps to conducting a content analysis are summarized below. See either Krippendorff (2004) or Patton (2015) for detailed descriptions of each of these steps.

1. Decide what data sources to use for the analysis. These best fit the research questions (unitizing).
2. Identify a representative data subset to analyze (sampling).
3. Transform the raw data into analyzable data; evaluate and interpret characteristics within and between data elements by assigning elements to categories based on an observed pattern or theme. This can include inter-rater agreement studies for the categories (recording/coding).
4. Evaluate and interpret the categorized data, looking for additional patterns, themes, correlations (e.g., sub-categories) and outliers (reducing data).
5. Infer the meaning of the categories. Test and validate the inferences with respect to the research questions (inferring).
6. Summarize and communicate the analysis findings (narrating).

Content Analysis in Systems Engineering Activities

Within a systems engineering context, both "attributes" of system components and "institutional realities" with respect to operational and maintenance concepts for a given SOI are identified and evaluated during a system's design lifecycle. Therefore, someone taking the time to gather existing text-based documents from either electronic or paper sources and look for patterns and themes is already done within systems engineering practice to varying degrees.

One example is the case where various stakeholders and/or representative users are interviewed to capture their inputs on what the SOI needs to do and what should be reflected in the corresponding system requirements and technical performance measures. The answers to the interview questions have to be evaluated and summarized in some fashion. Another example is performing trade studies, when various industry information sources are reviewed to understand the latest systems available on the market and current technology trends that may apply to the SOI. Reviewing different documents or websites, the systems engineer looks for very specific features and compares and contrasts them in some fashion. The INCOSE (2015) Systems Engineering Handbook describes, in detail, each of the standard technical processes and the various activities that take place within each process. Table 1 provides a sample of systems engineering activities described in the handbook that most likely involve the review of qualitative data from text-based sources.

Table 1. Sample of Systems Engineering Technical Process Activities for Content Analysis

(INCOSE, 2015)

Process	Activity
Business or Mission Analysis	• Analyzing gaps across the problem or opportunity trade space
Stakeholder Needs and Requirements Definition	• Eliciting and prioritizing stakeholder needs • Identifying solution constraints resulting from agreements or interfaces with other systems
System Requirements Definition	• Ensuring the system requirements adequately reflect the stakeholder requirements • Negotiating modifications to the requirements to resolve any issues identified
Architecture Definition Process	• Analyzing "relevant market, industry, stakeholder, organizational, business, operations, mission, legal, and other information" to guide architecture development
Design Definition	• Identifying types of design characteristics for each system element
Systems Analysis	• Comparing results from several types of models
Implementation	• Eliciting constraints related to implementation from "stakeholders, developers, and teammates" • Analyzing and resolving any anomalies that occurred during implementation
Integration, Verification and Validation	• Analyzing and resolving any anomalies that occurred during integration, verification and validation
Operations	• Identifying additional operations constraints and providing feedback to the system design team • Analyzing and resolving any anomalies that occur during operations
Maintenance	• Identifying additional maintenance constraints and providing feedback to the system design team • Analyzing and resolving any anomalies that occur during maintenance activities • Identifying trends in maintenance and logistics actions • Eliciting customer feedback on maintenance and logistics support process satisfaction

Of particular interest to this paper are the technical processes that take place after System Analysis. The Implementation, Integration, Verification and Validation processes typically span the "Engineering and Manufacturing Development" acquisition lifecycle phase. As described in Table 1, all of these processes share one activity in common: analyzing and resolving any anomalies that occur during each process's execution. During this phase, the product baseline for the SOI is reviewed and approved during the key Systems Engineering Technical Reviews (SETRs) that are required prior to the start of the "Production and Deployment" acquisition lifecycle phase: the Critical Design Review (CDR), Test Readiness Review (TRR), and the Production Readiness Review/Functional Configuration Audit (PRR/FCA).

In preparation for each of these SETR events, the contractor systems engineers evaluate the SOI's design and document its status in the required Contract Data Requirements List (CDRL) documents. Examples of these documents are Design Description documents, Product Drawings and Associated Lists (PDALs), and Deficiency or Discrepancy Reports (DRs). These documents are then reviewed and interpreted by the Government Systems Engineers, Logisticians, and Test & Evaluation (T&E) Engineers for accuracy and validity and in order to assess the SOI's adequacy and readiness. Any anomalies would be discussed with the contractors to either resolve or come up with a mitigation strategy, preferably before the SETR event.

While this may sound simple and straightforward, it can be a daunting task, even for systems with relatively few components and for documents housed in a configuration management software like DOORS®. Ensuring consistency within and across Design Description documents requires the system engineer to cross-reference the content of each document, looking for specific similarities and differences. This is important because each document focuses on detailed aspects of the same SOI. Similarly, the PDALs may contain hundreds of component and subsystem drawings, including those for the Commercial Off the Shelf (COTS) components. The contractor systems engineers have to review each component drawing, ensuring that the content makes sense and correlates with the other drawings that each one references. The interfaces depicted in these drawings must also match the same interfaces described in the design description documents. This matching task can reveal configuration errors that could impact component production in the next acquisition phase. For the DRs, it is the responsibility of the systems and T&E engineers to review these reports, evaluate them for patterns and themes, and interpret what those patterns and themes reveal about the performance of the software and hardware. The Government Systems Engineers, in an acquisition oversight role, independently repeat the same process for each one of these documents.

The systems engineer, as the Subject Matter Expert (SME), will be held accountable for the hardware and software's performance by the Program Manager. Looking for trends, correlations, and consistencies/inconsistencies helps the systems engineer evaluate the feasibility of the technical baseline and qualify the reliability and quality of the data used in the evaluation. For the Government Engineers, this kind of analysis also helps gauge the quality of the contractor's technical performance.

The Operations and Maintenance (O&M) processes described in Table 1 correspond to the "Production and Deployment" and the "Operations and Support" acquisition lifecycle phases. Like the previous technical processes discussed above, the O&M processes also analyze and resolve any anomalies that occur. Tracking system performance measures and periodically correlating that data to deficiency log data or maintenance action reports can reveal additional factors that are impacting system performance. Similar to the Implementation process, it is important that any additional constraints observed by users/operators, maintainers, other engineers or stakeholders within the O&M processes are captured, documented, and evaluated. Once fed back to the system designers, this information can then be used to shape requirements definition for system upgrade or modification contracts and new baseline contracts.

It is important to note that the systems engineers doing data analysis in the O&M processes may be different people than the ones who worked on the contract in previous phases of the acquisition lifecycle. Instead of working for the program office or the prime contractor, these systems engineers may work for the installation site and are responsible for capturing and analyzing system performance. Evaluating and packaging these data and data analysis results can be a different task if it is being done to support local management or will be provided to an outside organization for system design purposes.

Research on the Use of Content Analysis in Systems Engineering Activities

Systems engineers seem to be performing some level of content analysis. But, in which technical activities? How "well" is it being done? How valid are the results? Valuable insight can be gained by researching the actual use of content analysis in the technical processes previously discussed and what software tools are used and can be used to facilitate the process.

For example, Fortune and Valerdi (2013) developed a framework for determining how to reuse previously created engineering products for a new development effort. As part of the evaluation phase in this framework, the first step is to analyze both internally and externally developed products that are available, like requirements documents or modeling tools, then determine whether or not they apply to the SOI. Because this seems to involve a comparison of a previous system to the new SOI, an investigation into the effectiveness of using content analysis categories may prove to be useful. Since the next step in this framework is to estimate the costs and anticipated benefits from reusing the engineering products, having supporting evidence generated from a thorough content analysis may help to justify the investment.

It is easily hypothesized that the successful use of content analysis as a research methodology within a design environment or an operational setting would be impacted by factors such as

- Time required and resource availability to spend on the analysis
- Familiarity/Expertise with content analysis methods
- Familiarity/Expertise with the technical subject matter and data content
- Data access, particularly when data are spread across multiple print and electronic sources
- Data quality/quantity
- Individual personality—having the ability and patience to search for and identify patterns in datasets of various sizes

It would be worth researching the impact that content analysis would have on the system engineer's workload. Such a study could provide supporting evidence for hiring a dedicated data analyst on acquisition projects to perform various technical content analyses. Investigating the degree to which the other factors listed above actually impact content analyses can help identify constraints and possible mitigations to support the use of this methodology in different acquisition phases.

Another possible research path is the development of valid, relevant and repeatable analysis criteria that can be used across different system baselines. Granted, every system is unique. However, research to develop either (1) appropriate contexts and levels of depth for content analysis efforts within different acquisition phases or (2) generalizable categorizes for system attributes would help lay a foundation for integrating this methodology into the systems engineering toolkit. Having a common analysis tool that is easy to use would support the feedback of observed system performance trends from the operational and maintenance community to the design community, which would be used to develop requirements for system upgrade or modification contracts and new baseline contracts.

Finally, the implications of content analysis on training and skill development for systems engineers in the acquisition workforce should be investigated. Frank (2006) evaluated interview and survey data (using content analysis as part of his data analysis methodology) to characterize the cognitive characteristics and abilities of engineers with a high Capacity for Engineering Systems Thinking (CEST). While the ability to identify patterns and themes was not specifically identified in this study, the characteristic of understanding analogies and parallels between systems and the ability to conduct trade studies were identified. As an analysis methodology that specifically targets these abilities, it would be interesting to evaluate use of content analysis on the development or enhancement of these abilities. It would also be worth developing guidelines to use content analysis specifically in baseline comparison analyses, providing training on its use, then determining any impact to the perceived validity of the analysis results. Additional studies that test instructions on how to identify and validate data sources, gather data from these sources, and use commonly available software tools like Microsoft Excel would further demonstrate the feasibility of using this methodology.

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Update on the Department of the Navy Systems Engineering Career Competency Model

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Corina L. White—has expanded her professional work experience from 2007 to 2015 as a U.S. Navy civilian in several unique disciplines, including research and development, aerospace engineering, and materials engineering. She has had the opportunity to work with the National Aeronautics and Space Administration (NASA), Naval Air Systems Command (NAVAIR), and currently the Naval Postgraduate School (NPS). Her educational experience includes a bachelor's degree in chemical engineering from Prairie View A&M University and a master's degree in systems engineering from NPS.

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Jessica Delgado—is the Technical Workforce Strategy Lead within the Deputy Assistant Secretary of the Navy for Research, Development, Test, and Evaluation DASN (RDT&E). Prior to that, Delgado was the PESOH for all mortar programs for the Infantry Weapons Program Office of MARCORSYSCOM. Delgado started her career at NSWCDD in the Concepts and Experimentation Branch in the Chemical, Biological, and Radiological division as a scientist. She has a Master of Science degree in biology from the University of Puerto Rico and a Bachelor of Science degree in microbiology from the same university.

José Vélez—is currently serving as the DASN (RDT&E) Technical Workforce Lead shaping and defining Department of Defense (DoD) policy directly impacting and influencing the technical workforce within the Naval Research & Development Establishment (NR&DE). He received a Bachelor of Science degree in mechanical engineering from the University of Puerto Rico, College of Engineering, in 1979 and a Master of Science in engineering administration from George Washington University in 1985. He is a member of the Acquisition Professionals Community and is DAWIA certified at Level III in both the Engineering and Program Management career fields.

Abstract

The Department of Defense (DoD) acquisition workforce is growing rapidly, and the need to align tasks to job positions and competencies with individuals to ensure positions are filled with the "best fitting" candidate is extremely important. DASN RDT&E has funded NPS on a multi-year project to lead a multi-agency working group in the development of a Systems Engineering Career Competency Model (SECCM). The current phase of the SECCM development project is heavily focused on the verification of the model. OPM joined the SECCM working group to assist in the refinement, confirmation, and strategic planning required to ensure the systems engineering competency model is a legally defensible,

relevant, and sound tool. The analysis of the ongoing verification effort and an overview of how NPS and OPM plan to assist with DoN implementation of the SECCM will be discussed. Research results from the SECCM verification process can be used for key human resources functions, such as hiring, promoting, administering skill(s) gap assessments, and in career path modeling/development plans.

Introduction

The Department of Defense (DoD) has established a competency-based approach to strategic workforce management. This approach includes assessing the critical skills and competencies needed now and in the future within the civilian workforce, along with strategies to bridge competency and skill gaps. A competency-based approach supports strategic workforce planning and effective talent management. The specifications of 5 C.F.R. 300A, *Employment Practices*, a federal regulations guide, require (1) a job analysis for selection and competitive promotions in Federal employment, (2) compliance with the job-relatedness requirements of the *Uniform Guidelines on Employee Selection Procedures* (43FR38290), and (3) that resulting assessments target competencies required for the occupational position. The Uniform Guidelines are a set of principles designed to assist employers, labor organizations, employment agencies, and licensing/certification boards in complying with requirements prohibiting discriminatory employment practices. As such, the Uniform Guidelines are "designed to provide a framework for determining the proper use of tests and other selection procedures [in employment practices]" (Biddle Consulting Group, 2015).

A DoD working group (WG), led by the Naval Postgraduate School (NPS), has been studying and refining the definition of what competencies acquisition workforce engineers must have in terms of systems engineering. Since there is currently no occupational series for systems engineering in the U.S. government, the need to align tasks to job positions and competencies with individuals to ensure systems engineering positions are filled with the "best fitting" candidate is extremely important (Whitcomb, White, & Khan, 2014). With these thoughts in mind, Deputy Assistant Secretary of the Navy (DASN) for Research, Development, Test, and Evaluation (RDT&E) funded NPS on a multi-year project to lead a multi-agency working group in the development of the Systems Engineering Career Competency Model (SECCM).

Over the past few years, the SECCM WG has operated with members—including the U.S. Office of Personnel Management (OPM), Navy, Army, Air Force, Marine Corps, and the Missile Defense Agency—to develop and verify the competencies used by defense systems engineers. OPM joined the SECCM working group to assist in the refinement, confirmation, verification, and strategic planning required to ensure the systems engineering competency model is a legally defensible, relevant, and sound tool. Within the U.S. government, only a model that is verified in accordance with the Uniform Guidelines can be used with confidence for all human resource (HR) functions, especially for high stakes functions such as hiring, selection, writing position descriptions, and creating job announcements. Verification of the competencies within the SECCM is critical to allow it to be used as a basis for "high stakes" HR functions for all of the U.S. Department of Defense.

The SECCM WG identified a collection of knowledge, skills, and abilities (KSAs) that define the basis for developing effective systems engineers that evolved over time based on availability of related systems engineering competency data. One of the latest pieces of information arrived in 2016 when the Office of the Secretary of Defense (OSD) released their updated and refreshed competency model for the engineering (ENG) career field for systems acquisition. Their competency model includes systems engineer career professionals (previously under the Systems Planning, Research, Development, and Engineering career field) along with all other engineers under one career field: ENG. The SECCM was subsequently modified to match the new ENG model. In the current configuration management controlled state, the SECCM Baseline Rev 1 has 3,272 individual KSAs categorized within 44 competencies. The evolution of the SECCM is summarized in Figure 1.

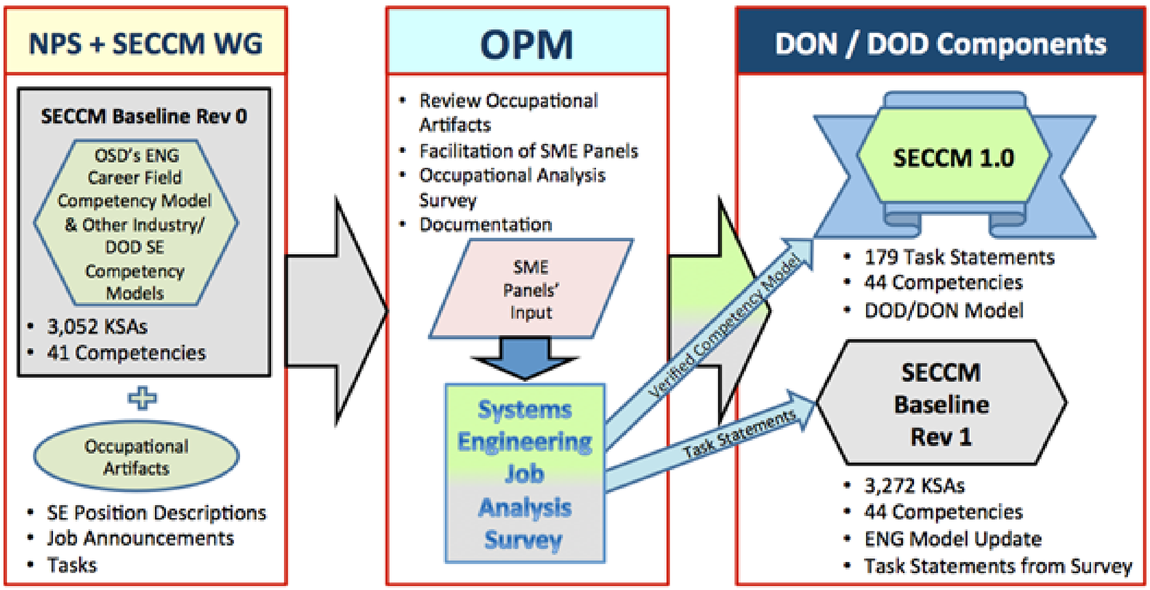

Figure 1. Evolution of the SECCM

The SECCM project focus is to concentrate on the details for career development aspects related to the model and the creation of a "road map" to aid in the implementation. The current phase of the SECCM development project is heavily focused on the OPM section for verification of the model. OPM is currently overseeing the occupational analysis aspects as a part of the verification process of the competencies identified within the SECCM.

Many organizations within the DoD have SE competency models that have been locally "verified" or "validated" for their own individual use. These uses include career development, tracking education and training requirements, and understanding the work-related activities that systems engineers have to accomplish. These SE competency models have been verified or validated locally in the sense that they have proven useful in their operational environment to define what the respective systems engineers do. However, none of these existing models is currently verified IAW the Uniform Guidelines.

Once verified, however, the SECCM can be used to guide career choice and self-selection by describing in detail what is required to be successful at a particular job/role. As a verified model, the SECCM would also assist human resource efforts to find the "right fit" for a position, as potential applicants would have an informed understanding of what KSAs are needed for a particular position prior to applying for it. Furthermore, as a verified competency model, the SECCM can also be used to assist with leadership development and career development plans. For example, appropriate training and development plans could be created based on the results of the verified competency model. Courses can be created to bridge specific competency gaps by developing specific competencies. Competency Assessment tools could also be derived to supplement academic qualifications of applicants (Patterson et al., 2000). Competency models can also be used to evaluate employees' performance, to reward employees by using the competencies to establish promotion criteria (Morgeson, Campion, & Levashina, 2009), and to manage employee information by using the competency models to record and archive employee skills, training, and job experience information. Employees could be compensated using the model to structure pay differences between jobs and/or to evaluate employees for pay increases. Retention of critical skills and reduction-in-force activities can also be managed through identifying and measuring competencies aligned to the current and future organizational objectives (Campion et al., 2011).

OPM Occupational Analysis Survey

OPM took a four-pronged approach to the job, or occupational, analysis: review of occupational information, facilitation of SME panels, administration of surveys, and documentation. The occupational analysis methodology focuses on identifying the competencies and tasks that are critical for employees functioning as systems engineers. This method of analysis establishes which competencies are suitable for assessment in human resources activities.

OPM began the occupational analysis with a review of the competencies along with additional occupational information provided by NPS and other DoD components, including MDA. The occupational information served to further define the competencies. Adding descriptions to the competencies served to ensure each competency included in the model is clear and unique. OPM also conducted an initial review of the KSAs to refine the list. OPM personnel research psychologists facilitated SME panels, removing and revising KSAs that were not behaviorally based or measurable to ensure the resulting task statements had the characteristics necessary to support a variety of HR activities based on the SME input.

The occupational information helped OPM identify a set of SE competencies and draft task statements that subject matter experts (SMEs) would evaluate during the review panels. Panels were held first with incumbents who currently perform systems engineering activities and then with individuals who supervise those who perform systems engineering activities. NPS recruited SMEs to participate in the panels, requiring them to meet experience criteria to ensure each participant had a minimum level of familiarity with systems engineering activities. SMEs provided input to further revise competency definitions and task statements, to identify competencies and tasks critical to systems engineering, which were not represented in the existing models researched, and to eliminate tasks not representative of the job. The revised competencies and tasks served as the foundation for an occupational analysis survey.

In preparation for the SECCM survey deployment, the SE population was needed to assist in the identification of those SEs to include in the survey pool. Identifying the population of systems engineers was a challenge for the DoN as well as the other defense organizations, as there is currently no professional engineering occupational code or position description for SEs within the DoD. The SE population was identified based on input from all participating organizations. There was no single best way to identify a systems engineer, so each component was required to identify their own population based on identifying those engineers who performed tasks related to SE.

The occupational survey was launched in September 2015. It was administered to a personnel sample representing the great majority of the SE population. Oversampling was done to ensure a robust sample for the results could be used to represent the population of SEs. Two separate questionnaires were developed, one for supervisors and one for employees. OPM invited employees who perform systems engineering activities and their supervisors to participate in the survey, only retaining data from employees with established minimum experience levels to ensure adequate familiarity with systems engineering work. Additionally, survey branching methodology was used, which required participants to respond to questions designed to distinguish participants who function as a systems engineer from those who serve in other engineering disciplines.

The survey was sent to 6,011 employees and 1,519 supervisors across the DoD. Survey participants were asked to evaluate each competency and task on criteria such as frequency, importance, required immediately upon entry into the position, and need for training. Figures 2 and 3 show a 21% response rate for the employee survey and 6% for the supervisor survey. The survey response rates increased with time due to the concerted effort the WG provided to ensure the survey respondents had support from senior leadership.

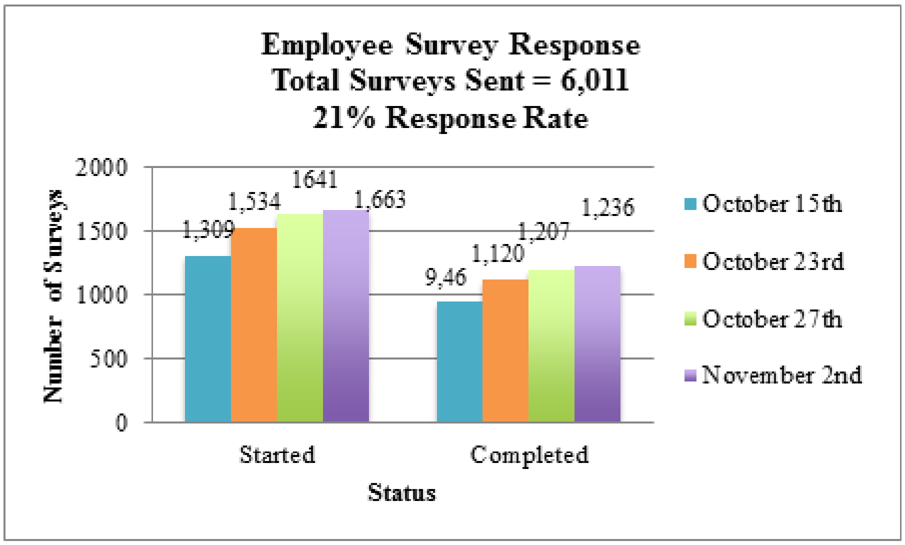

Figure 2. Employee Survey Response Rate Progression

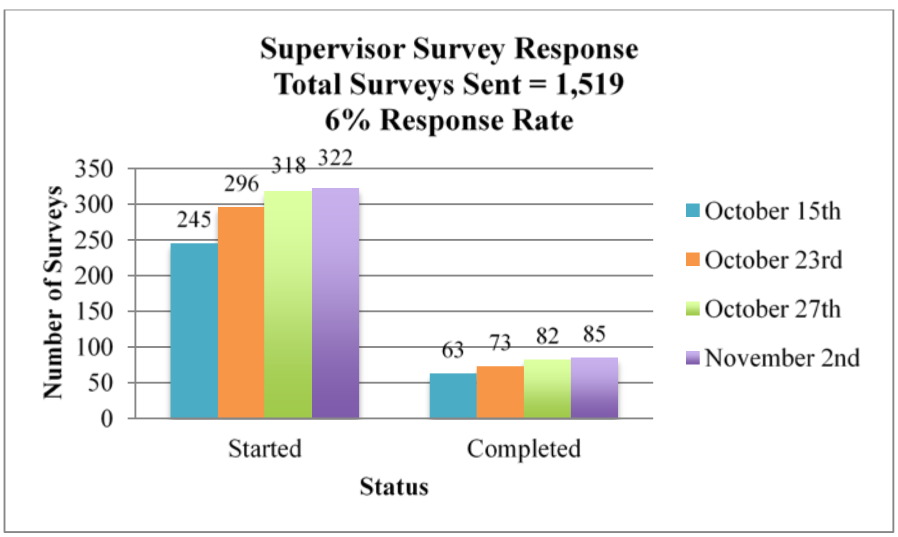

Figure 3. Supervisor Survey Response Rate Progression

In the occupational analysis survey, incumbents indicated how frequently they perform the tasks. For the competencies, the incumbents rated importance and degree to which training in the competency would help them perform their jobs more effectively. The supervisors rated the importance of the tasks, and for each competency, they rated importance and degree to which the competency is required at entry to the job. Supervisors provided separate ratings of the tasks and competencies based on the requirements for incumbents at each grade level (GS-07 to GS-15; OPM, 2016). The survey was estimated to take about 2.5 hours. Initial feedback from supervisors suggested that their survey took considerably longer, which could explain the lower response rate.

Department of the Navy Survey Analysis

OPM started the statistical analyses for the Navy and Marine Corps survey data on January 2016. To identify the critical tasks, the research psychologists analyzed task ratings of importance and the percent of respondents who indicated the task is performed by SEs. Competencies critical for performing systems engineering activities were identified by analyzing competency ratings of importance. The resulting critical tasks and competencies create the occupational profile for individuals performing systems engineering work. In conformance with legal and professional guidelines, OPM documented the methodology and results for all phases of the occupational analysis. The documentation is a necessary component for demonstrating the process is sufficient to serve as a component of a content validation approach for ensuring the validity of future human resources activities.

OPM used the results of the survey to identify the critical tasks and competencies for successful performance as a systems engineer at the GS-07 to GS-15 grade levels. The survey was administered to 3995 incumbents and 645 supervisors from the Navy and Marine Corps. The analysis resulted in identifying a number of critical tasks and competencies for systems engineers from GS-07 to GS-15, as shown in Table 1.

Table 1. Summary of Critical Tasks and Competencies by Grade Level
(OPM, 2016)

Grade Level	Critical Tasks	Critical Competencies
GS-07	18	2
GS-09	19	7
GS-11	76	6
GS-12	165	16
GS-13	174	36
GS-14	175	40
GS-15	176	43

Of note in Table 1 is the lower number of tasks and competencies determined to be critical for grade levels GS-07 to GS-11. Based on conversations occurring throughout the SME panels, it is possible many engineers do not enter into the systems engineering profession until later in their career because they begin in a specific engineering discipline and then transfer to systems engineering at higher grade levels. Therefore, the competency model developed for systems engineers focused more heavily on technical competencies specific to the systems engineering profession (OPM, 2016).

In addition, OPM psychologists analyzed the competency proficiency data to identify competency gaps, computed as the percentage of incumbents who rated themselves below the required proficiency level identified by supervisors. The skills assessment analysis revealed widespread skill gaps across the systems engineer workforce. Navy can use the competencies identified in the current occupational analysis as the basis for future initiatives in any of these areas. In addition, Navy can use the skill gaps identified across the systems engineer workforce to identify and target training and development for systems engineers (OPM, 2016).

Considerations for creation, formatting, promulgation, and use are important, since there are considerations for which competencies/KSAs/tasks can be used for high stakes human resource functions, as well as other workforce career planning, development, and shaping purposes. OPM's analyses of the survey results identify critical competencies and critical tasks. The Navy plans to promulgate the verified SECCM (Version 1.0) to all the Naval components, Systems Commands, and Warfare Centers for their use in writing position descriptions and job announcements, drafting assessment questionnaires for hiring actions, and using for gap analysis, employee analysis, and other human resource functions.

The next phase of survey results analysis includes the USA, USAF, and MDA, due from OPM by the end of FY 2016. Once all the survey results are known, the SECCM WG can review the results with OSD to inform and offer its results for possible use by the entire defense community.

Summary

The SECCM development was led by NPS as funded by DASN RDT&E. From its inception to FY 2016, the project has shifted to concentrate on the details for career development aspects related to the model. The current phase of the project is focused heavily on the verification of the model, which is significant because without a verified competency model, job announcements, position descriptions, and so forth cannot currently require SE competencies, knowledge, skills, and abilities. Unless a local occupational, or job, analysis has been completed, they can only desire them.

The results of the survey analysis is a verified SECCM. Furthermore, the proficiency level criteria for each individual competency at each proficiency level is documented in the model. Organizations that employ systems engineers will be able to use the verified SECCM to support their high stakes HR functions (i.e., job announcements, position descriptions, etc.). Additionally they will be able to develop: workforce vectors; component, command, center, and program workforce risk analyses; workforce mission/business case analysis; targeted training investment; and targeted enrollment communication and skill gap analyses.

The SECCM is also informing graduate academic programs to specify student outcomes and learning objectives within systems engineering programs that will ensure the students have the entry-level KSAs required to perform successfully in their job. The implications of this research can also be used to develop structured curriculum content, assessment, and continuous process improvement techniques related to the development of SE learning, and to develop more valid and reliable instruments for assessing what systems engineers need to learn, need to know, and need to do (Khan, 2014).

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Panel 4. Strengthening Schedule Estimates in MDAPs

Wednesday, May 4, 2016	
11:15 a.m. – 12:45 p.m.	**Chair: Rear Admiral Thomas J. Kearney, USN,** Director, Acquisition, Commonality, & Expeditionary Warfare, Naval Sea Systems Command ***Acquisition Cycle Time: Defining the Problem*** David Tate, Institute for Defense Analyses ***Schedule Analytics*** Jennifer Manring, Principal Economics and Business Analyst, The MITRE Corp. Thomas Fugate, Principal Acquisition and Program Management Analyst, The MITRE Corp. ***Toward Realistic Acquisition Schedule Estimates*** Raymond Franck, Professor Emeritus, U.S. Air Force Academy Gregory Hildebrandt, PhD Bernard Udis, Professor Emeritus of Economics, University of Colorado at Boulder

Rear Admiral Thomas J. Kearney, USN—is the Deputy Commander, Naval Sea Systems Command (SEA 06), Acquisition/Commonality/Expeditionary Warfare. Kearney grew up in Dover, NJ, and enlisted in the Navy in 1978. He was commissioned via the Villanova University Navy ROTC program in 1984 with a Bachelor of Science degree in mechanical engineering. Additionally, he holds a master's degree in political science (international relations) from Villanova University and is certified as a Level III Program Manager from the Defense Acquisition University.

Prior to command, his sea tours included assignments as a Division Officer and Navigation Department Head aboard USS *New York City* (SSN 696), Engineer Officer aboard USS *Henry L. Stimson* (SSBN 655 Gold), and Executive Officer aboard *USS Helena* (SSN 725), where he conducted deployments and patrols to both the North Atlantic and Western Pacific.

Ashore he served as an NROTC Instructor at Villanova University, Executive Officer/Engineer Officer of the Moored Training Ship (MTS 635), Squadron Engineer (Submarine Squadron 7), and as First Commanding Officer of Pre-Commissioning Unit USS *Virginia* (SSN 774).

Kearney commanded the USS *Alexandria* (SSN 757) from June 2003 to December 2005. During this period, his ship was awarded the Battle E for operational excellence, was runner up for the prestigious Battenberg Cup Award for top ship in the Atlantic Fleet, and received the Navy Unit Commendation for operations conducted during the first around-the-world deployment via the Arctic by a U.S. submarine.

Following command, Kearney entered the Acquisition Professional Community in 2006 and served as the Deputy Director of the Navy's Test and Evaluation Policy Office (OPNAV N912). He then served as the Foreign Military Sales Program Manager in the Undersea Weapons Program Office (PMS 404) and as Deputy Program Manager in the Submarine Acoustic Systems Program Office (PMS 401).

Kearney served as the Program Manager for Undersea Weapons and Targets from October 2009 to October 2012. During this period, his program was awarded a Secretary of the Navy Excellence in Acquisition Award, and he was the recipient of the 2011 Naval Submarine League's Vice Admiral J. Guy Reynolds Award for Excellence in Submarine Acquisition. He served as Vice Commander for Naval Sea Systems Command from June 2013 to April 2014, establishing the Acquisition, Commonality, and Expeditionary Warfare Directorate (SEA 06) as a new directorate within NAVSEA.

His awards include the Legion of Merit (two awards), the Meritorious Service Medal (five awards), and various other personal, campaign, and unit awards.

Acquisition Cycle Time: Defining the Problem

David M. Tate—joined the research staff of the Institute for Defense Analyses' Cost Analysis and Research Division in 2000. Since then, he has worked on a wide variety of resource analysis and quantitative modeling projects related to national security. These include an independent cost estimate of Future Combat Systems development costs, investigation of apparent inequities in Veterans' Disability Benefit adjudications, and modeling and optimization of resource-constrained acquisition portfolios. Dr. Tate holds bachelor's degrees in philosophy and mathematical sciences from Johns Hopkins University, and MS and PhD degrees in operations research from Cornell University. [dtate@ida.org]

Abstract

Acquisition cycle time—roughly speaking, the development lead time to field a working system once we have identified a need for a new materiel solution—is a hot topic in defense circles. This work takes a data-driven look at historical and current acquisition program cycle times. We show that the trend toward longer cycle times over the past few decades is restricted to a handful of high-profile programs, which has profound implications for effective policy response. We also show evidence that cycle times are driven by system complexity, and that schedule slip is associated primarily with overly optimistic schedule estimates. We conclude with a discussion of the increasing importance of software for development lead times, and the general problem of trading capability for timeliness in acquisition programs.

Introduction

The Cycle Time Problem—Perception

Cycle times (or development lead times) for defense weapon systems are a hot topic in the defense world. In September 2014, the Under Secretary for Acquisition, Technology, and Logistics, the Honorable Frank Kendall, issued Version 3 of the Better Buying Power (BBP) initiative. One focus area of BBP 3.0 is to "reduce cycle time while ensuring sound investments" (Kendall, 2014). The lead article (Schultz, 2014) in the November–December 2014 issue of *AT&L Magazine* was entitled "Please Reduce Cycle Time." RAND produced a 2014 report entitled Prolon*ged Cycle Times and Schedule Growth in Defense Acquisition: A Literature Review* (Riposo, McKernan, & Kaihoi, 2014). The House Armed Services Committee held hearings in October 2015 on the topic "Shortening the Defense Acquisition Cycle."

Many commenters on defense acquisition have asserted that it now takes too long to develop and field new systems, and that we should do something about it. They say that the pace of technological advancement, especially in electronics and information technology, is now so fast that our "advanced" military systems are nearly obsolete by the time they are fielded. Even seemingly mundane systems, such as troop transport vehicles and cargo aircraft, seem to take forever to field.

The various stakeholders in the defense community have put forward numerous theories for what is causing the problem, many of which place the blame squarely on someone else. Worse yet, the appropriate policy response to the cycle time problem depends sharply on which theory one subscribes to. Some observers diagnose excessive oversight and prescribe a more laissez-faire approach to acquisition. Others diagnose unaffordable ambitions and unnecessarily demanding requirements, and prescribe appetite suppression and fiscal discipline. Still others diagnose inept management and excessive bureaucracy, and prescribe streamlined processes and organizations.

The Cycle Time Problem—Reality

In this paper, we will address several important questions related to the cycle time problem. First, we will consider empirically whether there is a general cycle time problem across all programs, or a specific cycle time problem within a few programs. Second, we will look at some candidate reasons why development takes as long as it does. Finally, we will consider the overarching question of how to decide what to try to buy, and how to try to buy it, given an understanding of how long it is likely to take.

Cycle Times for Typical Programs Are Not Increasing

Figure 1 shows a scatter plot of cycle times[1] for Major Defense Acquisition Program (MDAP) subprograms (including initial development) as a function of when each system reached its Initial Operational Capability (IOC), or equivalent. Going back to the late 1980s, there is no apparent upward trend. Statistical analysis confirms that the trend is indistinguishable from zero, and that the median cycle time has been roughly eight years over that entire span. This absence of trend in the median holds for all commodity types—aircraft, ground systems, space systems, ships, etc.

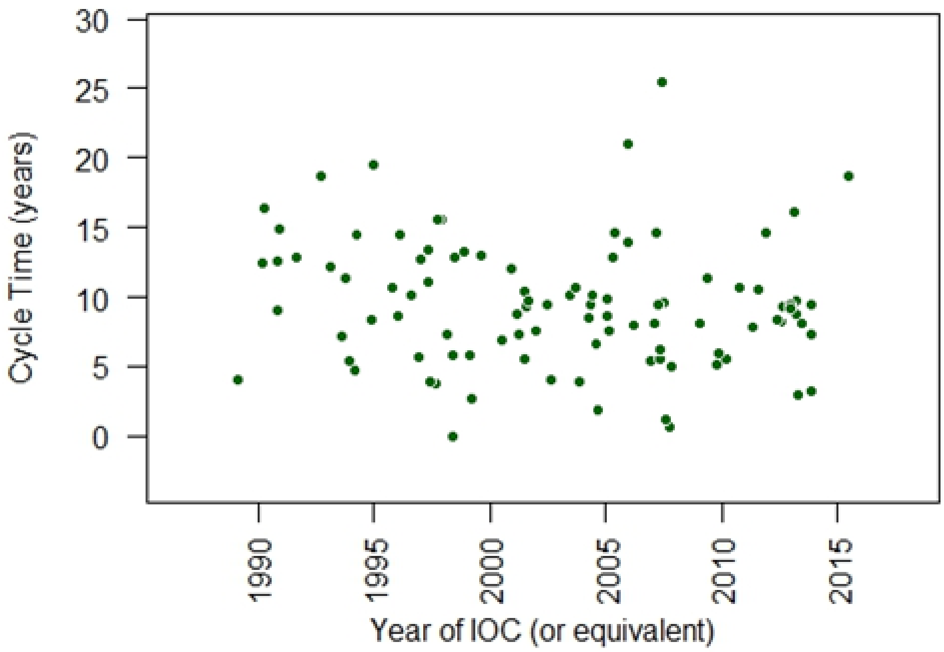

Figure 1. Program/Subprogram Cycle Time by IOC Year

Why, then, is there a perception that cycle times have been getting worse and worse? Figure 2 shows the same data, but with each point now proportional to the final (or

[1] *Cycle time* is defined here as the time in years from program initiation to IOC or equivalent. For most programs, initiation is at or just before what is now called Milestone B. For some programs, initiation is at Milestone (MS) A, or even earlier if the program began as a Technology Demonstration program. For programs with no formal IOC, the equivalent milestone might be OPEVAL, First Unit Equipped, etc. The plot shows cycle times for ~100 subprograms for which both cost and schedule data were available.

most recent estimated) total procurement cost of the system being developed, in inflation-adjusted dollars.

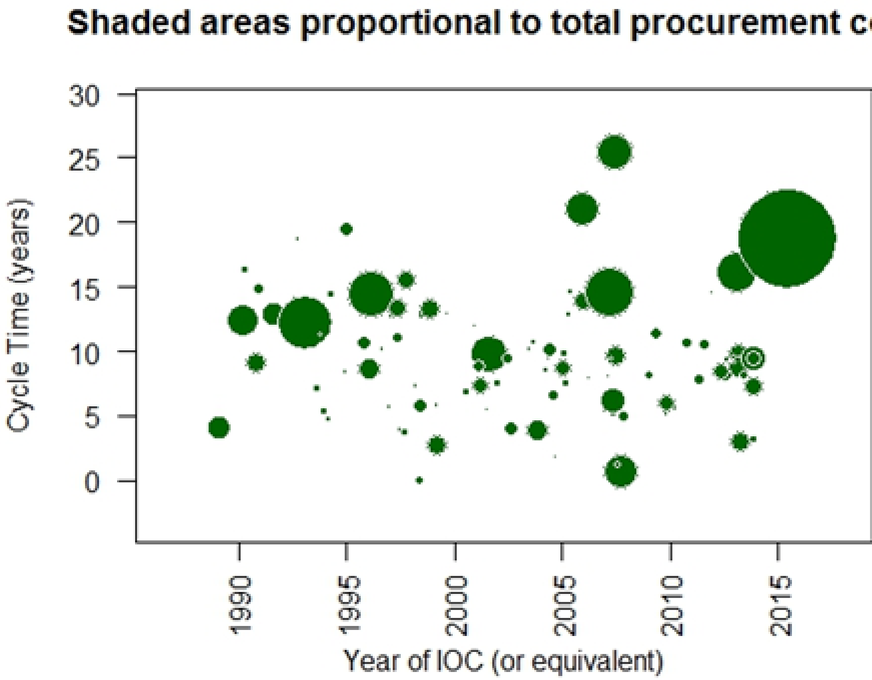

Figure 2. Cycle Time by IOC Year Showing Relative Program Size

Here, there is a noticeable upward trend for the programs that are spending the most money on procurement. The cycle times for these highly visible programs may be driving the perception that things are taking longer.

Cycle Time Growth Is Getting Worse for Some Commodity Types

The sense that things are taking longer is driven not just by actual cycle times, but also by cycle time growth, or "schedule slip." Even where programs are not taking any longer than they previously did, the Office of the Secretary of Defense (OSD) and Congress notice when programs take longer than promised.

Even here, there is no significant overall statistical trend in program schedule growth over the past 25+ years. Figure 3 shows the relative schedule growth of each of the subprograms portrayed in Figure 1 and Figure 2, broken out by commodity type. Unlike the overall cycle time story, here there are significant differences among commodity types. Overall schedule growth trends are flat or downward (with occasional outliers) among ground systems, aircraft, missiles, and ships. The trend is upward for space systems and Command, Control, Communications, & Intelligence (C3I) systems. In addition, instances of individual programs with schedule growth well above the overall trend for their commodity type are becoming more common.

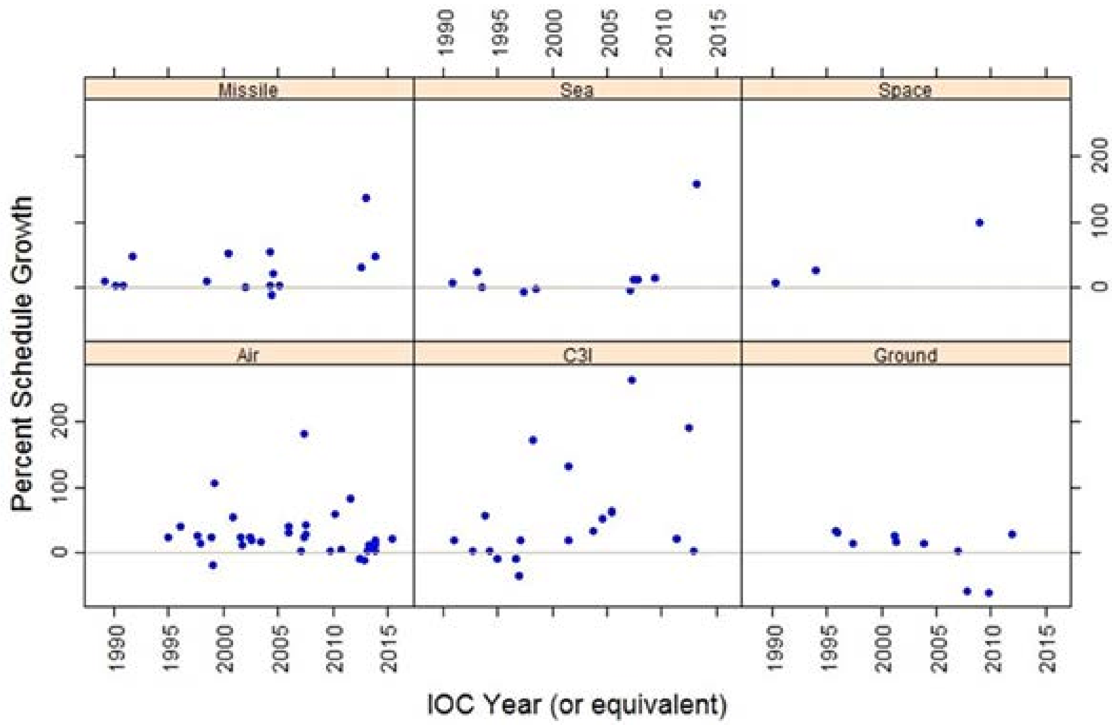

Figure 3. Percent Schedule Growth by IOC Year for Various Commodity Types

Of course, schedule growth does not necessarily indicate poor program execution. It may be that the program's funding was cut. It may be that requirements were changed. Or, it may be that the original schedule estimate was unreasonable.

We computed a measure of *relative schedule optimism* for MDAPs, defined as the difference between the average cycle time for programs of the same commodity type and the given program's estimated cycle time at program initiation, divided by the commodity average. Thus, for example, a program forecast to take six years when the average for its commodity type is eight years would have a relative schedule optimism of (8–6)/8 = 25%. Larger numbers indicate more optimism; negative numbers indicate pessimism relative to the average. Figure 4 shows a graph of cycle time growth versus this metric. We see that a clear relationship exists between schedule optimism and schedule growth for both new start programs and modifications of existing systems. Interestingly, the average percent schedule growth for a given level of optimism is greater than the amount of optimism. This suggests either that excessive optimism is a symptom of a deeper problem, or that there are cascading effects from being too optimistic. We will return to that question when we discuss software development in the section titled The Special Case of Software.

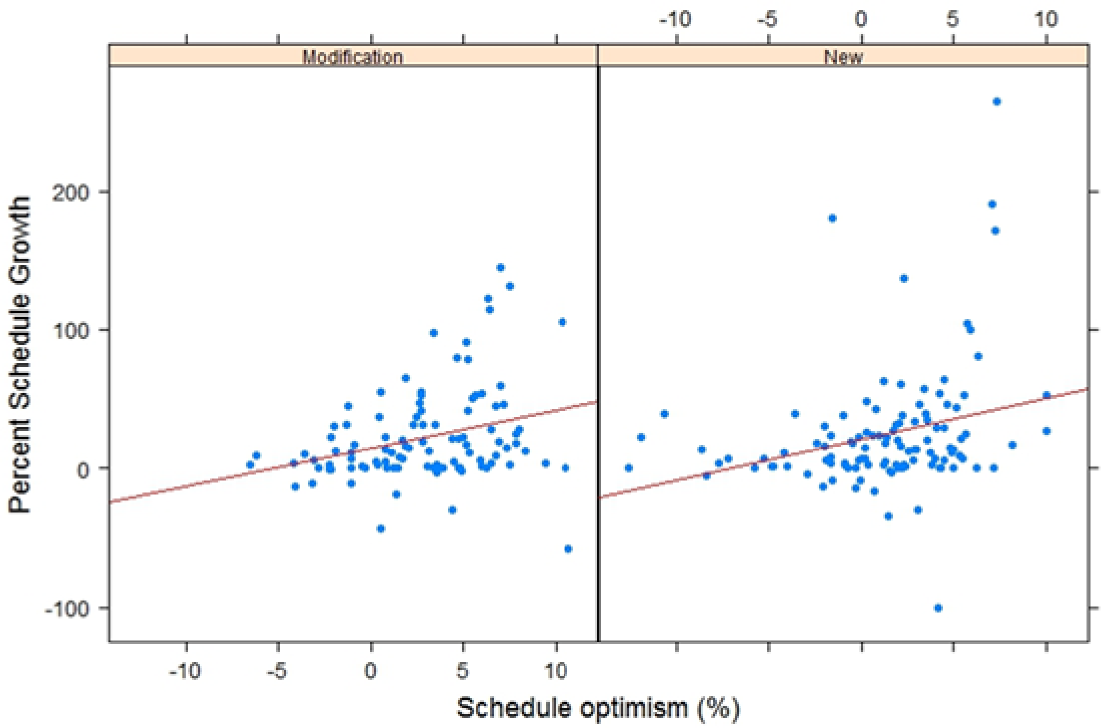

Figure 4. Relationship Between Schedule Optimism and Schedule Growth

Do Cancelled Programs Make the Picture Look Better or Worse?

A confounding factor in any study of MDAP cycle times has been the high rate of program cancellations over the past 15+ years. As famously reported in the Decker-Wagner report (2011),[2] between 1995 and 2009, the Army spent roughly one quarter of its Development, Test, and Evaluation (DT&E) funding on programs that delivered fielded capability. The other Services were by no means immune to this problem.

Cancelled programs bias the statistics on cycle time by censoring data from programs that would tend to take longer than average if carried to completion. The effect of individual cancellations on average or median cycle time depends on why the program was cancelled. Programs that were cancelled because they were going to be obsolete by the time they were fielded[3] should have their expected durations included in the distribution of cycle time outcomes if our goal is to understand the extent to which programs take too long to be relevant or timely. Programs that were cancelled for other reasons—for example, technical infeasibility or unaffordability—do not generally tell us anything about achievable cycle times for executable programs.

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[2] The actual title of this report is *Army Strong: Equipped, Trained and Ready: Final Report of the 2010 Army Acquisition Review*. It is often referred to as "the Decker-Wagner report," after its two co-chairmen, Gilbert F. Decker and Louis C. Wagner.

[3] Obsolescence can be due to changes in the threat environment, geopolitical events, new technologies, etc.

However, cancelled programs are certainly relevant to the larger question of how long it takes to mitigate a capability gap, once it has been identified. Of the major programs cancelled since 2000, few if any were cancelled solely due to premature obsolescence. In most cases where obsolescence was cited by OSD or the Service as a causal factor, the program was also technically infeasible or unaffordable. It is not unreasonable to think of the current Amphibious Combat Vehicle (ACV) program as the direct continuation of the earlier Expeditionary Fighting Vehicle (EFV) and Advanced Amphibious Assault Vehicle (AAAV) programs. By that measure, the Marine Corps has been attempting to acquire a long-range high-speed amphibious troop carrier since 1995, and does not expect to be able to field one until 2025 at the earliest. In the same way, the Army's ongoing attempts to replace the OH-58 Kiowa scout helicopter began in 1985 with the Comanche program. Each Service has outstanding modernization requirements left unfilled by failed programs; not all of those requirements have any current MDAP attempting to meet them. The delays in fielding these capabilities may have operational impacts, but they do not seem to result from inefficient "acquisition" in the usual sense.

Execution or Expectations?

The historical cycle time data raise some important questions. First, do long cycle times reflect an acquisition process problem (to be addressed by changes to the acquisition system) or an outlier problem (to be addressed by root cause analysis and improved oversight)? It would probably be neither efficient nor effective to overhaul the entire acquisition system if most programs are executing reasonably under the current system.

Second, is this a problem of execution or of expectation? How long *should* it take to develop a fifth-generation fighter aircraft, or a first-ever tilt-rotor transport aircraft, or a high-speed amphibious assault vehicle? Were the original schedule estimates implausible? Where do the development schedules found in Acquisition Program Baselines come from, anyway?

Finally, to what extent are our acquisition processes the pacing factor in MDAP development? Are there unnecessary regulations that slow down development without adding value? Are there unnecessary administrative processes (either within OSD or within the Services) that delay development? Is testing a cause of delay, or merely the bearer of bad news? Are there technical reasons why we should not expect to be able to go much faster than we currently do?

Which Came First—The Program or the Schedule?

When deciding which new programs to start and what kind of system they should aim to produce, decision-makers are informed by cost and schedule estimates. The National Air and Space Administration (NASA) goes so far as to treat cost and schedule jointly, recognizing both that they are highly correlated and that changes driven by one will affect the other. No one is surprised when the cost estimates are based on the content of the program—the capabilities the system is supposed to provide, the materials it will use, the maturity (or immaturity) of the technologies to be employed, etc. OSD performs an independent cost estimate for all major acquisitions, which is taken seriously during milestone deliberations and tends to offset some of the more optimistic tendencies of the sponsoring Services.

There is no corresponding attention paid to OSD concerns about schedules, however. Not infrequently, the initial schedule *estimate* for an MDAP is not an estimate at all, but a constraint set externally with little regard to program content or historical precedent. Sometimes this is driven by anticipated external demands for a system that is to be used on multiple platforms, as was the case for several of the Joint Tactical Radio System (JTRS) subprograms. Sometimes it is driven by a planned retirement agenda for existing systems, such as the plan for the Global Hawk Block 30 aircraft to replace the U-2. Sometimes it seems to be driven by impatience; the Army's never-quite-started Ground Combat Vehicle program was told the delivery date of the first production vehicle in its Initial Capabilities Document before even a design concept had been identified.

How Long Should It Take?

No one would argue with the claim that a cost estimate should be based on the content of the program, or that it should be informed by the history of past efforts to develop similar things. Surprisingly, the analogous argument for schedules gets much less traction. The link between program content and development cycle time has not been as clearly established among decision-makers. There is a lingering suspicion that better management, less red tape, or less oversight would allow successful completion of development projects much more quickly than they have been done in the past.

There have been some substantive studies that looked at this question in specific domains. Among the most comprehensive is Gene Bearden's work at the Aerospace Corporation on the cost and schedule drivers of space probes. Dr. Bearden developed a sophisticated complexity metric for space probe projects, based on the technical details of the operational domain (earth orbit or planetary), the propulsion technology, the required data links, the payload instruments, etc. He then showed that there is a powerful and consistent relationship between project complexity and development cycle time. More importantly, nearly all partial or complete mission failures occurred when NASA attempted to develop and launch probes more quickly than the estimated required development time. Figure 5 shows this relationship.

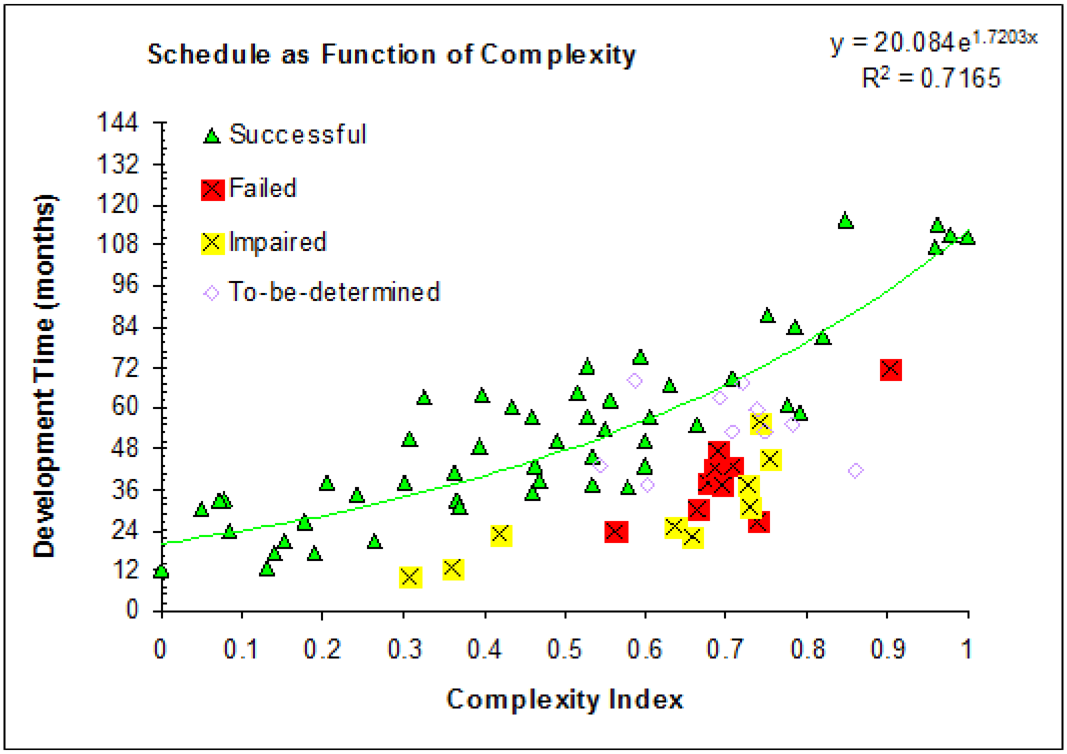

Figure 5. Relationship Between Space Probe Complexity, Development Time, and Mission Success

(Courtesy of and reprinted by permission of the Aerospace Corporation)

We also investigated whether MDAP cycle times are related to either the number of Critical Technology Elements (CTEs) identified in the program's Technology Readiness Assessment (TRA), or the number of distinct program requirement records in the "Performance" fields of the Defense Acquisition Management Information Retrieval (DAMIR) system. Both are positively correlated with cycle time, although we did not have CTE data for enough programs to establish statistical significance. For requirement counts, there is a strongly significant relationship with cycle time during times of growing defense budgets, and no relationship at all in times of decreasing budgets.[4] These results taken together suggest that schedule is driven by program content, but that programs perhaps shed requirements in times of tight budgets.

The Special Case of Software

The connection between complexity and cycle time is also well understood in the software industry. In his pioneering book *The Mythical Man-Month,* Fred Brooks (1975) presented a few key facts about software development projects:

[4] Given that the raw number of requirement records in DAMIR is only weakly correlated with actual program complexity, the existence of a strongly significant (p = 0.0002) relationship between requirements records and cycle time is somewhat surprising. The fact that this relationship is only apparent during times of growing budget is even more surprising. It is possible that this metric is measuring bureaucratic complexity more than technical complexity.

- Adding staff to a software project that is behind schedule makes it take longer.
- There is a lower bound on the number of defects in a software system. The more complex the system, the higher this bound.
- Software development consists of completing known work and discovering new work. There are fundamental limits on the efficiency of both aspects.
- The duration of a software development project depends strongly on the degree of coordination required among the various software modules.

Lawrence Putnam (1978) used analogous reasoning about completion and discovery to derive a quantitative model of project duration. He found that total development cost is a function of schedule—but not in the expected sense that a longer project costs more. Rather, there is a natural "most efficient" schedule for a given set of requirements, and any attempt to accelerate the development to finish more quickly than that natural duration results in increased cost. Worse still, complex projects are only slightly compressible; there is a sharp asymptotic limit to how fast you can try to complete the project without breaking it. Figure 6 shows this relationship schematically. For schedules longer than the natural schedule, cost increases roughly linearly with duration due to low staff utilization, as shown by the dashed line. For schedules shorter than the natural schedule, staff utilization is high, but completion outpaces discovery, leading to inefficient rework and low quality. Schedules significantly shorter than the natural schedule are simply not possible, and development efforts attempting to go faster than that generally fail.

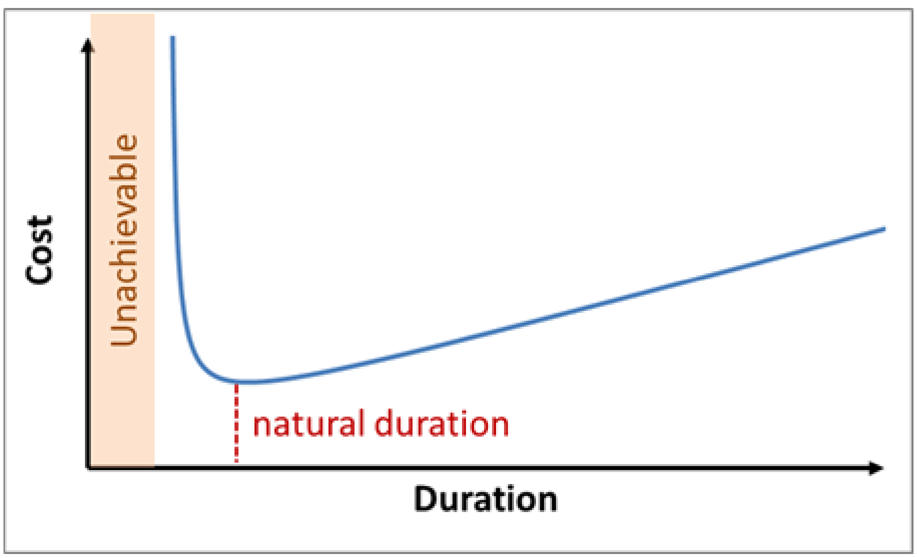

Figure 6. Cost as a Function of Duration for a Given Set of Software Requirements

Are Weapons Systems Like Software Systems?

We have shown that feasible schedules for space systems and for software seem to be constrained by program complexity. Is this true for all weapon systems? If not, which systems might it be true for?

Clearly, complexity is not a factor when buying truly commercial items. By extension, complexity should not be a factor when buying systems that are minor modifications of commercial items, or that use only established commercial technologies. This is at the heart of the Government Accountability Office's (GAO's) recurring admonition that acquisition best practice requires that all critical technologies for a program be mature[5] before MS B. It is also central to the Decker-Wagner report's taxonomy of acquisition risk categories, with corresponding development timelines. In that report, a low-risk acquisition is defined to be one that purchases an existing commercial item or modifies an existing system. A moderate-risk acquisition is defined to be acquisition of a system that uses only mature, proven technologies. Even then, the report cautions that you should expect 6 to 11 years from Materiel Development Decision (MDD) to MS C if you are developing a new system that does not use exclusively pre-existing components (p. 99).

However, maintaining our technological military advantage cannot be accomplished by only buying things that already exist. The Decker-Wagner report advises the Army to manage risk in its acquisition portfolio by limiting the proportion of higher-risk programs to "only those [systems] that are truly urgently needed because they represent 'game-changing,' revolutionary military capability, e.g., atomic bomb, night vision, fire-and-forget missiles, and stealth" (p.106). It also cautions that you should expect an 8–14-year development cycle (MDD to MS C) for such systems, even if you do everything right.

Are Weapon Systems Actually Software Systems?

There is another, more compelling reason to think that weapon system acquisition programs might behave like software development programs—namely, that they are software development programs. Nearly every MDAP today involves more software than even the most software-intensive programs of 20 years ago. The F-35 aircraft system, in the culmination of a trend begun more than 50 years ago, has almost no functions that are not implemented, mediated, or controlled in software.

We have noted that there is a natural minimum duration for a software development program. Even if it were true that hardware development and integration are no harder today than they have been in the past, we would expect there to be a size of software effort at which the software development portions of the program begin to dominate the schedule. Historically, the critical path for system development has run mostly through the hardware side of the project. Software contributed vital capabilities, but only a small portion of the program cost or duration. As we design systems that perform more and more of their functions using software, that might no longer be true.

In fact, there is some evidence that we may already be reaching the turnover point where software development drives schedule duration. To test the plausibility of this idea, I used the COCOMO-II software effort estimation tool to estimate the duration of large, difficult (but not too difficult) software development projects, as a function of Source Lines of Code (SLOC). I then collected data on the cycle times of recent software-intensive MDAPs, along with their SLOC at IOC. The results are shown in Figure 7.

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[5] The GAO defines maturity, for this purpose, as a Technology Readiness Level (TRL) of 6 or higher. TRL 6 is defined as successful demonstration of a representative prototype operating in an environment that is operationally relevant, given the system requirements.

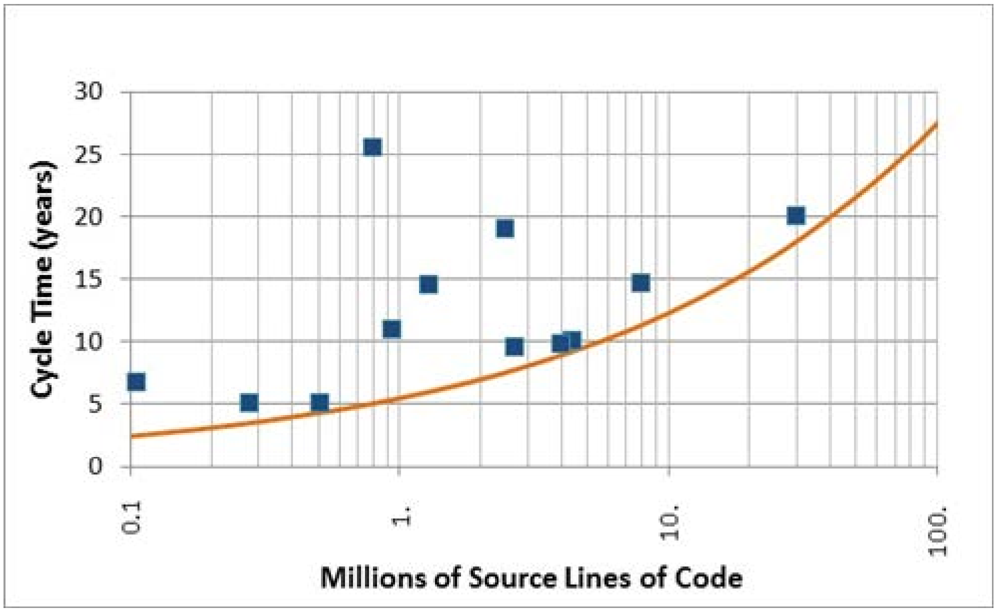

Figure 7. Development Times of Recent MDAPs vs. Software Size at IOC

The COCOMO-II prediction curve shown here is notional. COCOMO-II takes as input up to 24 separate "effort multiplier" parameters and five "scale factors" related to economies (or diseconomies) of scale for software projects. The curve shown here corresponds to a software project that is modestly above average in all dimensions.[6] It is intended to provide an empirically based estimate of the proper scaling of duration as a function of size for software similar to the kind found in Department of Defense (DoD) weapon systems. Astonishingly, without any adjustment, these initial parameter choices produce a curve that seems to behave like a tight lower bound on cycle time for the systems in question. This suggests that even if software is not already defining the lower bound for MDAP cycle times, it soon will.

Again, the space systems community may be slightly ahead of the DoD in reaching this conclusion. In a 2009 presentation, Dr. Steve Jolly (2009b) of Lockheed Martin Space Systems concluded,

> Software/firmware can no longer be treated as a subsystem. Systems engineering organizations need to engineer the software/avionics system—a change in leadership technical background. … The game has changed in developing space systems. Software and avionics have become the system [emphasis in original]. Structures, mechanisms, propulsion, etc. are all supporting this new system.

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[6] For those familiar with COCOMO-II modeling, the curve shown in Figure 7 corresponds to an Effort Multiplier (EM) of 1.5 and an exponent (E) of 1.1. The EM reflects a development only slightly higher than nominal in difficulty or complexity in all dimensions. The exponent corresponds to a total Scale Factor (SF) of 18, which is very close to the SF value for a "nominal" development.

In a related article for NASA's *ASK Magazine*, Jolly (2009a) speculates that this is because software now touches every part of the system. It is no longer an isolatable subsystem or module that can be designed in parallel with the system; it is the common element that ties together all parts of the system. The software is the integrating element, and as such must be the central feature of the design.

Not all weapon systems are as software-intensive as a NASA space probe—but many of them are. In particular, when the role of software in the program is no longer such that the software can be treated as a separable module, but rather as an integrative framework, it will be necessary to manage the program as a software development project with associated hardware and cyber/physical integration, rather than as a hardware development project with associated software.

Acquisition Implications

What Can Be Had Quickly?

Putting together the data regarding system complexity, software content, and technology maturity, we can see that acquisition cycle times are bounded below by the maximum of several possible limiting factors. If the system is technically immature, we will not be able to field it very quickly. If the system involves very large amounts of new software, or highly integrated software and hardware, we will not be able to field it very quickly. This would be true even with ideal program management, ample and stable funding, and Acquisition Reform that eliminates all red tape and oversight.

So what can we get quickly?

1. Truly non-developmental items—commercial products and systems that already exist. (Think MRAP.[7])
2. Upgrades of existing systems that insert already-mature technology and do not overstrain the size, weight, power, and cooling capacity of the current platform. (Think UH-60M or M1A2 Abrams upgrades.)
3. Integration of existing mature systems into new capabilities. (Think HIMARS.[8])
4. New systems developed using agile methods, in which users (user representatives) work interactively with developers to identify and evolve a set of capabilities that are useful enough to be worth fielding, rather than working toward pre-set Threshold and Objective requirements. (Think CREW.[9])
5. New systems with extremely limited requirements, where we are willing to live with capabilities at or below current systems in most dimensions, in order to get enhanced capabilities in one or two urgently needed dimensions. (Think F-117A.)

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[7] Mine-Resistant Ambush-Protected family of vehicles.
[8] High-Mobility Artillery Rocket System, derived by mounting a Multiple Launch Rocket System (MLRS) launcher on a 5-ton Family of Medium Tactical Vehicles (FMTV) truck.
[9] Counter-radio-controlled Explosive Device program; a cumulative series of technology deployments including (for example) the Thor III man-portable jammer.

6. New systems whose critical technologies and basic operational characteristics have already been demonstrated at TRL 5 or higher in *push* research and development or demonstration programs. (Think Predator.)
7. New modular subsystems that can be used to replace older, less-capable subsystems on platforms that have both modular architectures and sufficient design margin (e.g., size, weight, power, cooling, etc.) to be able to accommodate and integrate the new technology. (Think DDG-51 Modernization.)

Of these approaches, only the final three or four have the potential to sometimes produce leap-ahead technology advantage. Each of those, in turn, has its limitations and caveats.

In the case of "limited requirements" developments, operational effectiveness is liable to be short-lived, requiring more deliberate follow-on programs that incorporate the leap-ahead technology in a more well-rounded package. In the case of R&D *push* from technology demonstration programs, someone has to have had the foresight to fund many research and development programs (not associated with major systems procurement) in the relevant technology areas over the preceding decade, so that there are mature technologies on the shelf to choose among. Even then, the initial MDAP incorporating those technologies is liable to produce a partially successful and fragile initial solution that will need to be followed up with more robust designs, as was the case with Predator.

Rapid incorporation of new modular subsystems on an existing platform depends on the existence of a robust, overdesigned, modular-architecture platform that can host the upgrades. Initial development and deployment of those host platforms will typically not be especially rapid, and their initial capabilities may not be significantly better than legacy platforms. Their value is in their ability to enable future upgrades (see, for example, Patel & Fischerkeller, 2013).

Finally, in the case of agile development, you would have to get very lucky to produce a leap-ahead capability. Most iterative agile developments will produce useful and timely (but not revolutionary) capabilities.

When Should an Analysis of Alternatives Consider Cycle Time?

The most important decision in any acquisition is the choice of what to buy. The purpose of the Analysis of Alternatives (AoA) is to provide decision-makers with all of the relevant information regarding the cost, schedule, and effectiveness of each of the available alternatives—including a characterization of the risks in each of those dimensions. The worst acquisition failures are the result of choosing an alternative that is not physically possible, or is unaffordable, or has very little chance of being delivered in time to be useful.

Historically, schedule has not generally been considered as either a consequence of the choice of alternative, or as a Key Performance Parameter for the program. In some cases, this makes perfect sense—most any alternative for a peacetime tactical wheeled vehicle program will take about the same amount of time to develop, and there is little risk of early obsolescence regardless of which design approach is selected.

For other types of systems, decision-makers should care intensely about the trade-off between capability and cycle time. For example, missile countermeasures for aircraft are typically designed to counter specific threat systems. There is little point to a countermeasure development program that is unlikely to produce any deployable system until after the anticipated service life of the systems it counters. In addition, current capability gaps in countermeasures are exploitable today by potential foes. Even a partial solution today (or at least soon) would be more valuable than a perfect solution 10 years from now.

It seems only prudent that military planners should have some idea of the time urgency of a given system's development and should take that urgency into account when choosing among proposed alternative system designs. Of course, this would also require both honest and credible schedule estimates for all of the candidate alternatives.

What About Maintaining Technological Superiority?

Much of the concern about acquisition cycle time that has been expressed by DoD officials and Congress has to do with maintaining the historical technological advantage of the United States in military systems. Our all-volunteer force relies operationally on capability overmatch in lieu of sheer numbers, even as it relies morally on exceptional levels of force protection and defensive capability. Given the pace of advance for electronics and cybernetic systems in the private sector and by foreign militaries, staying ahead of the curve would seem to require introducing new technologies on impossibly fast timelines.

As we have discussed above, there are a limited number of potential ways to develop new capabilities on sufficiently responsive timelines. For all but the smallest systems, these methods depend on having taken early and effective action, both within and outside the formal "acquisition" process, in order to be ready to acquire useful systems quickly when the time comes. The two most effective ways to get leap-ahead capabilities on short timelines are both cases of technology insertion. In the first, a weapon system developed as part of a requirements-free technology demonstration project forms the basis for an acquisition program that finishes making the system sufficiently safe, effective, and suitable for operational use. In the second, a novel technology—itself possibly derived from a Science and Technology program or demonstration project—is inserted onto an existing platform or system. In both cases, it is vital that preparatory actions (and spending) have been made in the past—actions that permit the new program to avoid design false starts, inefficient concurrent development of platform and modules, and premature convergence on suboptimal designs. It would seem, then, that the key to being able to maintain technological superiority is to have executed the right set of deliberate actions in the past, on a rolling horizon.

Conclusions

Why Haven't Cycle Times Been Increasing?

In hindsight, it is surprising that cycle times have not shown a general increase over time. We know that the systems we develop and field have grown enormously in complexity, and that this growth is reflected by increased development cost and unit procurement cost, relative to the legacy systems that we replace or upgrade. This is not simply inflation or price hikes; the new systems are much more technologically advanced than the old ones, even relative to the current state of the art in commercial systems. How then have cycle times managed to remain stable?

One plausible answer is that our design and manufacturing capabilities have roughly kept pace with the increased complexity of the systems we procure. This is in part a tautology, enforced by the fact that we cannot build anything we do not know how to build. Those systems that sought to surpass the current state of the art by too much were cancelled, and so do not contribute to the observed statistics.

This is not a stable state of affairs. In particular, software productivity has historically grown much less rapidly than hardware system capability, and much less rapidly than the amount of software required for our most complex defense systems. In addition, complex software shows diseconomies of scale, so that development efficiency decreases with the size of the software to be developed. As we shift more and more of the functionality of our defense systems into software, we can expect to see a corresponding increase in development lead times.

Finally, we note that these findings may have significant implications for Acquisition Reform. If there are fundamental technical limits to how quickly certain types of systems can be acquired, no amount of management savvy or relief from regulatory burden will allow us to acquire those kinds of systems any faster than that. Reducing cycle time would thus need to involve a combination of using the "ways to acquire things quickly" (enumerated in the What Can Be Had Quickly section) with processes and regulations designed to facilitate those acquisition paths. It would also involve effective oversight to recognize what is feasible as early in the acquisition cycle as possible, and to choose acquisition alternatives accordingly.

Summary

Looking back at the past 30 years of major defense acquisition programs (MDAPs), we note the following patterns:

- The median cycle time and the distribution of cycle times for the majority of MDAPs have been fairly constant.
- The number of extreme outliers from this distribution has been growing over time. Outliers are more frequent in the most expensive programs and in software-intensive programs.
- Cycle time growth has been increasing, especially in C3I and Space programs. Much of this growth seems to be associated with overly optimistic schedule estimates.
- The amount of software in the most software-intensive MDAPs has increased by at least two orders of magnitude over the period in question. There is reason to believe that software (including software-hardware integration) is becoming, or has become, a schedule-limiting factor for these programs.

If program complexity in general, and software content in particular, are now limiting factors for the development lead times of new systems, this has important implications for how we choose which new programs to begin. When it is important to get new things quickly, we will need to test the system designs that are proposed (using credible schedule estimates for those designs) against our best estimates of the urgency and useful life span of the capability being acquired. In particular, we need to be aware when we are asking for an amount of software that cannot plausibly be developed in the time available.

In some cases, we will be able to get useful systems quickly enough simply by asking for less initial capability. For those capability gaps where existing technologies are not sufficient, it would be prudent to invest (on an ongoing basis) sufficient resources in broad technology development and maturation efforts to "keep the shelves stocked" with mature technologies. In parallel with those efforts, we would also need to design and field (also on an ongoing basis) flexible platforms that can quickly incorporate whichever of those as-yet-unidentified future technologies turn out to be needed. The technology development half of that plan is cost-prohibitive if we try to do it primarily within MDAPs; the future insertion half will not succeed if we allow requirements creep during initial development to trade away flexibility for immediate utility.

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Schedule Analytics

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Introduction

Developing and effectively managing schedules is critical to the success of a program. Program managers are becoming increasingly aware of the need for greater accuracy in schedule estimation, assessment, and risk management to control cost and deliver on time. A Government Accountability Office (GAO) assessment of 86 programs that made up the 2012 portfolio of Major Defense Acquisition Programs (MDAPs) found that the portfolio experienced total acquisition cost growth of 38%. In addition, the average schedule delay in delivering initial capability was 27 months when measured against first full estimates (GAO, 2013), representing a 69% increase over a 12-year period.[1] Most Major Automated Information Systems (MAIS) programs experienced schedule delays ranging from six months to 10 years. Clearly, schedule can pose a significant risk and drive cost growth.

The purpose of this research was to help strengthen the acquisition community's ability to produce data-driven realism in program schedules. This research effort had three main focus areas: (1) compile schedule data from programs to identify key schedule drivers and characteristics and build a data repository, (2) analyze the data from statistical and qualitative perspectives, and (3) document data collected and analysis performed, and how it can be accessed for analysis.

The detailed approach used in the research was comprised of the following high-level steps:

- Identify and review primary data sources

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[1] Calculated based on GAO data that the average schedule delay in delivering initial capabilities was 16 months in 2000 and, compared to 21 months in 2007, represents a 31% increase in schedule delays over a seven-year period. See the 2008 GAO report on 95 weapons systems cited by Meier (2010).

- Develop a list of program attributes to evaluate
- Develop an Excel-based data collection framework
- Collect data and populate data repository
- Synthesize and cleanse data
- Analyze and assess data
- Develop findings
- Document research

The initial focus of the data collection phase was to identify, understand, and review existing external data repositories or sources that collect enterprise-level acquisition information and data, particularly related to program schedule. Across the federal government, the Department of Defense (DoD) sources and the Office of Management and Budget (OMB) Information Technology (IT) Dashboard were data sources identified and reviewed for this research.

Based on the data source review, the study team determined that the Defense Acquisition Management Information Retrieval (DAMIR) was the best source of data for DoD large scale programs as it contained both MDAP and MAIS program data (DoD, 2015). Although the DAMIR data is high level, it provided sufficient schedule fidelity and additional cost and program parameters of interest to be useful for the research. However, detailed reviews of the OMB IT Dashboard data revealed that schedule data is highly aggregated. Program start date and program end date are the only schedule parameters included with no intermediate schedule milestone data available in the repository. The OMB IT Dashboard has a large amount of data; however, without further fidelity and definition for schedule data, it was determined that it would not be useful to this research. No additional enterprise-wide acquisition data sources with relevant schedule data were identified; however, there are likely other centralized systems that contain acquisition information but are not open source.

Ground rules and assumptions (GR&As) were developed to bound and scope the research and establish baseline conditions for the analysis. Key GR&As included the following:

1. Only actual data was analyzed. Future schedule dates were excluded from the analysis.
2. Milestone equivalents were assumed to compare data between older program milestones and new program milestones, e.g., MS II = MS B.

Programs with negative or zero schedule durations between milestones were removed from the analysis as these reflect acquisition process anomalies. Negative duration values could occur either when the program had unique circumstances that caused milestones to take place in non-sequential order or could represent an error in the data.

The study team developed an Excel-based data framework that included schedule parameters, cost parameters, and program attribute parameters that were both available and of interest to analyze. Cost by appropriation, major schedule milestone dates, and life cycle phase were collected. Program attributes collected included program type, assigned component, acquisition category, Joint Capability Area (JCA), new start or modification, and whether a breach occurred within the program. Additionally, program baseline costs were synchronized into constant year 15 millions of dollars (CY15$M) to avoid any dollar distortions in the data. Schedule durations between milestones were calculated (in months) and included in the repository. The analysis focused on analyzing predictors of schedule duration.

In total, the study team analyzed more than 2,600 data points, including 560 schedule milestone dates from 143 MDAP and MAIS programs from DAMIR. Table 1 shows a summary of the data points collected. Within the schedule data points, the largest data for MDAP and MAIS programs were for MS B and MS C. The data had all Services represented, with Navy and Air Force having slightly more data points. Lastly, the data showed each of the JCA areas represented, with Force Application having slightly more data points. Although the data was high level, it provided sufficient schedule fidelity and additional cost and program parameters of interest to have value for the research.

Table 1. Data Collection Summary

	MDAP	MAIS	Total
Programs	80	63	143
Data Points	1,400	1,250	2,650
Schedule Data Points	287	274	561

The data analysis began with synthesizing and cleansing the collected data. The next phase was characterizing the data. The size and makeup of the data by the different parameters collected was analyzed for insights, trends, and relationships. The analytic tool was Excel with data analysis add-in features as well as graphing capability. Scatter plots, trend lines, and various statistical analysis were conducted to gain insight into what relationships the data may reveal. Additional ways of analyzing the data, such as changes over time, were also performed for further insight.

Among the key findings was a wide range of variability and a lack of strong linear relationships between schedule durations and program attributes analyzed. This implies that the complexity of DoD large-scale programs was not easily explained by predictive parameters such as cost, program type, JCA, and Service, for example. Despite this, the research revealed several emergent trends. Presented in this summary are two emergent trends:

Trend 1: Average MS B to MS C durations, which accounts for the Engineering and Manufacturing Development (EMD) Phase of the DoD acquisition life cycle, have decreased 43% for MAIS and 42% for MDAPs over the last 25 years, as shown in Figures 1 and 2. This reduction in the EMD phase average duration was not easily explained by the data, but suggests that various efforts to improve acquisition outcomes may have contributed to reduced development schedules. For example, in the last 25 years, large acquisition programs have trended away from single pass (aka, “Big Bang”) efforts in favor of incremental development and delivery of needed capabilities.

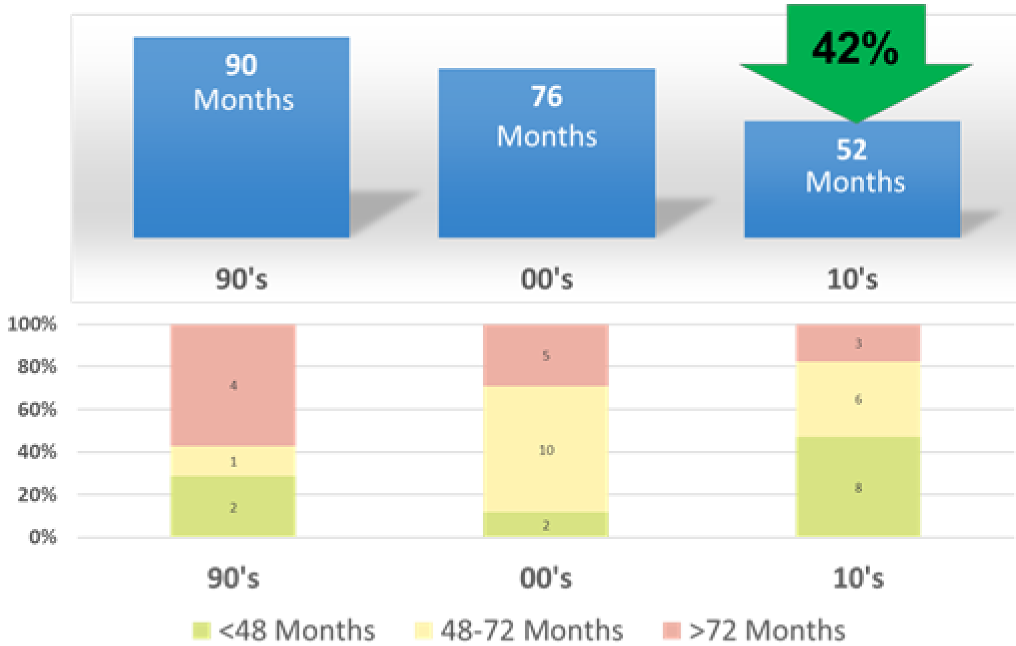

Figure 1. MDAP Development Times

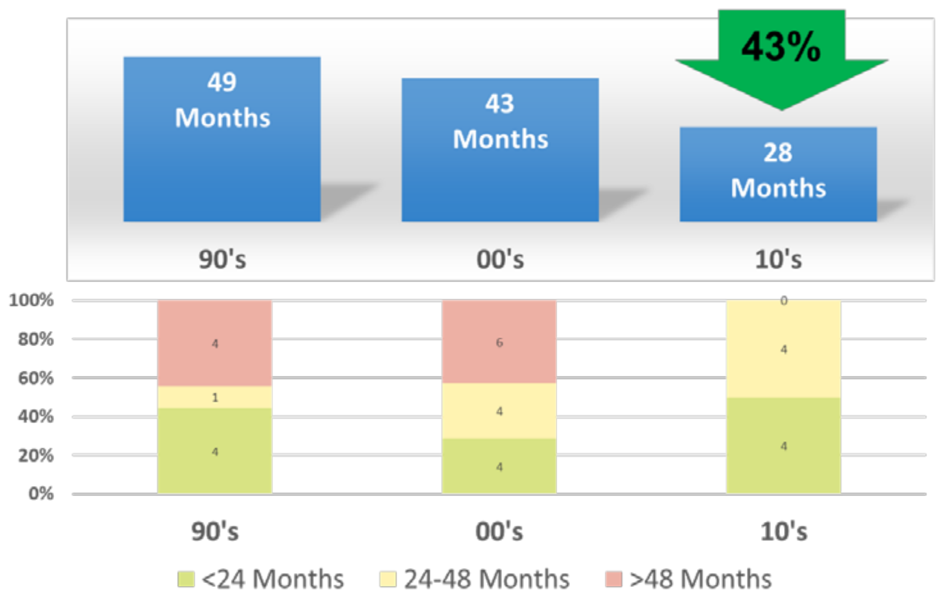

Figure 2. MAIS Development Times

Trend 2: From a cost correlation perspective, the study team observed that higher Research, Development, Test, and Evaluation (RDT&E) costs as a percentage of total Acquisition Costs correlated with shorter EMD schedule durations for both MAIS and MDAP efforts. This observation suggests that development schedules may be "bought down" with a greater share of the total acquisition budget, as depicted in Figures 3 and 4.

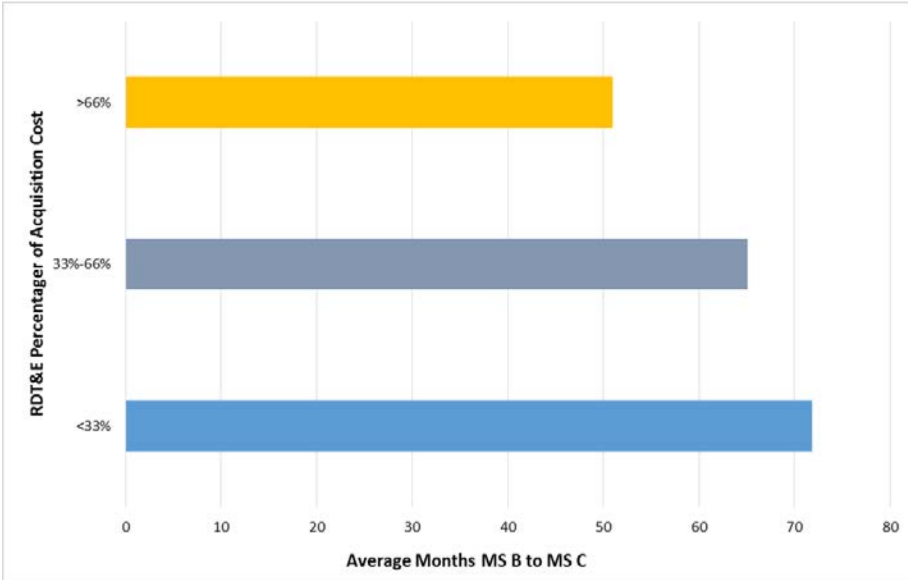

Figure 3. MDAP RDT&E Percentage vs. Schedule (MS B to MS C)

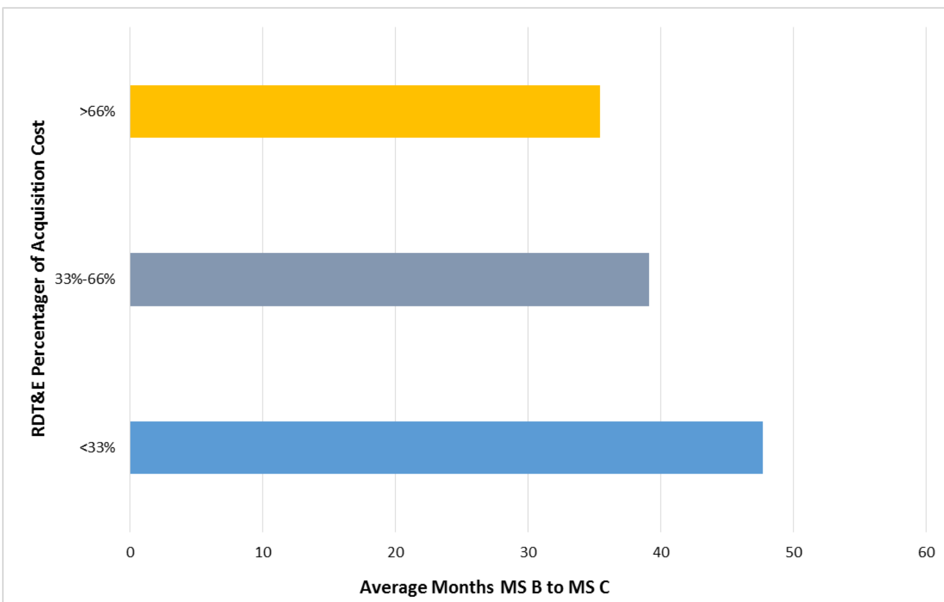

Figure 4. MAIS RDT&E Percentage vs. Schedule (MS B to MS C)

The data collected during this research can be used to help validate schedule realism and identify schedule outliers compared to major DoD programs with similar program attributes. For more comprehensive analysis and higher confidence predictive measures, additional parameter analysis such as requirements and funding stability, program office maturity, governance structures, and technology maturity is needed. Also, as noted, the dataset covered only large DoD programs. The study team did not find useful data for civil-sector and below ACAT-I threshold DoD programs.

In summary, the data suggested some emergent trends; however, the data had a lot of variability and a wide range for most schedule milestones. The data also does not appear to have strong linear relationships between schedule milestone length and program attributes analyzed for either MAIS or MDAPs. One explanation is that the complexity of large-scale DoD programs is not easily explained in full by the selected predictive parameters. Additional parameter analysis is needed to explain and predict schedule differences (such as funding stability, program manager experience, requirements change, technology readiness levels, etc.), but these parameters may be difficult to collect. However, the data collected is a rich dataset that can be used for analogy comparisons for large DoD programs. The study team recommends the data be used to perform high-level schedule assessments or for analogies to evaluate schedule realism throughout a program's life cycle.

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Acknowledgments

Toward Realistic Acquisition Schedule Estimates

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Abstract

Time needed to develop and field new military capabilities is becoming an increasingly serious problem. Among other things, development times have steadily increased. In this paper, we attempt to structure the schedule estimating problem, present some initial results, and propose a research agenda to improve schedule estimating. Accordingly, we seek preliminary answers to the following questions.

- What is the current state of the art for estimating acquisition program schedules? What should it be?
- What are salient features of program management trade-offs, especially between schedule and cost (which are related in complex, imperfectly understood ways)? In what areas should air combat performance measures need updating?
- What are the elements of a research agenda for learning more about schedule estimating?

We also present some preliminary results in the form a narrative case study of the F-35 program and empirical estimates of schedules.

The JCIDS (Joint Capability Integration and Development System) Instruction recommends “effective cost, performance, schedule and quantity trade-offs” as being highly conducive to successful acquisition programs (CJCS, 2015, p. A-9). However, these attributes have received rather unequal interest—with cost garnering the most attention.

For example, in the DoD’s latest acquisition performance report (DoD, 2015), “cost” appears 18 times in the table of contents and 86 times in the highlights; “schedule” appears six times in table of contents and 37 times in the highlights. (“Operational performance” appears only six times in the contents.) In our conference program, “cost” appears 14 times in five sessions, while “schedule” appears four times, in one session.

Cost is certainly important, and warrants much attention, which it's received. The DoD has devoted considerable time, attention and resources to more realistic cost estimating. And, seems to us, there's been a great deal of progress toward that goal.

But schedule is also important and is becoming more so. With multiple Revolutions in Military Affairs ongoing simultaneously, we have entered a hyper-adaptive era in military affairs—enabled, inter alia, by rapid advances in information technology. As Deputy Secretary Work has stated, innovators now encounter "fast followers" (Freedburg, 2015). Accordingly, the operational implications of longer schedules have indeed become more important. And the DoD's leadership recognizes that importance. A number of organizations have recently been created in order to field new capabilities more quickly.

In short, major changes in international military affairs and recent DoD emphasis has created a new environment, in which an ability to understand the schedule consequences of program strategies is especially important.

Accordingly, we discuss the matter of acquisition schedules within the context of contemporary military affairs below. Then we address schedule estimating tools and schedule estimating methods. In the section following that, we take the JCIDS instruction literally, and essay an abstract discussion of cost-time-performance trade-offs.

One promising variable for schedule estimating relationships is system performance, which is discussed next—primarily in the context of tactical fighters, the F-35 in particular.

The section titled Toward Explaining the Time Curve[1] is about empirical models for estimating schedules. One likely schedule driver is requirements growth. In a following section, we offer a narrative concerning the requirements growth that occurred from CALF (Common Affordable Lightweight Fighter) to JSF (Joint Strike Fighter, F-35). Finally, we offer concluding comments and thoughts about a research agenda aimed at making more realistic schedule estimating tools available to our acquisition professionals.

Introduction

Why Schedules Are Important

"The fact is that we are slower than the bad guys."

—Esti Peshin, Director of Cyber Programs for Israel Aerospace Industries (quoted in Sternstein, 2015).

Cost and schedule are critical variables in any acquisition program. And the DoD has indeed committed serious efforts over an extended period of time to develop the means for realistic acquisition cost estimates.

There are at least five good reasons for increased focus on realistic schedule estimates:

- Planning to pay for force modernization in an era of restrained budgets, especially in the next decade;
- Longer times to field new capabilities (absolute and relative);
- Rapid fielding initiatives throughout the DoD; and

[1] That is, the upward trend in time needed to field new systems.

- Current marching orders, including the Air Force “should-schedule” initiative.

(Apparently) Looming Budget Squeeze

There’s a budget squeeze for the DoD expected in the 2020s, driven largely by modernization programs. This has been well documented by experts both inside and outside the government (e.g., Congressional Research Service [Gertler, 2015]; Center for Strategic and International Studies [Harrison, 2016]).

This is especially difficult for the Air Force, whose top-3 priority acquisition programs account for almost all of resources expected to be available for modernization. For example, these (KC-46, F-35, Long-Range Strike Bomber), plus C-130J and unmanned aircraft account for 99% of the service’s aircraft acquisition budget for FY16 (Gertler, 2015, Summary, 1), with the situation continuing throughout the 2020s.

Furthermore, there’s every reason to expect budget squeezes to continue well into the future. The entitlement bills are now coming due—expected to account for about 15% of GDP in 2026. Net interest on the federal debt is estimated at 3%; “discretionary” expenditures for about 5%, about half of which is estimated for defense (Congressional Budget Office [CBO], 2016, esp. pp. 66, 84). Revenues are estimated at about 18% of GDP (CBO, 2016, p. 92), with long-term deficits of about 5% of GDP. This means major pressure on the “discretionary” categories—defense especially.

Therefore, some preplanning and painful prioritizing seems both necessary and inevitable. A number of options are available, none of them pleasant (Gertler, 2015; Hale, 2016; Harrison, 2016). And it’s reasonable to expect that the longer necessary decisions are postponed, the range of alternatives available will continue to narrow. But without reasonably good program schedule estimates, any early decision loses credibility and usefulness.

Schedules Have Become More Important: Time to Deliver New Systems Is Increasing

“(Acquisition) lead time in the U.S. is too long,” according to LTG Arthur Trudeau, Army Chief of Research and Development (1958, quoted in Peck & Scherer, 1962, p. 425). But lead times are getting longer. For example, the F-35 concept is generally regarded as being formed in July 1993, with the creation of the Joint Advanced Strike Technology (JAST) program (Defense Science Board [DSB], 1994, ES-1). The F-35B, for example, was declared operational on July 31, 2015 (USMC, 2015), meaning a lead time of 22 years.

This is illustrated in Figure 1. One implication is that the widely-mentioned 2030 IOC[2] of a next-generation fighter aircraft appears fanciful at best. If source selection for a sixth-generation fighter aircraft occurs in 2020 (optimistic), we can expect an IOC some time past the middle of the 2030s.

Schedules Are Becoming More Important in an Era of Faster Followers

As Robert Work, Deputy Secretary of Defense, put it, we’re in an era of “fast followers” in military affairs (Freedburg, 2015). And there’s excellent reason this problem is

[2] Fielding a new fighter in 2030 has been advocated as an operational “requirement” (Gen Mike Hostage, quoted in Mehta, 2012) and also to alleviate fighter aircraft shortfalls (Tirpak, 2009, 38).

getting worse; as an Air Force flag officer put it, “Emerging threats’ timelines are decreasing. (Our) acquisition times are increasing.”[3]

The current schedule difficulty is made more acute due to the adaptiveness of our rivals. Given especially the extended period of development for many U.S. weapon systems, those countermeasures have time to development. Thus, for example, potential adversaries have seriously pursued countermeasures to U.S. stealth fighters (e.g., Fulghum, 2012; Keller, 2016; Majumdar, 2014; Sweetman, 2015c, 2015d). The principal enabling technology is rapid computing, which can combine fragmentary sensor information into a unified picture (Clark, 2014). All in all, stealth may indeed be overrated (as the CNO, Admiral Jonathan Greenert, stated, quoted in Hasik, 2016a).

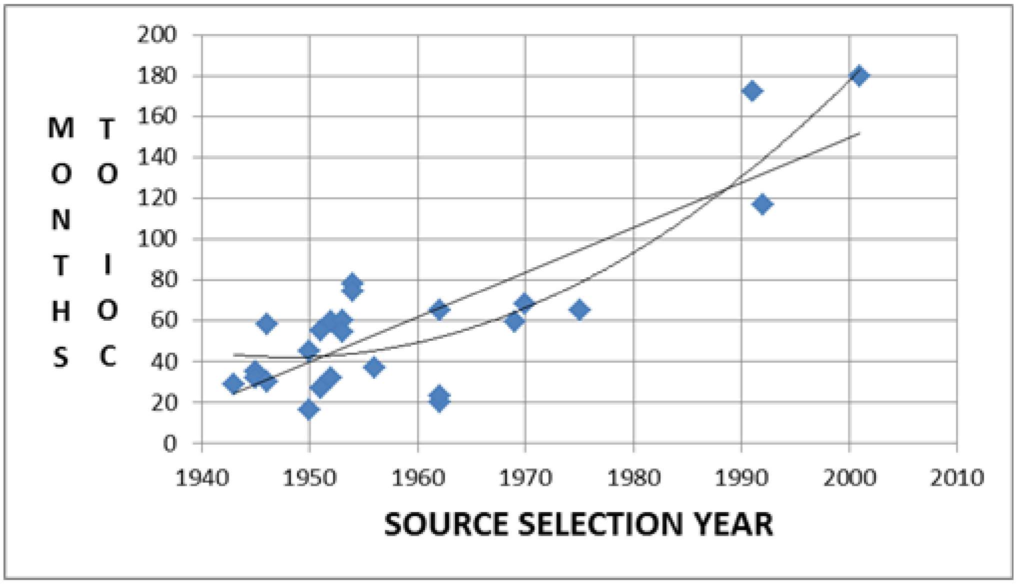

Figure 1. The Time Curve in Months to IOC vs. Source Selection Year for Tactical Fighters
(expanded from Blickstein et al., 2011, Table 4.5, p. 48)

This is relevant to schedules. It’s possible that a stealthy aircraft, if delayed long enough, can operate only at considerably reduced effectiveness (Franck et al., 2012, p. 68). Therefore, it’s important that new capabilities, and upgrades, be fielded in a timely manner and that planners have a realistic estimate of how long it will take to field new combat capabilities.

Current Marching Orders Regarding Schedules

Recognizing the problems discussed above, the services and the DoD have undertaken initiatives to field new capabilities sooner. These have included the Air Force Office of Rapid Capabilities (RCO) and OSD’s Strategic Capabilities Office (SCO). The RCO began in 2003; its basic purpose is to accomplish “expedited and operationally focused concept-through-fielding activities to support immediate and near-term needs” (Clark &

[3] Observation offered at a symposium in May 2015, not for attribution.

Freedburg, 2016; U.S. Air Force, 2009). In addition, the Navy has proposed an office which will “be something that closely mirrors the Air Force RCO,” according to the Navy’s senior acquisition officer (Clark, 2016).

The SCO originated in 2012. Its basic purpose is “to re-imagine existing DoD and intelligence community and commercial systems by giving them new roles and game-changing capabilities to confound potential enemies (with) the emphasis … on rapidity of fielding” (Carter, 2016; Clark & Freedburg, 2016). In addition, an ongoing legislative initiative, associated with Rep. Mac Thornberry (R-TX), is intended to streamline acquisition processes (Hasik, 2016b).

Also, Secretary of the Air Force Deborah Lee James (2015) has begun the “should schedule” initiative: “The previous incentive focused on cost, now we‘d like to target delivery time. … If we can collectively beat the historical developmental schedules and reward the behavior in government and industry that speeds things up, we have a real chance to make a difference.”

To implement the “should schedule,” Secretary James proposes, *inter alia*, that schedule be a major factor in source selections: “If an industry partner can propose a solution that credibly offers a way to accelerate successful EMD, then that company would have a competitive advantage for the award” (James, 2015).

This sounds good, but let’s consider a future acquisition scenario. Suppose a major acquisition program involves proposals, from Firms A and B, and that Firm A wins the competition. Let’s further suppose that estimated schedule is a major factor in that decision. Finally suppose this particular program involves a long-term, high-value, winner-take-all contract—like many competitions these days. And it’s a safe bet that Firm B will protest.[4] While “any accelerated EMD plan would need to survive a detailed scrub by independent engineers” (James, 2015), that might well not be enough. At minimum, those proposed schedules should also survive a detailed scrub by the GAO.

On Schedule Estimating Methods

Program schedule time can be analyzed and forecast according to the following (non-inclusive) menu:

- Schedule length arising from an orderly relationship involving key variables;
- Schedule as a result of a series of management decisions intended to produce the best outcome with respect to performance, cost and time;
- Schedule resulting from the interactions among a set of tasks needed to complete the program.

We know quite a bit about the last item—through, for example, Program Evaluation and Review Technique, Critical Path Method and Gantt Charts (Blanchard & Fabrycky, 2006, esp. Chap. 11; Defense Systems Management College [DSMC], 2001).

[4] The protest may or may not have a convincing rationale. See, for example, Bill Sweetman’s (2015e) analysis of the Boeing-Lockheed Martin protest of the LRSB source selection.

We know less about the second but can learn more through case studies (as discussed below), and official post-mortems like those conducted for cost problems by the OSD's Office of Program Assessment and Root Cause Analysis (PARCA) office.[5]

We know some things about the first, through descriptive analyses such as illustrated in Figure 1. And we can do more to improve empirical methods. Along those lines, the discussion below provides an interesting empirical analysis of schedule lengths.

It's possible to formulate an orderly-relations approach in a manner similar to formulating Cost Estimating Relationships. We offer the term "Schedule Estimating Relationships." We already have a fair number of possibilities for key explanatory variables. These include the following:

- risk reduction measures (including those prior to source selection);
- contract type;
- technical maturity of subsystems and components;
- requirements growth (or not);
- "complexity" and "density"; and
- funding instability (or not).

Worth noting is that some (perhaps all) items on this list could also apply to program cost estimation.

There's nothing original here; the first four items have been publicly cited as lessons learned and applied to the LRSB program (Butler, 2015; Seligman et al., 2015; Sweetman, 2015d; Tirpak, 2015). In addition, below, we discuss requirements growth in the F-35 program.

"Complexity" is suggested as an explanatory variable by a particularly interesting comment by a senior DoD official: "Our complexity reach exceeds our engineering grasp."[6] One plausible metric for complexity is lines of code (virtual complexity perhaps). For example, Hallion (1990) reports 64,000 lines of code in the F-15A and 2.4 million lines in the F-15E. Lines of code in the F-35 vary with source and date. A 2014 CRS report estimates F-35 software as containing approximately 29 million lines of code and still growing (Gertler, 2014, p. 14).

In addition to virtual complexity, we could consider "density," indicating physical complexity. Density is "how tightly systems and equipment are placed within a hull structure" (Grant, 2008). There is other interesting research on "density" as a cost driver for warships (e.g., Terwilliger, 2015).

[5] In fact, *post-mortem* analysis of schedules arguably fits directly within the PARCA charter. (http://www.acq.osd.mil/parca/performance-assessments.shtml).

[6] Ninth Annual Acquisition Research Symposium, May 2012, Monterey, CA. Comment understood as not for attribution.

Schedule Estimating Goals

We think that something like the current structure for cost estimates is a useful analog in thinking about a similar structure for schedule estimates. This is illustrated in Figure 2.

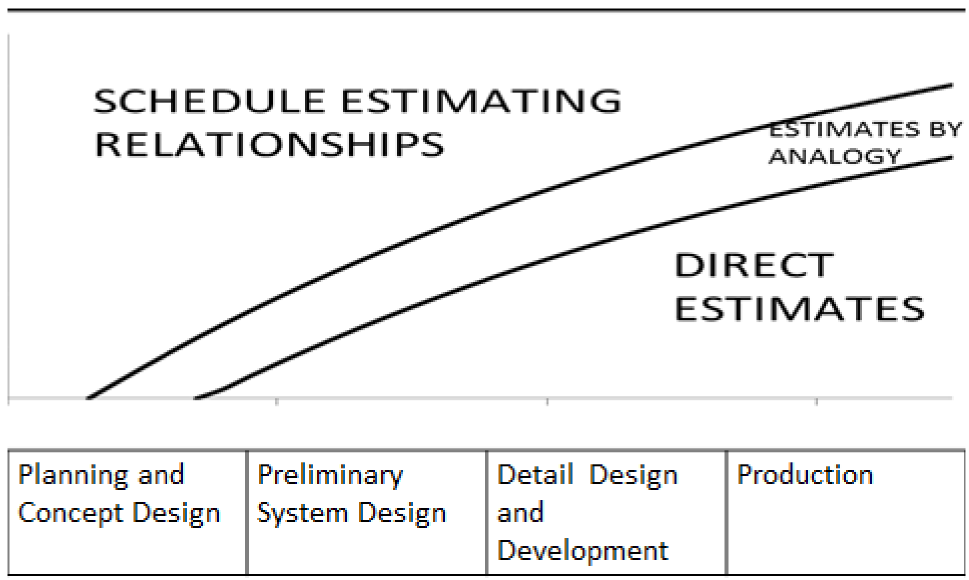

Figure 2. Schedule Estimation by Program Phase
(adapted from Blanchard & Frabrycky, 2006, Figure 17.9, p. 595)
Note. Source draft referred to cost estimation by program phase.

In that vein, a comprehensive schedule estimating repertoire would include the following:

- macro-level, statistical methods to do those estimates in the early stages of the program (ex ante),
- more specific methods to update schedule estimates during the program (in media res), and
- methods for explaining the results of events and decisions previously in the program (ex post).

For estimates done early in the program, we think “Schedule Estimating Relationships” featuring historically important schedule drivers are promising. They can provide preliminary estimates of acquisition schedules to inform concept and requirements determination. They could also serve as an independent check of scheduling aspects of bidders’ proposals.

During program execution, it’s highly desirable for program managers to have the means to update schedule estimates. To a considerable extent these already exist, as discussed, for example, in the DAU’s *Scheduling Guide for Program Managers* (DSMC, 2001). A number of tools (discussed above) are available to program managers and their staffs (Blanchard & Fabrycky, 2006, esp. Chaps. 11 & 18).

Finally, schedule analysis and prediction methods can usefully support after-the-fact (ex post) analyses of program successes and difficulties. Such tools could enable schedule analyses similar to those now conducted by the OSD’s Root Cause Analysis office for selected programs with cost problems.

Cost–Performance–Schedule Trade-Offs

Schedules arise from trades (perhaps implicit) among cost, schedule and performance. And “making … effective *cost, performance, schedule*, and quantity trade-offs” (emphasis added) is a major theme of the JCS directive for the Joint Capabilities Integration and Development System (JCIDS; CJCS, 2015).

We know a fair amount about the structure of cost, performance, and schedule trade-offs, but there’s more worth finding out. As one report put it, “the literature linking cost, performance, and schedule is by no means abundant. This is due in large part to the sheer complexity of the interrelations between performance characteristics and technical specifications, as well as the unique missions … systems” (Voltz, 1992, p. 13). In this section, we offer a preliminary explanation of those trade-offs taken two at a time: Cost and Performance; Cost and Schedule; Performance and Schedule.

Cost and Performance

Of these three, we probably know most about Cost vs. Performance. Basically, we expect to pay more to acquire higher performance. Figure 3 shows a notional trade-off with effects of technical progress.

That relationship has been investigated in a number of empirical studies. One of those (Hildebrandt & Sze, 1986, p. 15) led to the following cost-performance relationship (in log-log form) shown below. This is the result of a regression analysis of a data base of 66 fighter and attack aircraft with first flights from 1950 (F-89) to 1979 (F/A-18).

$$\ln CAC = 1.99 + \ln{*}P + 1.31\ln{*}ASP - .31\ln R - .03T - .50{*}ATTACK - .89{*}M0D + b_i{*}\ln Y, \qquad (1)$$

where CAC is cumulative average cost; P is resource price levels (primarily labor and materials); ASP is an aircraft performance index; R is production rate; T is year of first flight; ATTACK is dummy variable (1 for attack aircraft, 0 otherwise); MOD is a dummy variable for aircraft models that are modifications or upgrades of an existing aircraft type; bi is the relevant learning curve parameter; and Y is cumulative production. Franck (1992) used the same data to infer patterns of cost-performance design choices.

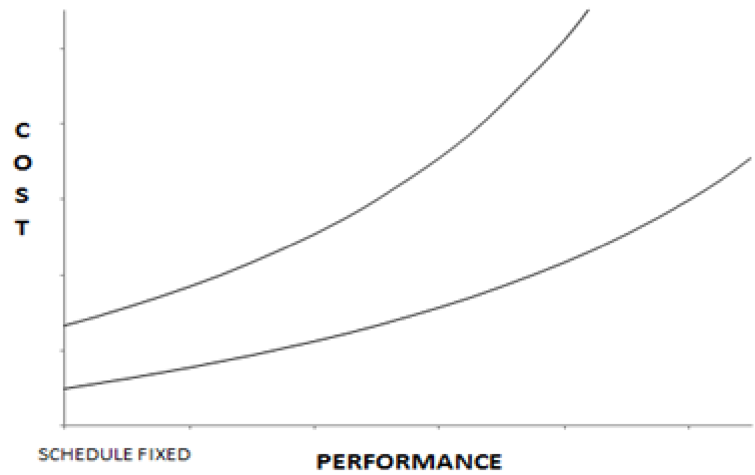

Figure 3. Cost vs. Performance Trade-Off
(adapted from Gansler, 1987, p. K-8; Sullivan, 1981)

The first-flight variable is intended to capture the effects of technical progress. All other things equal, we expect to pay less for a given level of performance with improvements in technology. This is illustrated in Figure 3, which includes effects of technical progress. As previously stated, as performance increases, so does cost. However advancing technology shifts the cost-performance curve down and to the right (lessening to cost of any given level of performance).

Program Schedule and Cost

Effect of development time on program cost is somewhat ambiguous. Keeping a team in place longer means greater overhead expenses (sometimes called the “standing army” effect). But shorter development times can mean less chance to develop technology and sort among alternative approaches and incurring the costs associated with cascading effects of wrong turns.

These seem, in general, to be countervailing effects. Less time means less overhead cost over the life of the program. More time means better chances to avoid pitfalls and manage risk. In theory, the best course of action is reached by balancing increases in overhead (indirect) cost with direct program cost. This is shown in Figure 4.

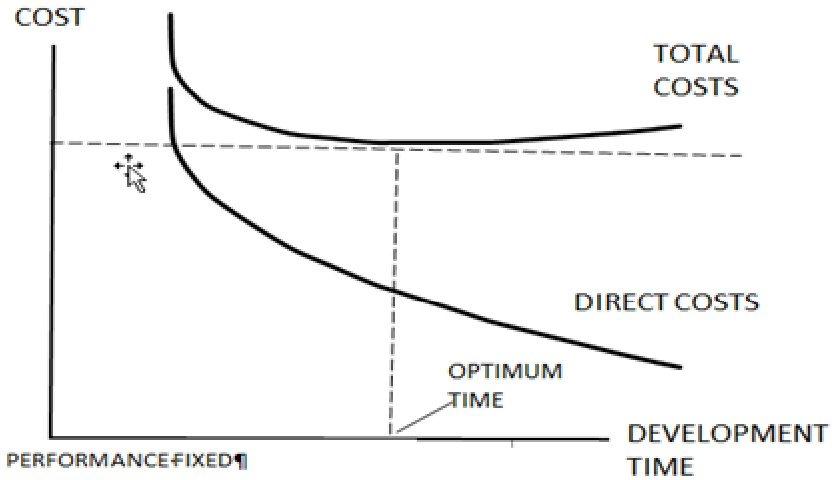

Figure 4. Total Cost Analysis for Selecting Optimum Program Duration
(adapted from DSMC, 2001, p. 60; Zschau, 1969, pp. 28–30)

This sketches nicely, but solving the implied problem is more complicated. For example, not all relevant costs are internal to the acquisition program itself. As the DSMC *Scheduling Guide* points out, “Each month added to the development and production of a new … system tends to reduce by 1 month the operational life of the product” (DSMC, 2001, p. 61). This suggests that monetized effects of fielding delay should be added to total costs—a difficult task.

Nonetheless, those costs of delay can be all too real and multifaceted, as illustrated by the F-35 program. The effects included a projected shortfall of tactical fighters in both the Air Force and Navy (Tirpak, 2010; Trimble, 2010). To help bridge that gap, it was necessary to keep the older “legacy” aircraft in service for longer than originally planned—and consequently spend more money than originally planned to retard their rate of obsolescence. For example, the U.S. Air Force has been obliged to devote considerable resources to upgrading its “legacy” fourth-generation systems and to extending their operational lives (GAO, 2012). Overall, “the failure of the so-called fifth-generation fighters … to arrive on time and on cost has cascading effects throughout U.S. and allied fighter forces” (Sweetman, 2012).

Schedule and Performance

A notional representation of system performance vs. program time appears in Figure 5. The figure implies that increasing program time allows for a more considered approach that permits better decisions. However, increases in indirect cost caused by a longer program crowd out resources directly useful for system development. And beyond some point, the slope of the Performance vs. Time curve goes negative.

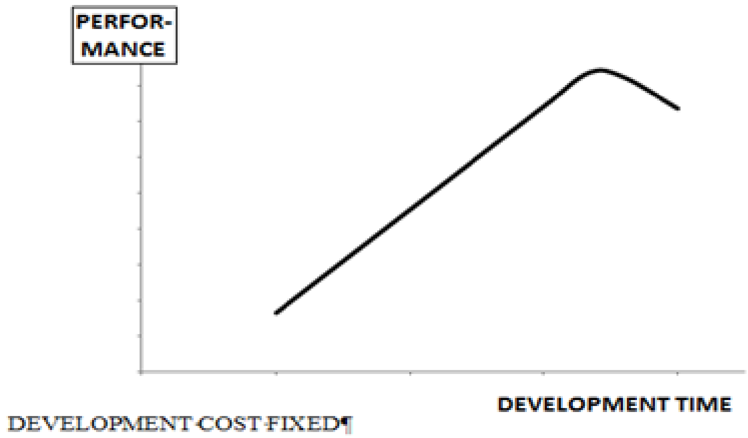

Figure 5. Performance vs. Development Time Trade-Off
(adapted from Zschau, 1969, pp. 28–30)

While certainly understandable in the abstract, there are some difficulties with this trade-off in practice. Among other things, development programs that proceed with a strictly fixed budget are very rare, if not nonexistent. This limits opportunities to develop a model grounded in actual experience.

The Concurrency Issue

Program "concurrency" is generally understood to involve beginning production prior to completion of development testing (DoD, 2015, p. 46), or more broadly as "combining or overlapping phases" ("Concurrency," n.d.).

Concurrency is frequently cited as a "high risk strategy that often results in performance shortfalls, unexpected cost increases, schedule delays, and test problems" (GAO, 2012). On the other hand, Goure (2015) noted "a number of reasons to pursue concurrency," including early identification of production problems and faster fielding of new hardware.

One very interesting study suggests an optimum level of concurrency (from the perspective of cost). However, the authors did not find strong empirical evidence to support that hypothesis (Birchler et al., 2011, p. 252). Nonetheless, some form of dynamic, simultaneous-equation model might prove useful.

Measuring Performance

Metrics for cost and schedule time are generally well understand. Metrics for performance are much less definite. Generally system "performance" is reported as a vector. For tactical fighters, the elements of the vector are characteristics such as maximum speed, service ceiling, thrust-to-weight ratio, combat range, weapons carriage, and Radar Cross Section (RCS). One noteworthy effort to develop performance indices (scalar measures) for a variety of combat system types was undertaken by the Analytic Sciences Corporation (ANSER). This occurred mostly in the 1980s and described as the TASCFORM method (Regan & Voigt, 1988).

Within that overall project, the TASCFORM-Air model of combat capability was intended to assess tactical fighters, attack helicopters, and bombers in various conventional missions (Regan & Voigt, 1988, p. 1-1). Tactical aircraft were assessed in the context air-to-air ("air combat") and "surface attack" against both land and maritime targets (p. 2-2). The basic intent of TASCFORM-Air was to systematize observable technical features and combine those with judgments of air combat experts to provide (scalar) indices of fighter capability in several operational contexts.

The capability measures applied directly to individual aircraft are organized in a hierarchy:

- Weapon Performance (WP, a function of weapons carriage, range, maneuverability and speed);
- Weapon System Performance (WSP, WP plus target acquisition, susceptibility to countermeasures, weapon enhancements, navigation and survivability)
- Adjusted Weapon System Performance (AWSP, WSP plus “obsolescence” and sortie rate; p. 2-4).

So, how does the F-35 performance look relative to fourth-generation fighters? A comparison of the aircraft types in the Weapons Performance dimensions (which emphasize payload, range, maneuverability, and speed) shows there’s not much difference.

- Hard points: F-35 has a comparable number of weapons hard points relative to the F-18 and F-16 but much fewer in stealth mode.
- Max Speed: all three aircraft are all comparable.
- Ferry Range is comparable, if F-35 has external tanks.
- There’s a Combat Range advantage for the F-35 when operating in a high-high-high profile, compared with range in a high-low-high profile for the fourth-generation fighters.
- Maneuverability: Thrust-to-weight ratio, max Gs, and wing loadings are comparable for F-16, F-18, and F-35.
- Sortie Rate: not yet determined. The F-35 is still maturing.
- Survivability: favors stealthy aircraft, but nonetheless subject to countermeasures (discussed above).

Force capability is generally presented as numbers and types of systems. Force capability indices are also discussed in TASCFORM (pp. 2-4, 2-30–2-36), in which force capability is assumed to be the sum of individual performance (by tail number). These measures do not fully address force effectiveness as a function of networking and shared situational awareness.

The fifth-generation fighter advocates have a new perspective on system and force capabilities. New aircraft models such as the F-22 and F-35 are seen as disruptive innovations. Within this perspective, the operational capabilities of the fifth generation are due to the combination (synergy perhaps) of airframe characteristics and “ability to work within and interact with a broad array of networked systems” (Deptula, 2011; Space Daily Staff, 2006).

Moreover, fifth-generation characteristics, especially stealth, increase the proportion of resources devoted to offensive air operations. Fifth-generation aircraft likely need fewer fighter sorties to support penetration of advanced and integrated air defenses, and fewer tanker sorties (due to smaller strike packages).

Regardless of one’s opinion of fifth-generation performance advantages, it’s hard to avoid the conclusion that a credible method of measuring system (and force) performance should account for the advantages of stealth, shared battlefield awareness, and networked operations.

F-35: From CALF TO JSF[7]

The Lockheed Martin F-35 Joint Strike Fighter (JSF, Lightning II) is a single seat, single engine, fifth-generation multirole fighter designed to perform ground attack, reconnaisance, and air defense missions while in stealthy operation. It was originally visualized as a relatively affordable strike fighter available in three largely common versions for the Air Force, Marines, and Navy. It didn't work out that way.

Then-Major General Christopher Bogdan (JSF Program Executive Officer designate) commented that the F-35 "is not a single program (but rather) three separate airplane programs (with) common avionics and a common engine." He also stressed the difficulties involved in reaching agreement on decision-making. In his words, "It's hard enough to get one service to answer questions about requirements. Imagine three services, eight partners, and two FMS customers" (Bogdan, 2012).

All three models are designed for limited supersonic operation, and to carry their primary weapons internally, to preserve their stealth characteristics. Although physical differences arose from methods of takeoff and landing, requirements were also driven by different operational needs.

The F-35A was a replacement for the F-16, the A-10, and perhaps the F-15 fighter. In addition, it is intended to complement the F-22 air superiority fighter. The Air Force sought an advanced attack aircraft with stealth, advanced avionics, and low life-cycle operating costs providing improved range, speed, and appreciable weapons load capacity.

The F-35B is a short takeoff and vertical landing aircraft (STOVL) acquired to replace its AV-8B Harrier and its F/A-18A/B/C/D strike fighters. It was designed to operate from forward battlefields, helicopter carriers, and as a "jump jet" from smaller conventional carriers. The F-35C (CV) chosen by the U.S. Navy resembled the Air Force's F-35A but was modified for carrier operations. It is intended to replace earlier versions of the F/A-18.

Joint and International Nature

At the time of JSF conception, there was a clear preference at the highest levels of the DoD for joint projects. Typically, the rationale for jointness is that a largely joint project lessens costs of developing, procuring, and operating and supporting some large number of separate aircraft designs with similar (but not necessarily identical) requirements.

A study by the RAND Corporation undertook to examine this issue (Lorell et al., 2013), which focused on the costs of jointness. The critical finding is

> the need to accommodate different service requirements in a single design or common design family leads to greater program complexity, increased technical risk, and common functionality … beyond that needed for some variants, potentially leading to higher overall cost, despite the efficiencies (of common design). (Lorell et al., 2013, iii)

[7] This section relies in part on background information from Aboulafia (2015) and Gertler (2014). Also we found the Wikipedia article on the F-35 to be a good source for those seeking basic information on the program ("Lockheed Martin F-35 Lightning II," n.d.).

The F-35 won the DoD source selection, with an industry team of Lockheed, Northrop Grumman, BAE Systems, and Pratt & Whitney. (Aboulafia, 2015, identified the F-35 suppliers in more detail.)

From the earliest days of the JSF project, the Office of the Secretary of Defense stressed international participation. The UK joined the JSF project as a Level 1 Full Collaborative Partner. There were five (Level II) Associate Partners and three (Level III) Informed Partners in the Systems Development and Demonstration Phase (Schreiber, 2002, p. 164).

History and Antecedents

Defense procurement funding fell sharply in the early 1990s, implementing the Bottom Up Review recommendations—ending such programs as the NATF (Naval Advanced Tactical Fighter) and the A-12/ATA. Fearing loss of domestic military aircraft design skills, the DoD undertook a series of largely unsuccessful programs. This effort include support for design of advanced technology aircraft available for production.

The list of aircraft concepts not leading to production includes the following (e.g., Aboulafia, 2015, esp. pp. 10–11):

- A-X/A/F-X, a Navy-dominated joint program was canceled due to the A-12's high cost, and by the 1993 appearance F/A-18E/F (Super Hornet).
- ASTOVL/SSF (Advanced STOVL/STOVL Strike Fighter) was an ARPA project intended to develop a supersonic AV-8B Harrier successor. NASA and the UK both participated in this effort. It was merged by Congress with JAST in mid-1994.
- CALF (Common Affordable Lightweight Fighter) was the formal name for DARPA's ASTOVL project that included a conventional take-off design capability. Sometimes known as the X-32, CALF was merged into JAST in November 1994.
- JAF (Joint Attack Fighter) explored the same ideas as JAST, as was also true of the JSSA, the Joint Stealth Strike Attack Aircraft.
- MRF (Multi-Role Fighter) was a Navy/Air force program designed to produce a follow-on aircraft for the F-16, F/A-18 and several other legacy planes. It was sidetracked by the appearance of the F/A-18E/F (Super Hornet).

JAST/JSF

The F-35 Joint Strike Fighter emerged from the Joint Advanced Strike Technology Program (JAST). However, JAST's original goal was to develop technologies for advanced strike aircraft (DSB, 1994). It happened that JAST's plans to fund several concept demonstrator aircraft in 1996 coincided with ASTOVL's planned timing of the start of its Phase III (full-scale flight demonstration). The managements of both programs concluded that it would be logical to make JAST the U.S. military service sponsor for the flight demonstration phase of ASTOVL. In any case, FY95 budget legislation directed an immediate merger of ASTOVL into JAST (DoD, JSF History, 2015).

In early 1997, Lockheed Martin and Boeing were selected to develop flying airframes for the concept demonstration phase. They were designated X-32 (Boeing) and X-35 (Lockheed Martin), respectively, with evaluations between September 2000 and August 2001. On October 26, 2001, the Lockheed Martin team was announced as the winner, after which the program transitioned to the JSF System Development and Demonstration (SDD) phase (Aboulafia, 2015, esp. pp. 11–12).

Cost and Scheduling Problems

Few new weapon systems have earned such a widespread reputation for problems encountered in the design and development stages as the F-35. A few comments are useful here. Early development problems in many new products were followed by highly effective operational performance. The C-17 is one example (Franck et al., 2012). But the F-35 involved much more difficult design and development problems (Blickstein et al., 2011, esp. pp. 42, 49).

The RAND Corporation and others reviewed the Joint Strike Fighter and provided a root cause analysis of its cost problems. The RAND report identified "in some measure" an overly optimistic government estimate of the influence of acquisition reform and "produceability initiatives" as responsible for underestimates of future procurement cost growth. When combined with a perceived strong need for an improved F-16 replacement, the OSD proved willing to begin "a technologically complex, highly concurrent F-35 program." The end results included schedule slippage and cost growth that resulted in a Nunn-McCurdy breach (e.g., Rutherford, 2010).

Explaining the Time Curve

In this section, empirical models are discussed that focus on the key variable: Months from Initial Award to IOC (or Time to IOC) for fighter aircraft. As shown previously, this variable has increased with later initial award years for fighter aircraft.

In this empirical analysis, contract-level data contained in Selected Acquisition Reports (SARs) or the F/A-18E/F, F-22, and F-35 (and, where possible the Air Force F-35A) is emphasized. For each published SAR, generally on December 31, both program and contract level data are included. Because each SAR for fighter aircraft contain data for two or more contracts (both airframe system and engine), data at this level not only increases the size of the data set but also permits inclusion of contract type, changes in the target cost, years elapsed since time of contract award, and contract variance. Contract variance information (not required for Firm Fixed Price contracts) includes both cost and schedule variance. The former provides information on the difference between the planned and actual contract cost, the latter on the difference between the planned work performed and scheduled. (Future analysis will extend this work to include program-level data including the various program-level variances.)

Examination of the available data indicates that complex interactions among the relevant variables complicates the traditional regression analysis view of explanatory variables affecting the dependent variable. Our analysis includes both explanation and association. Including association variables provides insight into the strength of the relationships between these variables and the dependent variable (other variables held constant).

We are also investigating professional-judgment measures of fighter effectiveness for fighters, which would increase the regressions' explanatory power. One variable obtained from non-SAR sources, included in the current analysis, is the percent of an aircraft's structural weight consisting of composites.

To understand the empirical analysis, an influence diagram appears in Figure 6—in the form of path analysis in which *Time to IOC* is related to contract-specific cost variance and other variables. In turn, current minus initial target cost is related to contract variance data, contract type, and several other variables. We also identify the expected signs of the regression coefficients when possible.

Broadly speaking, Figure 6 displays those variables that directly related to *Months from Initial Contract Award to IOC,* namely *Contract Current—Initial Target Price, Program Year, SAR Year—Contract Award Year*, and C*omposites* as a *Percent of AC Structure Weight.* There are also indirect relationships between certain explanatory variables and time to IOC. This occurs through these variables' direct relationship with [*Contract Current—Initial Target Price*]. The variables with an indirect relationship with time to IOC are *Program Year, [SAR Year—Contract Award Year], [Contract Cost Variance and Contract Schedule Variance], Aircraft MDS,* and *Contract Type.*

The only variables with uncertain sign of regression coefficients are Aircraft MDS and Contract Type. It is likely easiest to understand this diagram through a discussion of the regression results. First, Figure 6 shows the direct relationship between explanatory variables and Time to IOC.

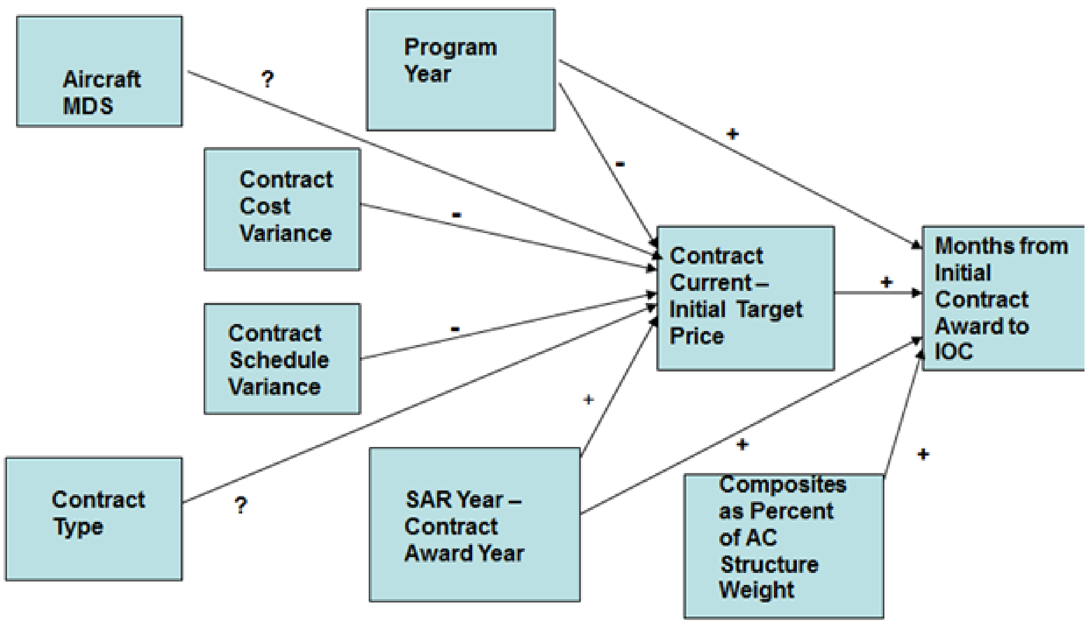

Figure 6. Structure of the Regression Model

The results in Table 1 show all variables being statistically significant given the hypothesized signs of the coefficients in the figure. When the current target minus the initial target price increases, this likely means that a specification change occurred. One would expect specification change to be associated with a longer Time to IOC. As *Program Year* increases, this is likely related to a longer program length. In turn, this is likely related to an increase in Time to IOC. An increase in *[SAR Year—Contract$_i$ Award Year]* indicates that a schedule delay is likely.

The most interesting independent variable may be *[Composites as a Percent of AC Structural Weight].* We show that as this increases, which is exactly what occurred when shifting from the F/A-18E/F to the F-22 to the F-35 programs, the dependent variable increases. It is known that working with composite materials is more complex than traditional materials, and as result, can be expected to increase the length of the program to IOC.

Table 1. Direct Effects for Months-to-IOC Regression

Explanatory Variable	Coefficient	t-statistic
(Constant)	50.409	12.478
Contract Current - Initial Target Price ($B)	1.309	2.880
Program Year	2.030	10.015
SAR Year - ContractAward Year	0.986	3.853
Composites as Percent of Structural Weight	3.051	21.242
FFP Contract	12.450	5.920
Dependent Variable: Months from Initial Contract Award to IOC		
R^2 = 0.846; N = 164		

We turn now to the indirect effects regression. We have seen that *[Contract$_i$ Current Target—Initial Target Price]* has a positive direct relationship with the key dependent variable. But there are also variables that have a direct relationship *with [Contract$_i$ Current Target—Initial Target Price],* and, therefore, an indirect relationship *with [Months from Initial Contract Award to IOC].* Table 2 displays this set of regression results.

Table 2. Indirect Effects in the Regression Model

Explanatory Variable	Coefficient	t-statistic
(Constant)	3.222	3.941
Cumulative Contract Cost Variance	-4.810	-4.725
Cumulative Contract Schedule Variance	-6.072	-3.339
Program Year	-0.213	-3.934
SAR Year - Contract Award Year	0.168	3.506
F-35	-1.333	-3.867
F/A-18E/F	-1.979	-4.257
CPAF Contract	-0.860	-2.019
Dependent Variable: Contract Current Target - Initial Target Price		
R^2 = 0.665; N = 110; Financial Variables, $B		

The *Cumulative Contract Cost* and *Schedule Variance* coefficients are interesting. Contract Cost Variance Budgeted Cost of Work Performed minus Actual Cost of Work Performed; and Schedule Cost Variance equals Budgeted Cost of Work Performed minus Budgeted Cost of Work Scheduled. So, as these variables both increase, the extent to which the contractor is over budget and behind schedule decreases. Therefore, motivation to revise target price also decreases, consistent with the negative coefficients.

As *Program Year* increases, specifications become more settled, and target price revisions are less likely, consistent with the negative coefficient. However, as contracts become longer, requirement and specification changes become more likely.

One advantage of employing both direct and indirect modeling is that one can more effectively assess indirect effects of Aircraft MDS and Contract Type on Time to IOC. Both the F-35 and the F/A-18E/F are negatively related to *[Contract$_i$ Current Target—Initial Target Price].* For the F-35, this negative coefficient offsets somewhat the positive relationship between *[Contract$_i$ Current Target—Initial Target Price]* and *[Months from Initial Contract Award to IOC].* Finally, we find that CPAF contracts are negatively related to *[Contract$_i$*

Current Target—Initial Target Price], likely meaning smaller increase in specifications that, in turn, increase target price.

Draft Research Agenda

Acquisition schedules are becoming more important. Therefore, our final aim in this paper is to propose a research agenda aimed at producing more accurate schedule estimates, particularly in major defense acquisition programs.

Schedule Estimation Research: A Draft List of Questions and Tasks

1. What is the current state of schedule estimation and control? What's needed? Where are the gaps?
    - Interview subject-matter experts regarding current state of schedule analysis, and areas for improvement.
2. How can operational performance metrics better capture contemporary operations?
    - Update performance metrics for information-age warfare. Start with some existing method, such as TASCFORM.
3. What model(s) best capture the trade-offs among program cost and schedule, as well as operational capability of fielded equipment? Can those models give insight into "troubled programs," with difficulties in cost, schedule, and performance?
    - Analyze previous case studies (e.g., from Kennedy School of Government) for insights into program schedule drivers.
    - Publish new case studies dealing with contemporary acquisition programs, based, among other things, on a thorough analysis of relevant SARs.
4. What estimating relationships best capture time to field new hardware? What schedule drivers are generally most important?
    - Based on available data, formulate and empirically test models with hypothesized schedule drivers.
    - Formulate and test prediction markets for cost and schedule problems.
5. Is there a prediction market design that would produce useful information about impending cost and schedule difficulties?
    - Design a prediction market for defense acquisition programs. Test it in an experimental setting.

While this is a very ambitious research program, it is readily decomposable into smaller projects. And that we were able to significantly advance the cost estimating state of the art suggests we can do the same with schedule estimation. Moreover, we'd likely find considerable insights from cost estimation methods useful for schedule estimation.

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Panel 5. Quantitative Analyses of Acquisition Outcome Drivers

Wednesday, May 4, 2016	
1:45 p.m. – 3:15 p.m.	**Chair: William Gates,** Dean, Graduate School of Business and Public Policy, NPS ***Consequences of BBP's Affordability Initiative*** Gregory Davis, Research Staff Member, Institute for Defense Analyses Lawrence Goeller, Defense Acquisition Analyst, Institute for Defense Analyses Stanley Horowitz, Assistant Director, Cost Analysis and Research Division, Institute for Defense Analyses ***Further Evidence on the Effect of Acquisition Policy and Process on Cost Growth*** David McNicol, Research Staff Member, Institute for Defense Analyses David Tate, Research Staff Member, Institute for Defense Analyses ***Preparing to Be Wrong*** Prashant Patel, Research Staff Member, Institute for Defense Analyses Michael Fischerkeller, Research Staff Member, Institute for Defense Analyses

William Gates—became Dean of the Graduate School of Business and Public Policy at the Naval Postgraduate School in February 2009. He received his PhD in economics from Yale University in 1984 and joined the NPS faculty in 1988. Prior to that, Professor Gates spent nine years as an economist at the Jet Propulsion Laboratory in Pasadena, CA. Professor Gates' recent research has focused on adapting auctions and other competitive business practices to defense applications, including defense acquisition, setting reenlistment/retention and voluntary separation bonuses, and setting assignment incentive pay allowances to attract volunteers to less-attractive military job assignments. His other research interests include cost–benefit analysis and cost growth and principal–agent issues in weapon system acquisition. Currently, Professor Gates is leading a team of NPS students and faculty members supporting the DoD's and DoN's talent management initiatives.

Consequences of BBP's Affordability Initiative

Gregory Davis—has been at the Institute for Defense Analyses (IDA) since 2006, conducting research on as broad a range of topics as he can find. Before coming to IDA he was an AAAS Science and Technology Policy Fellow in OSD(PA&E), where he was introduced to the world of national security. He holds a PhD in physics from the University of Rochester and a BA in physics with high honors from Kenyon College. Dr. Davis' career in particle physics began after the top quark discovery and ended too early to claim credit for the Higgs Boson, although he contributed to the collaborations that discovered both. [gdavis@ida.org]

Lawrence N. Goeller—has been a Defense Acquisition Analyst for 30 years. After obtaining his doctorate in physics from Rice University in 1986, he worked as a SETA support contractor for the Air Force acquisition community in the Pentagon, and then ASD/C3I, where he focused mainly on military satellite communications and terrestrial communications systems. From 2004 to 2012, he worked in government for OSD/CAPE/CA, where he produced Independent Cost Estimates for a number of ACAT 1D programs. He joined IDA in 2012. [lgoeller@ida.org]

Stanley A. Horowitz—is Assistant Director of the Cost Analysis and Research Division at IDA. Much of his work involves analysis of the Defense personnel compensation and management policies and the cost, measurement, and enhancement of readiness. Recently he has also been studying the use of inflation indexes in DoD. He has directed studies of Reserve Component readiness, Reserve costing, Reserve training, and Reserve volunteerism. In 2015, he received the Andrew J. Goodpaster Award for Excellence in Research from IDA. Horowitz was trained as an economist at MIT and the University of Chicago. [shorowit@ida.org]

Abstract

We studied the affordability constraints placed on acquisition programs since Better Buying Power was introduced by the Under Secretary of Defense for Acquisition, Technology, and Logistics in 2010. This initiative can be thought of as extending programming from five years in the future to the full life of each acquisition program—typically in excess of 25 years—and discussing the full plan at Defense Acquisition Board (DAB) meetings. We discuss the management issues involved in carrying out this initiative, along with the results it has had. The most significant outcome is that it has brought Service programmers to the Office of the Secretary of Defense's DAB process. Program managers now need to have their long-term plans approved by the programmers who verify that they fit with the long-term plans of the Service. While an Affordability Analysis is not a cost estimate, it cannot be any more precise than the numerous program cost estimates used to conduct the analysis.

Introduction

The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) affordability initiative formally began in 2010 as part of Better Buying Power (BBP) and has been in place, with some modifications, ever since. Each Major Defense Acquisition Program (MDAP) and Major Automated Information System (MAIS) program that is reviewed by the Defense Acquisition Board (DAB) is required to conduct an Affordability Analysis and present the results. The Acquisition Decision Memorandum (ADM) following the DAB reflects the analysis by placing affordability constraints on the program, which will be tracked to verify that the long-term spending plans of the Service remain affordable. Affordability Analysis was formally mandated in the latest version of Department of Defense Instruction (DoDI) 5000.02 in January 2015.

Affordability Analysis is an exercise in which the entire spending of the Service is projected over the lifetime of the program in question, usually in excess of 25 years. All other projected spending in the Service should leave space for the program in question under the expected top line, and the purpose of the analysis is to measure that space. Once that space is determined, many assumptions are made to generate two simple constraints: one for investment spending and another for Operations and Support (O&S). Since 2013, the responsibility for this analysis has belonged to the Service staffs. Generally, they present a "sand chart" that piles all spending by portfolios on top of each other, adding up to the expected Service topline, and a second sand chart that shows the expected spending for all of the programs in the portfolio that includes the program under consideration.

In 2009, many programs were ended early, including the Army's Future Combat Systems (FCS), the Marine Corps' new presidential helicopter, and the Air Force's F-22 Raptor—of these, only the F-22 entered service at all. The Honorable Ashton Carter was then the USD(AT&L) and the Honorable Frank Kendall III was his principal deputy. Carter went on to become Deputy Secretary of Defense in October 2011 and then Secretary of Defense in February 2015. Upon Carter's first promotion, Kendall became acting USD(AT&L) and was confirmed in May 2012, where he is today. These two men were the original proponents of BBP, the first edition (1.0) signed by Carter and the subsequent ones by Kendall. The BBP initiatives have had the backing of the same senior defense team for seven years, providing unusual leadership continuity.

The stated reason for BBP 1.0 was to reduce spending by improving efficiency. An additional reason was the idea that future rounds of cancellations like they had just experienced should not be repeated, and Affordability Analysis would help prevent it.

In this paper, we look at what has happened in the years since the DoD began mandating Affordability Analysis. So far, although a few programs have been cancelled, another wave like 2009's has not occurred, although another wave so soon would have been quite unexpected, regardless of the policy that was followed. There have been some other ramifications, and they are the subject of this report.

An ongoing tension exists within the DoD between programmers and the acquisition community, and Affordability Analysis is in the center of it. Programmers consider all spending over several years and make all of the pieces fit under the assigned top line in a process repeated annually. The USD(AT&L), as the chief acquirer, makes decisions about programs individually as they come up sporadically throughout the year. The USD wants to prevent having portfolios short on funds because that leads to stretches and cancellations, but his tools are decisions for individual programs. Affordability Analysis is an attempt by the USD to solve this problem with his tools.

Most of the research for this paper was conducted using Acquisition Decision Memoranda, handouts presented at DABs by program managers, and data archived in the Defense Acquisition Management Information Retrieval (DAMIR) System; all are marked "For Official Use Only (FOUO)." Consequently, there are very few actual data in this report. We do have a larger report that includes all of the data and, as of this writing, the distribution rules on it have not yet been set.

The Goals of Affordability (and Their Evolution)

Reducing Spending

The original Memorandum for Acquisition Professionals, *Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending*, dated September 14, 2010, was signed by Carter and came to be known as BBP 1.0. This section begins with a discussion of the vision for affordability expressed in the original memo. It is followed by a more lengthy description of the specific guidance therein, with emphasis on the establishment of affordability targets and requirements (later changed to affordability goals and caps).

The 2010 Guidance: BBP 1.0

BBP 1.0 presented a list of 23 principal actions to improve efficiency in the Defense acquisition process. The first five of these actions are associated with the "Target Affordability and Control Cost Growth" area. The motivation is stated in the first paragraph of the 17-page memo itself:

> To put it bluntly: we have a continuing responsibility to procure the critical goods and services our forces need in the years ahead, but we will not have the ever-increasing budgets to pay for them. We must therefore strive to achieve what economists call productivity growth: in simple terms, to DO MORE WITHOUT MORE. … Secretary Gates has directed the Department to pursue a wide-ranging Efficiencies Initiative, of which this Guidance is a central part. This Guidance affects the approximately $400 billion of the $700 billion defense budget that is spent annually on contracts for goods … and services. … We estimate that the efficiencies targeted by this Guidance can make a significant contribution to achieving the $100 billion redirection of defense budget dollars from unproductive to more productive purposes that is sought … over the next five years. (USD[AT&L], 2010, p. 1)

We can offer some initial observations based on this guidance. The first is that there is no statement of a formal intention to "revolutionize" defense acquisition; the goal is simply to achieve a specific amount of cost savings over five years that can be used elsewhere within the Department. How these savings or "redirections" are to be measured is left unstated. A second observation, which is modified elsewhere in this and later memos, is that in the fundamental acquisition tradeoff between cost and requirements, neither is to be favored (or sacrificed); instead, these redirections are to be achieved through improved efficiency—presumably through better management and oversight.

The body of the BBP 1.0 memo goes on to direct 23 specific actions, broken into five major areas:

- Target Affordability and Control Cost Growth
- Incentivize Productivity and Innovation in Industry
- Promote Real Competition
- Improve Tradecraft in Services Acquisition
- Reduce Non-Productive Processes and Bureaucracy

The first of these five, "Target Affordability and Control Cost Growth," addresses the principal subject of this paper: affordability. The other major areas will not be discussed in this document.

Affordability Vision, Circa 2010

We begin with the question, "What problem is the affordability approach of BBP 1.0 intended to address?" This question is not to be asked in a vacuum; it depends on how the specific goals of affordability (as expressed in BBP 1.0) differ from other policies and oversight mechanisms such as Nunn-McCurdy (N-M) thresholds. The memo offers the following definition: "Affordability means conducting a program at a cost constrained by the maximum resources the Department can allocate for that capability."

One proximate cause that led to BBP 1.0 was the cancellation of a number of programs after years of development and billions of dollars expended; chief among these was the Army's Future Combat Systems (FCS). The perception at the highest levels of the Office of the Secretary of Defense (OSD), and within the legislative and executive branches of the federal government, was that FCS in particular had been "unaffordable from the start" and that this was widely known even at program inception. The cancellation of this program was an embarrassment to the Army and to the DoD as a whole. When FCS was a going concern, no Affordability Analysis was conducted, and it is conceivable that the Army might have made it fit. However, Tate et al. (2007) documented that the costs of FCS would be far higher than was in the Army's plan. So, even if the official cost estimate might have made it look affordable, the better estimate would have made it more difficult to fit in the plan.

The vision of affordability, then—in the context of BBP 1.0—is at least in part to "prevent future FCSs." The unaffordability of FCS seems clear in hindsight, but how does one tell which programs that are currently being initiated are likely to become "future FCSs?"

In general terms, two concepts arose as part of the vision. The first was that the five-year planning horizon associated with the Future Years Defense Program (FYDP) was insufficient to prevent initiation of doomed programs: five years does not, in general, even cover the development phase of large programs. Since most of the program costs are incurred during the Procurement and O&S phases, the costs of these phases must be explicitly considered from inception and not pushed off into an out-year "bow wave." Key parts of the guidance, therefore, directed those responsible for managing the programs to consider the entire life cycle of the program—30 or 40 years—rather than "just" the FYDP.

The second concept was that programs should not be considered in isolation, that it must be recognized and acknowledged that, in constrained budget environments, cost growth in one program will affect the funding available for other programs. This, it was argued, must be formally recognized and tied to the question that the program manager (PM), the Service, and the OSD should all have in mind: At what point does the cost of a program (including the opportunity cost of other systems) exceed its value to the warfighters and taxpayers? Complicating matters is the well-known but widely disliked practice of stretching out the schedule of troubled programs—as well as programs that are not troubled, but that must contend with others that are. This lowers the per-year costs of each of these programs—this is the purpose of the practice—but generally increases the total costs and delays operational availability.

BBP 1.0's Guidance

BBP 1.0 has five "principal actions" related to the "Target Affordability and Control Cost Growth" area:

- Mandate affordability as a requirement.
- Drive productivity growth through Will Cost/Should Cost management.
- Eliminate redundancy within warfighter portfolios.
- Make production rates economical and hold them stable.
- Set shorter program timelines and manage to them.

The principal action mandating affordability gave rise to this paper, and we will look at it in depth. The other four mostly are seen as techniques for increasing productivity. We will also look at "Eliminate Redundancy Within Warfighter Portfolios" because it is the first mention of portfolios and is necessary for understanding how Affordability Analysis is conducted. BBP 1.0 also says,

> Requirements and technology level for the [program] will have to fit this schedule, not the other way around. *When requirements and proposed schedules are inconsistent, I will work on an expedited basis with the Services and the Joint Staff to modify the requirements as needed before*

> *granting authority for the program to proceed.* (USD[AT&L], 2010, p. 4) [Emphasis in original, and in all cases that follow]

This is not a focus on making certain that our warfighters have the best stuff possible, but rather trading that away to stay on schedule. Trading away requirements supports the central mission of BBP 1.0: reducing spending.

Mandate Affordability as a Requirement

After presenting the definition of affordability given earlier—"conducting a program at a cost constrained by the maximum resources the Department can allocate for that capability"—this principal action directs program managers to "treat affordability as a requirement before milestone authority [will be granted]." The memo continues:

> *Specifically, at Milestone A, my Acquisition Decision Memorandum (ADM) approving formal commencement of the program will contain an affordability target to be treated by the program manager (PM) like a Key Performance Parameter (KPP) such as speed, power, or data rate—i.e., a design parameter not to be sacrificed or compromised without my specific authority. At Milestone B, when a system's detailed design is begun, I will require presentation of a systems engineering tradeoff analysis showing how cost varies as the major design parameters and time to complete are varied. …* This analysis would then form the basis of the "Affordability Requirement" that would be part of the ADM decision. … this guidance will apply to both elements of a program's life cycle cost—the acquisition cost (typically 30 percent) and the operating and support cost (typically 70 percent). For smaller programs, the CAEs [Component Acquisition Executives][1] will be directed to do the same at their level of approval. (USD[AT&L], 2010, p. 2)

The guidance officially states that the PM must incorporate an affordability target as a KPP at the Milestone A DAB. Not stated here, but implied, is that the PM must also incorporate an affordability requirement as a KPP at the Milestone B DAB, and beyond.[2]

The guidance does not formally state, nor really even hint at, how these affordability goals and caps are to be calculated. Many different forms for the constraints were used by different programs at DABs, some of which were difficult for OSD to observe, but it has become standard for APUC or PAUC to be used to define the constraints when the program is buying many units, and total investment to be used for programs in which that is not the case.

Generally, the stated affordability definition—"conducting a program at a cost constrained by the maximum resources the Department can allocate for that capability"—requires that the Services quantify their allowable level of expenditures by capability area and fit all the programs in that area within that level. Since costs in a capability area cover many programs, tradeoffs must be considered in applying a cap to an individual program. It is difficult to answer the questions: At what point does the cost of (for example) a new helicopter become so high that you would rather cancel the program and either live with the

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[1] The Components are the military Services and other agencies.
[2] The terms "target" and "affordability requirement" were later replaced with "goal" and "cap," respectively.

old ones, or start over? To what extent would you rather cut back other programs in the portfolio? The idea of asking the PM and the Service to think about this before contract award is outstanding—but the answer depends on many factors, some of which change over time and only some of which are under the PM's control.

The requirement to determine and state affordability goals and caps is done to act as a trip-wire for cost growth sufficient to require a re-examination of Service priorities and available resources. It thus overlaps significantly with N-M reporting. We have no objection to this; the target audience is different, and it could prove more useful.

Eliminate Redundancy Within Warfighter Portfolios

This action introduces two concepts that are fundamental to the affordability vision. The memo text begins with the example of a program that the Army decided to cancel (thus freeing up resources for other Army programs) based on the fact that its capabilities could be met by other systems. It reads, in part,

> This was a classic value decision that could not have been made by looking at the … program in isolation. The Army had to look at the entire "warfighting portfolio" … to see that [the program's cancellation] would not, in fact, result in a major sacrifice of military capability. …
>
> *I intend to conduct similar portfolio reviews at the joint and Department-wide level with an eye toward identifying redundancies. … I am directing the components to do the same for smaller programs and report the results.*

This is the first mention of the term "portfolio" in the Better Buying Power guidance. As the concept of affordability evolved, portfolios of families of programs (e.g., "tracked vehicles" or "surface ships") became central. The so-called "sand charts" that must be presented in the affordability section of each DAB review are snapshots of these portfolios—often created by extending out indefinitely the spending in the last year of the FYDP.

The significance of requiring portfolio information to be presented at DAB reviews is not to be underestimated, and it represents something new in the standard OSD Acquisition process. Up until this time, the Milestone reviews were between one program manager and the appropriate level of acquisition executive, typically USD(AT&L) for Acquisition Category (ACAT) I programs. The requirement to discuss interactions with other programs, even if superficially, forces the PM to engage with the Service prior to Milestone approval. It should not escape notice that a representative of the Service programmer's office now has a seat at ACAT I Milestone reviews, which was not formerly the case.

Expecting offsets to come from within a single portfolio is less than ideal, but is a significant step. The ability to trade not just within but between portfolios, and even between Services, is a major theme in the book *How Much Is Enough?* (Enthoven & Smith, 2006) and ought to be. This is especially so because the portfolios used are almost always by platform type. For example, trucks and utility helicopters are in different Army portfolios (transportation and aviation), and while there are many missions where neither could replace the other, on the margins, trades between them might be the best choice. For a cross-service example, the Army's AH-64 Apache helicopters perform similar missions to the other Services' close air support aircraft.

The 2013 Guidance: BBP 2.0

The Memorandum *Implementation Directive for Better Buying Power 2.0—Achieving Greater Efficiency and Productivity in Defense Spending*, or BBP 2.0, which was signed by Kendall as the Under Secretary on April 24, 2013, incorporates a number of subtle changes with respect to BBP 1.0, dated two-and-a-half years earlier—some detailed changes and some important "vision implementation" changes. As this is neither the genesis of Affordability Analysis nor current, we treat it with less depth than the other two. There were two important changes from this iteration of BBP.

BBP 2.0 (USD[AT&L], 2013) states, "Constraints stem from long-term affordability planning and analysis, which is a Component leadership responsibility." Explicitly giving the setting of constraints to Component leadership was important. Now the Services would have ownership of the constraints as well as the USD who signed the ADM, guaranteeing that the spending plan brought to the DAB would be approved by Service leadership. Might this have helped prevent the FCS debacle?

Perhaps the most stunning quote in BBP 2.0 (USD[AT&L], 2013) is this: "If affordability caps are breached, costs must be reduced or else program cancelation can be expected." This may have been implied before, but in BBP 2.0, this threat became explicit. Kendall doubled down on the importance of this initiative. With the costs of breaching so clearly high, there might now be pressure not only on the program office to not breach the constraints, but also on the OSD, which might also feel compelled to not report a breach to prevent having to conduct such a severe action, which might not be warranted.[3]

In the September–October 2013 issue of *Defense AT&L,* Chad Ohlandt, a researcher at RAND then serving on a detail at the Acquisition Policy Analysis Center in AT&L, published an article called "Dispelling the Myths of DoD's Affordability Policy." The five-page article lays out in very broad terms what the Services are supposed to do and why. He wrote that "Affordability is all about using that knowledge to avoid starting or continuing programs that we cannot reasonably expect to pay for in the future." The timing of this article suggests that there were still questions within the acquisition community about the purpose of Affordability Analysis and how to do it.

New Priority: Technological Superiority

By 2015, Kendall's focus had shifted somewhat. Using funds efficiently was still important, but he was also concerned about technological dominance, and said so in BBP 3.0.

The 2015 Guidance: BBP 3.0

The memo *Implementation Directive for Better Buying Power 3.0—Achieving Dominant Capabilities Through Technical Excellence and Innovation*, henceforth referred to as BBP 3.0, was signed by Kendall on April 9, 2015. While the commitment to affordability remained, the tone changed significantly.

As was the case with BBP 2.0, BBP 3.0 (USD[AT&L], 2015) is brief—this time only a single page. It is accompanied by two attachments: a one-page Summary Page, and a 33-page attachment called "Better Buying Power 3.0 Implementation Guidance." We will again discuss three parts of this memo, although it will be a slightly different aggregation: the one-page memo itself, the one-page Implementation Guidance "Overview," and the half-page section of the Implementation Guidance that specifically refers to affordability.

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[3] We expect most parents recall making a threat that had to yield compliance … only to find themselves holding the pieces of a broken antique dish and now having to decide if they really are going to cancel the family vacation.

BBP 3.0 Memo Body

In this memorandum, Kendall writes, “There is more continuity than change in Better Buying Power 3.0. Core initiatives focus on: ensuring that the programs we pursue are affordable. … We will continue all of these efforts.”

On one hand, all of the guidance about the importance of maintaining long-term affordability, via requirements reduction if necessary, still remains in place: “New in Better Buying Power 3.0 is a stronger emphasis on innovation, technical excellence, and the quality of our products.” Here we see the emphasis on innovation, which is likely to discourage trading capability for affordability. With less trading, there might be more cost growth. Furthermore, an emphasis on innovation will lead to more ambitious programs that are more likely to yield cost growth. Cost growth from either source would squeeze other programs and can lead to unaffordable portfolios. On the other hand, ambitious programs sometimes fail, and if they are canceled they can open up affordability space as well.

BBP 3.0 Implementation Guidance: Overview

The Overview, page 1 of the Implementation Guidance, states,

> The theme that ties the content of BBP 3.0 together is an overriding concern that our technological superiority is at risk. Potential adversaries are challenging the U.S. lead in conventional military capability in ways not seen since the Cold War. Our technological superiority is based on the effectiveness of our research and development efforts.

Previously, the emphasis had been on reducing spending. This guidance is new.

BBP 3.0 Implementation Guidance: Achieve Affordable Programs

While there is a new focus in BBP 3.0, much of the guidance on affordability remains the same. Perhaps the most important change is, again, in tone: “ACAT I programs projected to exceed approved caps will undergo a Defense Acquisition Executive (DAE) review to determine appropriate corrective action” (Implementation Guidance, p. 2).The USD has not given up the possibility of cancelling programs that exceed their affordability constraints, but the apparent stakes have been lowered considerably.

Formal Guidance: DoDI 5000.02

In January 2015, Kendall signed DoD Instruction (DoDI) 5000.02, *Operation of the Defense Acquisition System.* It is consistent with BBP 3.0 and codifies that all of the affordability work that had been done before is now required along with many other changes to the process. The new instruction has a five-page enclosure entitled “Affordability Analysis and Investment Constraints,” which explains in some detail how Affordability Analysis should be conducted. It also contains a simple example of calculating a constraint for a fleet of trucks when it is assumed that the budget, inventory, capability, and unit cost all will be constant for the foreseeable future.

The Accomplishments of Affordability

Currently, a little more than a third of active acquisition programs have an affordability constraint, which implies that a complete Affordability Analysis was conducted. Those that do not have one are older programs and therefore have not been through a DAB recently. Most are post Milestone C and have been in production for a while.

The most common form of affordability constraint is a limit on Average Procurement Unit Cost (APUC). The next most common form limits Program Acquisition Unit Cost (PAUC). When BBP 2.0 was signed in April 2013 (discussed previously), responsibility for conducting the Affordability Analysis and creating constraints was explicitly given to the Services (BBP 1.0 did not indicate who was to be responsible for this). In the early days, affordability metrics were sometimes based on many other metrics, such as “unit recurring flyaway cost” in one specified year and “Average Ship Acquisition Cost.” Most programs now have metrics—discussed later in the Affordability Metrics section—that can be easily checked against a value reported in the annual Selected Acquisition Report (SAR), usually APUC, PAUC, or total investment.

This brings us, finally, to the fundamental question: To what degree have actual ACAT I programs adjusted their plans as a result of the affordability initiatives? The answer is: probably “a bit,” but it is difficult to tell.

The obvious place to look for the effect of Affordability Analysis is in requirements documents. We did look, and found no evidence that they were influenced by affordability constraints. We were unable to find any requirements documents written over the last five years in which a requirement was relaxed and was clearly done to make a program affordable. We also did not hear such stories from our interviews with members of the acquisition community; what we did hear were accounts of programs that changed how they met requirements or bought hardware. The biggest change we noted was the role of the Service programmers, often called “the 8s”[4] in the acquisition process.

While changes to constraints were fairly easy to find, changes to programs were much harder, for two reasons. First, the barrier between the Services and OSD precludes insight into how the Services, and the Program Offices, have actually reacted to the affordability guidance presented in BBP 1.0. Second, there are many factors that separate programs that stay on track from those that do not. These include contractor competence, program manager talent, number and magnitude of technical challenges, stability of funding, stability of requirements, and a variety of unknown unknowns—all in addition to affordability guidance. It is difficult for the OSD to sort out these effects.

Changing Constraints

If constraints change too easily, then they are not constraining. Kendall has said that he will modify affordability constraints if there is a change in quantity, so we wanted to see how often affordability constraints changed. While there is an official list of affordability constraints in DAMIR, that file does not include changes, only those that are currently in force. The Office of the Secretary of Defense (Acquisition Resources and Analysis) kindly gave us a spreadsheet that tracks all constraints ever levied. That file showed that there are 17 programs that have had their affordability constraints changed.

Of these 17, only four had one binding cap changed for another, as opposed to a non-binding goal replaced by either a new goal or cap. The four caps all changed on the same day in 2015. One of these four programs had suffered significant cost growth but was also deemed to be important enough to warrant a higher cap. One ADM raised the cap for that program and lowered the caps for three others in the same Service portfolio.

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[4] “The 8s” refers to the Army’s G8, the Air Force’s A8, and the Navy’s N8. Each of those is an office on the Service staff that programs funds over multiple years. The Navy’s N8 has delegated their role at DABs to N2/N6 or N9 for most programs; these offices also take a long view of their portfolios.

We do not know what underlying analysis went into these new caps. The ADMs that we read (all marked FOUO and therefore not publicly available) only show what the new and old caps were; we could not see if meeting the new constraints yielded a portfolio that was just as affordable as meeting the old constraints, because the constraints were in different base years and each constraint was associated with a different spending profile. Our experience suggests that these calculations were done by a staff member at the Service and were accepted by the OSD after some scrutiny. Still, this clearly shows that the OSD and the Service were thinking about affordability in terms of a portfolio of programs and not one program at a time.

Bringing in the Service Programmers

The new affordability mandates have brought representatives of the Service programming offices to the table for Milestone reviews. This has improved the communication between the programmers and the acquisition communities inside the Services. The long-term spending plans presented at a DAB in the past may not have been seen by the Service's programmer. Making the Services responsible for "owning" affordability forces the PMs and the programmers to interact on these issues far more than they have in the past.

Every year the DoD sends the SARs (prepared by program offices) and the President's Budget (PB; prepared by the Service programmers) to the Congress. Within the FYDP, these must agree. However, for years beyond the FYDP, there can be significant disagreement between what the two documents say. For example, both the F-35 and Joint Light Tactical Vehicle (JLTV) programs show discrepancies between the December 2014 SAR submission and the January 2015 PB submission. In the 2016 budget submission, the Navy reported total costs for the F-35C carrier variant of $55.66 billion and for the F-35B short take off and vertical landing variant of $47.66 billion, for a total of $103.32 billion over the life of the program. The December 2014 SAR lists the combined total at $86.8 billion. These numbers clearly show that even in the era of Affordability Analysis, the N8 that wrote the budget submission and the program office that wrote the SAR were not on the same page. Affordability Analysis will not fix that annual problem, but it does require agreement at DABs when both groups are in the room.

Affordability Analysis also demands longer term planning from the programmers. Before Affordability Analysis, only the five years in the FYDP received significant focus. Now they are required to plan over longer durations. The Army has a new tool called the Long Range Investment Requirements Analysis (LIRA), which they use for this purpose. LIRA tracks planned Army expenditures over many years, which is exactly what Kendall has required. Unfortunately for the OSD, the G8 has stated that the Army does not intend to grant access to LIRA to any other organization—this system is for Army internal use only, which means that while the OSD can look at the results of the Army's long-term studies, unlike with the FYDP, they will not be able to verify or validate the models or their inputs. We believe the other Services have similar systems and similar concerns about sharing data.

Ground Combat Vehicle

In 2011, the Army's Ground Combat Vehicle received Milestone A authority but no affordability constraint, and it appeared in PB 2014. But the program went no further in the acquisition process. The vehicle they planned to buy was longer and heavier than had been anticipated, which likely would have presented significant operational difficulties. However, affordability was also a problem, as it would have needed more than half of the expected funds in the combat vehicles portfolio. That this program went no further is a success for which Affordability Analysis can claim at least partial credit.

Management Considerations

To make Affordability Analysis as useful as possible, there are several factors that need to be thought through. While it has already yielded some wins for the DoD, as discussed previously, we think some improvements could be made. We also want to highlight what is working well.

Affordability and Cost Estimates

The relationship between the affordability of a program and the cost estimates of the programs in its portfolio should be considered. Affordability constraints are not cost estimates, and for any program that is going forward, the constraint must be greater than or equal to the cost estimate—otherwise it ought not to proceed. However, what cost data should be used for the other programs in the affordability analysis? A program can become unaffordable because cost estimates have risen for other programs in its portfolio.

Consider new program A which will be in a portfolio with incumbent programs Z, Y, and X. Each incumbent program has a cost estimate that should be in their SARs and budget submissions, but also an affordability constraint that is higher. Should A's target assume that Z, Y, and X each stay within their cost estimates or that they float up closer to their affordability targets? If only cost estimates are used, programs could see cost rises that make the portfolio unaffordable without any one exceeding its constraint. However, if the affordability targets are assumed, the space for program A is smaller and the difference between the cost estimates and the affordability constraints might be seen as a "slush fund" to be taken away from the portfolio. So far, it seems, the Services are assuming that all programs in the portfolio will stick to the cost estimates when doing their affordability analyses, making it possible that all programs could remain under their constraints and still yield an unaffordable portfolio.

Affordability Metrics

Affordability metrics should be designed so that the USD can be notified when something is happening that requires his attention but—as long as the program does not threaten the portfolio's affordability—allows it to continue without his involvement.

Investment Metrics

One natural way to make an affordability constraint would be to say that the Service may spend no more than X_j on the program in each year j from the present to the expected end of the program. This sequence of numbers is what a detailed Affordability Analysis yields. However, this has never been used and there are at least two reasons this ought not to be adopted. First, such a requirement would take away much discretion in future years. There may be good reasons to increase the spending in one year and decrease it in another: perhaps to get the capability in the field sooner or simply as a trade to increase efficiency by buying at a higher rate. Historically, this discretion has belonged to the Services, and Kendall has not suggested that he wants to take it away. Another reason not to adopt this requirement is that it is complicated to state. Kendall wants to describe the affordability constraint simply in an ADM, and while he has used tables with three numbers for the F-35, this approach would require a table with as many as 40 numbers in it, which might be unwieldy.

One simplification would be maximum annual obligations. The ADM would say, "This program may not exceed X dollars in any given year." This relates to affordability; as long as the annual obligations stay low, other programs will also be affordable. Because program funding generally is not flat, in some years the cap would be higher than the available dollars, but that would be sorted out by the Service programmers. Unfortunately, this metric not only allows stretches and increases to total cost, it practically demands them when there are cost problems. While this does relate to affordability, it is likely to be counterproductive.

As discussed earlier, AT&L and the Services have largely settled on the use of the APUC or PAUC[5] as the metric of choice for most programs because they can track it annually when the SARs are written. Also in use are metrics based on total investment or total procurement dollars. Typically, metrics based on totals are used for programs such as the GPS Operational Control System (OCX) or Space Fence, where the program is buying a single capability—not some integer number of identical (or more often similar) items like ships, missiles, or ground vehicles. Total expenditure metrics are also easily tracked by the SARs.

The primary problem with APUC and PAUC is that they are not closely related to affordability. If a Service has a problem with affordability, they can reduce the number of units they plan to buy or stretch the buy over more years. Either choice will decrease the costs in each year, making the portfolios more affordable. At the same time, these actions increase unit cost. While this appears to be a "bug," it is actually a "feature." It means that the USD will be alerted and forced to act when the Service makes a decision that increases unit costs in order to make a program fit in the budget.

A weakness of unit cost is that even for programs that are buying many units, the definition of "one" is not always clear. For example, the Army's ATIRCM/CMWS5F[6] program bought two different systems for the protection of helicopters. Some "units" were only CMWS systems and others included both. They also had some other accounting choices that affected unit cost (Balaban et al., 2010). The Navy's Integrated Defensive Electronic Countermeasures (IDECM) program is similar, with different "blocks" all included together. Some of the "units" include avionics systems and others include only replaceable decoys. In the Air Force's Global Hawk program, each unit was a single remotely piloted aircraft, so counting units was fairly straightforward, but the prices varied significantly from one variant to another because the payloads were very different, and some payloads were included in the Global Hawk program and others were not. It is not uncommon for the program office to be able to change the mix of what it plans to buy, which may make the unit cost look favorable even as costs rise.

Total expenditure metrics are similar to unit cost, but without the units in the denominator. Stretching the program has the same effect here as it does in unit costs. While very few programs that buy integer systems have used these, we think more should consider it. This metric has the benefits of average unit cost in that a stretch can trigger an affordability breach, but it is also more closely related to affordability. A drawback to total

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[5] APUC is the total procurement dollars in a base year divided by the total number of production units. PAUC is the total dollars in the program (RDT&E plus procurement) divided by the total number of units. Both metrics are set in Acquisition Program Baselines (APBs) when programs go through milestones. The PAUC and APUC are calculated each year and compared to the APB to determine if there is an N-M Breach. Using them for affordability targets introduces another use for these numbers. Each year, the PAUC or APUC is compared to the affordability constraint to see if the affordability constraint has been breached.

[6] The name ATIRCM/CMWS is a combination of two systems. One system is the Common Missile Warning System (CMWS) and the other is the Advanced Threat Infrared Countermeasure (ATIRCM).

expenditure is that programs that are successful and have their quantities increased then look unaffordable.

Another interesting consideration regarding choosing between total investments and average unit cost is in long-term plans. If the metric used is average unit cost, program offices are incentivized to show more and more units going out into the future because these units can show increased learning, thereby lowering costs, and they provide more units over which to spread development costs. Total investment encourages programs to report fewer units into the future. Because the N-M rules already use PAUC and APUC, the combination of the N-M rules and affordability rules would provide counter-balancing incentives.

O&S Metrics

As the dominant life-cycle cost of most programs, O&S costs are critical to maintaining affordability in the broadest sense.

Maintenance practices have changed significantly in the age of digital electronics, composite materials, parts obsolescence, and technology refreshes. We note that the lone example of O&S costs in the January 7, 2015, version of DoDI 5000.02 involves a low-tech example of a truck program (DoD, 2015). The problem of developing a practical methodology for estimating O&S costs for a modern, high-tech program at inception—that is, Milestone A—is larger than affordability, but the portfolio's affordability cannot be accurately estimated without estimating the O&S costs.

To accurately model future O&S costs, one must first be able to accurately determine these costs for current programs. Goeller et al. (2014), along with researchers in many other organizations, discovered that allocating O&S costs to programs is vastly more difficult than assigning RDT&E and Procurement costs, although it is improving. There are a number of reasons for this:

- Commonly, the O&S resources of several programs are combined into a single Program Element, making isolation difficult.
- Often O&S costs of one system—for example, a cruise missile—are actually funded out of another program—for example, a B-52 wing.
- The actual logs of expenditures are not all centrally located, despite large efforts to implement programs such as Visibility & Management of Operation & Support Cost (VAMOSC) and Air Force Total Ownership Cost (AFTOC).
- In some cases, maintenance is covered by a warrantee contract with the vendor that supplied the system—meaning that the cost to maintain that system is not only unknown to the government, it is contractor proprietary. This maintenance is funded with procurement dollars rather than Operation & Maintenance dollars and can be years away from when the maintenance is performed.
- Even where O&S costs can be isolated by program, the funding often represents what the maintenance organization was given—and not what they actually needed to satisfy all of their requirements. This problem can go in both directions—a plane might fly more hours than required because they have the funds or it may fly fewer hours than is considered optimal because there were insufficient funds to support more. Actual O&S costs are, in fact, a combination of what is required and what is provided.

All of these problems are being worked on, and even a casual look at the SARs today show that the work here is more sophisticated and careful than it was five years ago. There are other issues besides difficulty.

Placing a requirement on O&S costs for a program in development could provide poor incentives to the program office. Because actual costs are likely to be analyzed even on prototype hardware, suboptimal decisions about how to operate and test it might be made. Perhaps a truck must be tested in sandy conditions, where it is particularly difficult to maintain. Because of the high costs associated with this, a PM might feel compelled to run another meaningless long test in more benign conditions to lower the measured O&S costs.

It is not clear what the O&S constraints that have been set will do, and the way they are phrased makes them quite different. Some are totals over many years, which would provide different incentives than others that are on a per-year basis, so a program could meet the constraint in some years and not in others. In any event, once the O&S costs are the dominant cost in a program, the USD(AT&L) usually has very little say over the program's future. Would the Under Secretary want a new program started to replace a fielded system because the O&S costs are too high? This is unclear. Designing systems with an eye toward lower O&S down the road is wise, but it is not at all clear what an affordability constraint can accomplish.

Limits of Affordability Analysis

Current Bow Wave

The "bow wave" has been a concern in the Pentagon since at least the Kennedy Administration, when Secretary of Defense Robert McNamara's team created the FYDP to extend planning horizons. The FYDP's "out years" are not a perfect prediction of the future, but they do enforce a level of discipline to Service programmers and ensure that there is some possible way to continue five years out with the spending plans of today; there cannot really be a bow wave within five years, anymore. However, there can be a bow wave beyond the FYDP that will cause headaches for programmers when those bills come due; Affordability Analysis is intended to reduce that.

Today, some analysts perceive a large bow wave beyond the FYDP in large part because of big programs like the Navy's new ballistic missile submarines and the Air Force's long range strike bomber (LRSB; Gertler, 2015; Hale, 2016). In an ideal world, Affordability Analysis would make this bow wave impossible. These programs are both in the early stages, meaning there is significant uncertainty, but they are likely to be expensive. We will not assert that this proves Affordability Analysis has failed, but were Affordability Analysis not in use, the bow wave might be worse. More than half of all acquisition programs still have no affordability constraints. Affordability Analysis is a tool that may make the bow wave easier to deal with over time.

Affordability Games

In some ways, the acquisition system is a game, and the laws, regulations, and policy are the rules. Affordability Analysis and constraints are new rules, and they have led to some gaming by the Services and program offices. The JLTV is one case.

In Figure 1, the horizontal axis shows cumulative units delivered. Each black circle represents an annual lot delivery, and three of them are called out by year to orient the reader. The dots and the solid red line show what we call the "Cumulative Average Unit Cost." This is what the program's APUC would be if the program were executed until that point and then terminated. If the 2015 lot were purchased and nothing else, the program's APUC would be $835,000. This is normal; it is expected that the longer the program runs, the lower the APUC should be. Two things about this chart are particularly noteworthy. First, according to the black dots, the program will not meet the affordability goal set at Milestone B unless it continues producing according to plan until at least 2038. Second, starting in

2028, for no known reason, the cost estimate starts to fall below the fitted learning curve. Without this unexplained decrease, the JLTV would never meet its affordability target. The chart may make the differences look small, but in 2040, if the costs each year match the learning curve instead of the prediction, the total extra cost would be $300 million over 25 years.

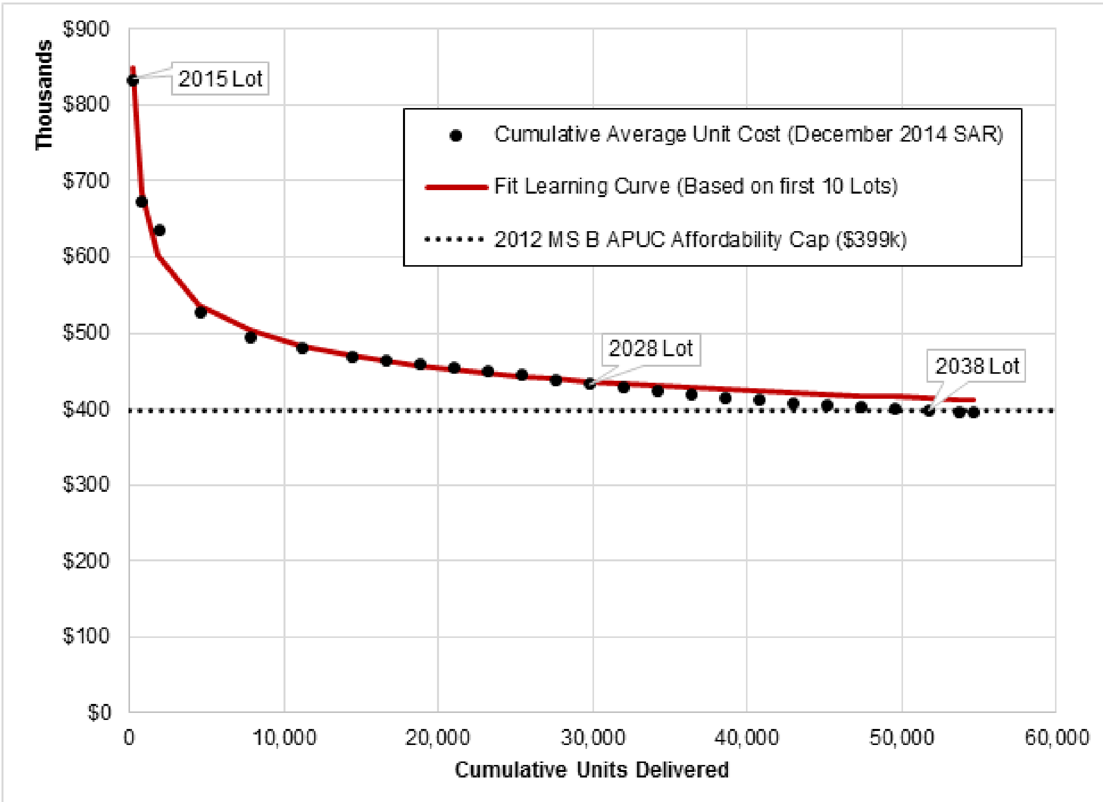

Figure 1. JLTV Costs in BY 2012 Dollars Based on the December 2014 SAR Estimate

The most recent PB submissions for JLTV show a significant decrease in cost with a new APUC of $333,000. This is probably good news for the Army and taxpayers. We do not know if the program has achieved this by finding efficiencies, reducing capability, or merely quantifying optimism. This change was not made to satisfy the existing affordability cap, as they met that the year before and it did not require a change. It is possible that the Army conducted its own internal Affordability Analysis and decided they needed to reduce the cost of this program. Whatever the case, it is clear that, for a while, the JLTV program office was showing some strange numbers, apparently to keep their program's costs below the cap assigned at Milestone B.

Innovation and Predictability

The first two BBP memos were about reducing spending. This is a laudable goal, but it cannot be the DoD's only one. BBP 3.0's full title includes the words *Achieving Dominant Capabilities Through Technical Excellence and Innovation*—which suggests another focus is coming back to the fore: The DoD should be acquiring state-of-the-art systems. Designing such systems is inherently difficult and unpredictable; it is also a long-standing American tradition.

Unfortunately, Affordability Analysis is predicated on knowing costs. Every program in the portfolio has a cost estimate. Those estimates are combined with the expected budgets to determine how much funding is available for the system under evaluation. If those cost estimates are highly uncertain, it is impossible to know how much extra funding is available. If any of those programs are pushing the state of the art, it is difficult to know what they will cost. FCS may have gone too far, but reaches in the past have yielded excellent results, and we need those from time to time. We present a historic system that shows how long this problem has been around.

Ian Toll's 2008 book, *Six Frigates: The Epic History of the Founding of the U.S. Navy*, tells of the Washington Administration's program to build six heavy frigates as the backbone of a new navy. "The estimated cost of construction, victualling, and three months' pay for officers and crew was $600,000. It was an estimate that would seem preposterous in retrospect." This was a huge sum at the time, dwarfing all federal expenditures other than the interest on the enormous national debt that had been accumulated during the War of Independence, and then there were huge cost growth and schedule slips besides.

The program was plagued with many of the issues we see today. Dramatic requirements changes—is their purpose to defeat the Barbary Pirates or fight the navies of France and Britain? Uneven funding—at one point, the Congress required that the program be reduced from six to three ships, but they then changed their minds again. Pork barrel spending (before the term was invented)—the six ships were built in six cities, a decision Mr. Washington made, knowing that he was trading away efficiency. The ultimate result, however, was similarly awesome: warships, including the USS *Constitution*, that were the most capable the world had ever seen.

We can and will build cutting-edge equipment in the future, and, in contrast to the recent past, the current environment is starting to encourage such development again. Even if we are always smart, such programs are difficult to predict: Some will cost more than expected, some will fail, and some will be tremendous successes. These programs are difficult to fit into 40-year models.

Conclusion

Affordability Analysis is a useful but limited tool for the OSD to try to make sure the Services are planning their acquisitions far into the future. Constraints are a part of that process, and allow the USD a rough monitor of the affordability of each Service's programs when they are not undergoing DABs. The direct effects are likely positive but have been modest.

The unexpected success is that this initiative has brought the Service programmers into the DABs. Several times in the life of each program, the program manager and his "eight" sit in the same room and look at the same long-term spending plan. We believe that this is unprecedented and a significant benefit for the Department of Defense.

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[7] Also referred to as BBP 1.0
[8] Also referred to as BBP 2.0

Further Evidence on the Effect of Acquisition Policy and Process on Cost Growth

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Abstract

Institute for Defense Analyses Paper P-5126 found that additional acquisition reforms after those introduced in mid-1969 by then Deputy Secretary of Defense David Packard did not significantly reduce cost growth on Major Defense Acquisition Programs (MDAPs). That conclusion—while interesting—is incomplete, as it leaves open the possibility that the Packard reforms reduced cost growth compared to the record of the 1960s, which is the issue examined in this paper. The paper finds that average cost growth of MDAPs that entered Engineering and Manufacturing Development during fiscal year (FY) 1970–FY 1980 was significantly lower than the average of those that entered during FY 1964–FY 1969. It also probably was significantly lower than the average during FY 1994–FY 2000 when Office of the Secretary of Defense (OSD)–level oversight of MDAPs was less stringent. These stand as instances of a significant association between changes in OSD-level oversight and cost growth. The paper also provides evidence that average cost growth in FY 1964–FY 1969 and FY 1994–FY 2000 was particularly high largely because the proportion of MDAPs that experienced extremely high cost growth was significantly larger than it was in other periods.

Introduction

McNicol and Wu (2014; hereafter referred to as P-5126) reported two significant findings. First, Major Defense Acquisition Programs (MDAPs) that entered Engineering and Manufacturing Development (EMD) during "bust" funding climates on average had much higher cost growth than those that entered EMD during "boom" climates. Second, the paper found that additional reforms after those introduced in mid-1969 by then Deputy Secretary of Defense David Packard had not significantly reduced cost growth.

As P-5126 noted, the latter conclusion leaves open the possibility that the Packard reforms reduced cost growth compared to the record of the 1960s. If in fact they did, the conclusion of that paper would have to be amended to read: The introduction in 1969 of effective Office of the Secretary of Defense (OSD)–level oversight of major acquisition programs reduced cost growth, but the additional reforms of the 1970s, 1980s, and early 1990s did not result in further reductions. Along the same line, it is of interest to revisit the mixed evidence P-5126 found on the effect on cost growth of less active OSD-level oversight of 1994–2000. The crucial question is whether there is statistical evidence that cost growth decreased when OSD-level controls were imposed and also increased when those controls were relaxed.

This is not simply an historical question, because the main features of today's OSD level acquisition oversight process remain those of the process installed by Packard in mid-1969. Moreover, the issue is salient now because of its implications for ongoing discussions of reform of the DoD weapon system acquisition process.

The database available for P-5126 did not contain cost growth estimates for any MDAPs that entered EMD during the 1960s, so that paper could not compare cost growth pre- and post-Packard. This paper uses cost growth data for programs that entered EMD in the 1960s from two previous studies (Jarvaise, Drezner, & Norton, 1996; Tyson, Om, Gogerty, & Nelson, 1992). It also uses a different cost growth metric and employs additional statistical tests.

The next section briefly describes the OSD-level acquisition oversight introduced by Robert McNamara in the mid-1960s and the changes made to it in 1969 by Packard. It is necessary to do this because the McNamara reforms are no longer part of the collective memory of the DoD acquisition community. Subsequent sections then turn to the statistical analysis and the conclusions it suggests. These sections assume that the reader has a working familiarity with acquisition process and policies. Those who do not may wish to consult Fox (2011). Readers who want a more detailed understanding of the data used and the way they were binned should consult Appendixes A and B of McNicol, Tate, Burns, and Wu (2016).

Origins of the OSD-Level Acquisition Oversight Process

From the creation of the National Security Establishment in 1947 through 1960, the OSD had no institutionalized process for the oversight of major weapon system acquisitions.[1] The origins of the OSD-level process for overseeing major weapon system acquisitions lie in initiatives taken by McNamara, of which the following are especially relevant for current purposes:

- Promulgation of policy on contract types
- Establishment of milestone decision points and the Development Concept Paper (DCP)
- Active oversight of ongoing MDAPs[2]

[1] The Secretary of Defense could, and on occasion did, act to cancel or initiate major acquisitions. Major acquisition programs were also subject to review during the budget cycle by the Office of the Assistant Secretary of Defense (Comptroller) and the Office of Management and Budget. Additionally, a major building block of McNamara's process began operating in 1959. See O'Neil and Porter (2011, p. 25).

[2] These categories are abstracted from Fox (2011, p. 35–45). Fox also notes that McNamara moved to consolidate acquisition functions in defense agencies—e.g., the agency that became the Defense Logistics Agency—and promoted the use by program managers of particular management tools such as PERT and earned value. In addition, there are several cases—most notably the F-111—in which McNamara played a very active role in the oversight of the program. These cases almost certainly are exceptions, but the literature survey done for this paper uncovered little about how the process worked in the more typical cases. Adding to the confusion, the sources consulted suggest that during

These initiatives were an embryonic OSD-level acquisition oversight process.

McNamara directed the use of Total Package Procurement (TPP) when it was judged to be practicable and, when not, Fixed Price Incentive Fee (FPIF) or Cost Plus Incentive Fee (CPIF) contracts.[3] By 1966, McNamara had concluded that TPP contracts were in fact not a practicable way to acquire major weapon systems, although acquisition policy apparently still had a tilt towards fixed price contracts, even for development. Packard picked up on this topic where McNamara left off. He ruled out the use of TPP and discouraged the use of FPIF for development contracts in favor of CPIF. (Cost Plus Award Fee may not have been included in the contracting play book yet.) As a general matter, Packard's policy was to match contract terms to the riskiness of the acquisition.

Packard's establishment of the Defense Systems Acquisition Review Council (DSARC) often is seen as the hallmark of his 1969 reforms. The notion of milestone reviews, however, entered the OSD-level acquisition process in 1964 with issuance of DoD Directive (DoDD) 3200.9, *Initiation of Engineering and Operational Systems Development*.[4] This original version of the directive set one point at which OSD—in principle, the Secretary of Defense—approval was required for an acquisition program to proceed. In 1965, a second decision point was added, and the Director, Defense Research and Engineering (DDR&E), instituted the precursor of the DCP, which, starting in 1968, was required to initiate any major development project. DDR&E coordinated initial DCPs with concerned OSD offices (and probably the Joint Staff and other Services; O'Neil & Porter, 2011) and acted as what now would be called the Milestone Decision Authority (MDA) for the initial DCP (Borklund, 1969). Once approved by DDR&E, the proposed new start went to the Secretary of Defense, although the sources consulted do not indicate whether it went as a separate action or as part of the Service's budget submission. It is also not clear which OSD official was the MDA for the second milestone.

Viewed against this background, the establishment of the DSARC was an evolutionary step. The Development Concept Paper was renamed the Decision Coordinating Paper (retaining the acronym) to reflect the broader scope of the new milestone definitions. The MDA at Milestone (MS) I and MS II was DDR&E; the Assistant Secretary of Defense for Installations and Logistics was the MDA for MS III. Decisions at the DSARC level were advisory to the Secretary and Deputy Secretary of Defense but, apart from exceptional cases, they probably reached that level by way of the Service's proposed budgets (and the Comptroller was the backstop enforcer of the requirement for milestone approval before a program could advance to the next stage).

The OSD had a much larger role in oversight of major acquisition programs under the DSARC process than it did pre-1961. The picture in contrast to the McNamara years is

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the McNamara years a major acquisition program might arise in either the Planning, Programming, and Budgeting System (PPBS) or in the acquisition process.

[3] Fox (2011, p. 38), following Adams, Murphy, and Rosenau (1983, pp. 19–20). A TPP contract is one that covers EMD, at least a significant portion of procurement, and at least part of the support of the system (e.g., depot maintenance).

[4] The first version of DoDD 3200.9 was issued in 1964. A revision that made provision for the Contract Definition Phase was issued July 1, 1965. See Glennan (1965, p. 12). O'Neil and Porter (2011, pp. 25–47) sketch how the process evolved and worked during the 1960s.

less clear-cut. On one hand, under the new acquisition directives, the Secretary of Defense, while retaining full legal authority over acquisition programs, would act through the established acquisition process except in extraordinary circumstances, which in comparison to cases such as the F-111 implied less OSD-level control over acquisitions. On the other hand, the DSARC had a greater substantive scope for the more typical program and was more tightly organized. For the large majority of major acquisition programs, then, the new DSARC process probably was more effective.[5]

The most consequential of Packard's 1969 reforms involved the substance of the milestones.[6] The 1965 version of the DoDD 3200.9 process had three phases. The first of these "was called concept formulation. During concept formulation OSD and the Service(s) involved assured themselves that they were buying the right system to meet real needs and that the technology was fully ready" (O'Neil & Porter, 2011, p. 30). Concept formulation typically was initiated by a Service but involved DDR&E and the Office of the Assistant Secretary of Defense for Systems Analysis (OASD[SA]), and included what would now be called an Analysis of Alternatives led by OASD(SA). It also apparently included what would later be called a Mission Element Need Statement as well as the main parts of an Acquisition Strategy and plans for oversight of the program as it proceeded.

Approval to proceed from the Concept Formulation phase authorized the Service sponsoring the program to fund at least one company to prepare a definitized contract proposal. The OSD (milestone) review of these proposals was the basis for award of a contract, usually to a single source, for development and procurement of the system. That is to say, the second of DoDD 3200.9's milestones combined what now would be called MS B and MS C authority.

Packard's reforms separated the decision to allow the program to enter EMD from the decision to enter the production phase (now MS C) and required OSD-level approval of each decision. Packard also established a new Validation Phase, which has at various times since been called Demonstration and Validation, Program Development and Risk Reduction and, currently, Technology Maturation and Risk Reduction. MS I (now MS A) authorized entry into this phase. DoDD 3200.9's Contract Definition phase was collapsed into the new and broader Validation phase. These changes were more revolutionary than evolutionary.[7]

The provisional judgment offered here is that Packard's acquisition reforms provide a plausible reason for expecting program outcomes—measured by cost growth, schedule slips, and performance shortfalls—to be better than what was achieved during the

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[5] Murdock (1974, pp. 155–179), disagrees with this judgment. Murdock is primarily concerned with Systems Analysis and resource allocation, but also comments specifically on the acquisition process. In particular, he notes that the new Decision Coordinating Paper did not provide "any mechanism for ongoing managerial control." This is accurate in that the Packard reforms placed management of the programs in the hands of the Services. It is incomplete in that the Services were responsible for staying within what would later be called the Acquisition Program Baseline, and the MDA was enjoined to act in cases in which they did not.

[6] Fox (2011, p. 57), provides a useful schematic comparison of the DoDD 3200.9 milestones and those of Packard's DoDD 5000.1/DoDI 5000.2.

[7] DoDI 5000.2, issued October 23, 2000, formally established MSs A, B, and C (replacing MSs I, II, and III) as the main decision points for an MDAP. The definitions are such that MS B is placed several months earlier in the process than MS II.

McNamara-Clifford years. This judgment does not imply that the DoD was doing a better job of deciding what to buy, but only that, as a result of the Packard reforms, the OSD became more effective in oversight of acquisition programs from MS II through the completion of procurement.

Statistical Analysis of Average Cost Growth

The statistical analysis presented here rests on definitions of periods delimited by major changes in acquisition policy and process. Two of these already encountered are labeled “McNamara-Clifford” and “DSARC.” Four additional acquisition periods are introduced below. Another part of the scaffolding of the analysis is funding climate. Two climates are distinguished—“bust” and “boom.” Three of the acquisition periods include both bust and boom phases and three were entirely in a single funding climate. Finally, the analysis rests on a set of conventions concerning which MDAPs are included in the database and the way in which cost growth is measured. See Appendix A of McNicol et al. (2016) for an explanation of the basis of the boundaries separating the successive acquisition periods and the funding climates. Appendix B of McNicol et al. states the conventions used in assembling the database and identifies the sources of the data used.

This section considers whether there are statistically significant differences in cost growth across the successive acquisition regimes in bust climates. The measure of cost growth used is Average Procurement Unit Cost (APUC). “APUC growth” means growth in APUC in program base year dollars normalized to the baseline quantity approved at MS B. Attention in this section and most of the one that follows is limited to MDAPs that entered EMD during bust periods because the interesting findings arise from the analysis of those periods. Results for boom periods are briefly mentioned at the end of the following section.

Table 1 reports average APUC growth experienced by MDAPs that passed MS II/B during each of the six acquisition regimes in a bust climate. It is important to bear in mind that APUC growth is computed by comparing the MS II/B baseline value for APUC—which can be thought of as a goal or a prediction—to the actual APUC, normalized to the MS II/B quantity[8] (or, for ongoing programs, to the projected APUC in the December 2012 Selected Acquisition Reports [SARs], which were the most recent available when this project began).[9] The APUC growth figures shown are the quantity normalized average for the MDAPs in that acquisition regime, binned by the year the MDAP passed MS II/B. This is done on the hypothesis that the acquisition policies and processes in place when an MDAP passes MS II/B, particularly the rigor of the MS II/B review, have an effect on the amount of cost growth it experiences in the future.

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[8] About three-quarters of the MDAPs that passed MS II/B in the period FY 1988–FY 2007 acquired at least 90% of their MS II/B baseline quantity. The median program acquired 100% and the average program acquired 111%. See McNicol et al. (2015, p. 7–8).

[9] We follow the convention of not including in the database any MDAP that was not at least five years beyond EMD (so that cost growth would have time to appear). The most recent SARs available when P 5126 was written were those for December 2012. Consequently, MDAPs that passed MS B during FY 2007 were the most recent included in the database.

Table 1. Average APUC Growth by Acquisition Regime for MDAPs That Entered EMD During a Bust Funding Climate

Acquisition Regime	Period (FY)	Average APUC Growth*
McNamara-Clifford	1964–1969	85% (20)
DSARC	1970–1980	39% (53)
Post Carlucci DSARC	1987–1989	44% (12)
Defense Acquisition Board (DAB)	1990–1993	32% (11)
Acquisition Reform (AR)	1994–2000	78% (27)
DAB post AR	2001–2002	113% (6)

Note. Numbers in parentheses are the number of observations in the cell.
* Normalized for changes in quantity.

A plausible reading of the averages in Table 1 is as follows: Packard's radically new acquisition phases and his more highly structured process were successful in reducing APUC growth, which fell to less than half the average level it had during the 1960s. Perhaps encouraged by Packard's success and public distaste for cost growth, acquisition reform efforts persisted, but had no appreciable further effect on average cost growth prior to the AR years. Reduction of OSD oversight during the AR era coincided with the return of average APUC growth to nearly its 1960s level. In sum, the Packard reforms of late FY 1969 appear to have reduced APUC growth; they were not significantly improved upon in this respect through the bust years that followed; and the AR years were associated with higher APUC growth, which may be related to a reduction of OSD-level oversight.

The question for the statistical analysis in an exploratory context is: Can cause reasonably be ascribed to the period-to-period changes in APUC growth, or are those changes more likely simply random fluctuations in the data?

It is useful to break this question into three parts. First, is the difference between the average APUC growth post Packard reforms (39%) and the average for FY 1964–FY 1969 (85%) statistically significant? The tests used found this difference to be statistically significant at the 9% level.[10] It is worth noting these reductions probably cannot be attributed only to the policies on contract type that Packard instituted. Four of the 20 programs in the data set for FY 1964–FY 1969 used TPP, and one used a Firm Fixed Price (FFP) development contract. The average APUC growth for these five contracts was 131%; the average cost growth for the remaining FY 1961–FY 1969 programs was 70%.[11] TPP and FFP contracts were less commonly used during FY 1970–FY 1980, but three of the MDAPs

[10] The Mann-Whitney U test rejected the null hypothesis (P = 0.093) that the samples for the DSARC period and the McNamara-Clifford period were drawn from the same population. (n_1 = 53, n_2 = 20, U = 394). A two-tail t-test assuming unequal sample variances found the difference in the means to be significant (p = 0.074). The Kolmogorov-Smirnov (K-S) test showed that APUC growth estimates for the McNamara-Clifford period probably are not normally distributed. The result of the t-test, even with the correction for unequal variances, is therefore somewhat suspect.
[11] For further discussion of TPP and FFP development contracts, see Tyson et al. (1992, Chapter X); McNicol (2004, pp. 53, 57–59); and O'Neil and Porter (2011, p. 29–31).

that passed MS II/B during this period used a TPP contract and one used an FFP development contract.

Second, are the differences in average APUC growth for the three periods between McNamara-Clifford and AR statistically significant? The tests used did not reveal any statistically significant differences between the averages of APUC growth in these three periods.[12] This implies that the lower average APUC growth (32%) of MDAPs that passed MS II during the DAB years (FY 1990–FY 1993), for example, cannot be attributed confidently to the full implementation of the DAB in 1990, because a change of this size has a considerable probability of occurring by chance.

Third, and finally, were the AR years associated with significantly higher average APUC growth? The results in this case were mixed. One test indicated that average APUC growth over the AR years was significantly higher than it was in FY 1990–FY 1993. That result, however, was not confirmed by another test.[13] This is similar to the result found in P-5126 and it occurs for the same reason—the variability of APUC growth in the AR period was too large for the differences in the means to be statistically significant.

The Bayesian analysis presented in Appendix C of McNicol et al. (2016) provides a stronger result for the AR years. It finds clear evidence that both the McNamara-Clifford period (FY 1964–FY 1969) and the AR years (FY 1994–FY 2000) had a much higher probability of high cost growth than did the bust climate portion of any of the three intervening periods (DSARC, Post-Carlucci DSARC, and DAB).

Returning to the interpretation of Table 1 offered above, the statistical analysis of average APUC growth supports two of the three points offered above—the Packard reforms did reduce APUC growth and the further reforms introduced post-Packard and pre-AR did not yield significant further reductions in APUC growth. The results on the third point are not clear-cut. The statistical tests reported above do not support attributing the high mean APUC growth during FY 1994–FY 2000 to acquisition reform, but the Bayesian analysis does support such an interpretation.

Statistical Analysis of the Proportion of Extremely High APUC Growth Programs

The preceding section looked for effects of acquisition policy and process in differences between successive periods in the average APUC growth of MDAPs that passed MS II/B during them. Although reasonable, framing the analysis in this way glosses over the possibility—explored in this section—that acquisition policy and process mainly work by influencing the proportion of MDAPs that experience extremely high cost growth.

Some relevant data are provided in Table 2. The average APUC growth figures are the same as those presented in Table 1. In addition, Table 2 reports the number of MDAPs

[12] We compared the three periods using Analysis of Variance (ANOVA). ANOVA failed to reject the null hypothesis that the observations in the three periods were drawn from identical normal populations. The K-S test found it highly likely that the samples were consistent with ANOVA's assumptions.

[13] A two-tail t-test assuming unequal variances found the difference to be significant. (P = 0.084.) The K-S test rejected the null hypothesis that the observations for FY 1994–FY 2000 were normally distributed. A Mann-Whitney U test did not find a significant difference between the average APUC growth of the AR years and that for the period FY 1990–FY 1993.

in the cohort that experienced at least three different levels of APUC growth—50%, 100%, and one standard deviation (S) above the sample mean ($\bar{X}$). The sample mean is 57.4% and the standard deviation is 85.4%, so one standard deviation beyond the mean is 143%. ($\bar{X}$ and S are computed for the bust periods only.) In what follows, MDAPs in the last of the categories will be called "extremely high cost growth" programs. These are arbitrary breaks adopted because they proved to be useful. Note that the figures for the number of systems in the right tail are not additive. For example, of the 20 MDAPs that entered EMD during the period FY 1964–FY 1969, 10 had APUC growth of at least 50%. Of these 10, six had APUC growth of more than 100%, and of the six, four had APUC growth of more than 143%.

The striking feature of the data in Table 2 is the paucity of extremely high cost growth programs after the introduction of the Packard reforms in 1969 and before AR. A total of 76 programs in our sample passed MS II during the 18 years of the DSARC, Post-Carlucci DSARC, and DAB periods in bust funding climates. Only one of these has an estimated quantity normalized APUC growth from the MS II baseline of at least 143%.[14] The other side of this coin is the greater frequency of extremely high cost growth systems in the McNamara-Clifford years and during the AR period. Four out of 20 programs of the McNamara-Clifford years showed extremely high cost growth, as did seven out of 27 MDAPs that passed MS II during the AR years.

Table 2. Average APUC Growth by Acquisition Regime and the Number of High Cost Growth MDAPs in Each Cohort, Bust Funding Climates

Acquisition Regime	Period (FY)	Average APUC Growth*	≥ 50%	≥ 100%	≥ $\bar{X}$ + S
McNamara-Clifford	1964–1969	85% (20)	10	6	4
DSARC	1970–1980	39% (53)	19	7	0
Post-Carlucci DSARC	1987–1989	44% (12)	4	3	1
DAB	1990–1993	32% (11)	5	1	0
Acquisition Reform	1994–2000	78% (27)	11	7	7
DAB post-AR	2001–2002	113% (6)	2	1	1

Note. Numbers in parentheses are the number of observations in the cell.
* Normalized for changes in quantity.

Statistical analysis gives substantially the conclusions suggested by inspection of the data in Table 2:

- The frequency of extremely high cost growth programs was significantly higher in the McNamara-Clifford years than in the DSARC period.

[14] This is the FGM-148A Javelin. Roland also had a very high APUC growth (308%) but was placed on the cancelled list. Roland was developed during the mid-1960s by a French-German consortium. In 1975, the U.S. Army decided to develop and procure a U.S. version. The planned procurement was severely reduced, but enough was acquired to equip one Army National Guard battalion. This does not fully meet the definition of a cancellation but was judged to be closer to a cancellation than to a truncation of the program.

- The frequency of extremely high cost growth programs also was significantly higher during the AR years than during the DSARC period.[15]

In contrast to the results of the preceding section, both the McNamara-Clifford period and the AR period, then, stand out as having a significantly larger proportion of extremely high cost growth programs.

Table 3 lists the extremely high cost growth systems. Thirteen of the 14 passed MS II/B during bust climates. Helicopters (2), satellite programs (3), and launch vehicles (2) are over-represented but do not dominate the list, particularly for the 1960s.

Table 3. Extremely High Cost Growth Systems

System Name	MS II/B FY	APUC
Bust Climates		
AGM-69 Short Range Attack Missile (SRAM)	1967	4.56
MIM-23 Hawk (Improved Hawk)	1965	2.07
Versatile Avionics Shop Test (VAST)	1968	1.83
M47 Dragon Guided Missile	1966	1.72
FGM-148A Javelin Advanced Anti-Tank Weapon System	1989	1.59
Space Based IR Sensor (SBIRS) High	1997	3.90
Evolved Expendable Launch Vehicle (EELV)	1998	3.42
Global Broadcast Service (GBS)	1998	2.60
Guided Multiple Launch Rocket System (GMLRS)	1998	2.15
H-1 Upgrades	1996	1.97
CH-47F (Improved Cargo Helicopter)	1998	1.81
Patriot Advanced Capability-3 (PAC-3)	1994	1.49
Advanced Extremely High Frequency (AEHF) Satellite	2001	4.78
Boom Climates		
Titan IV Expendable Launch Vehicle (ELV)	1985	1.49

We also explored whether the proportions of systems with cost growth of at least 50% or 100% might show the same pattern across acquisition periods as the extremely high cost growth systems. Analyses parallel with those just described, with observations of at least 50% APUC growth and 100% APUC growth showing no significant differences across the acquisition periods.

Appendix D of McNicol et al. (2016) presents results obtained from a technique (quantile regression) that compares the APUC growth distributions across acquisition regimes at several points. The comparison reported used deciles. The results were

[15] These statements are based on results for Fisher's Exact Tests: (1) $p = 0.004$ in the comparison of McNamara-Clifford to the DSARC years, and (2) $p < 0.001$ for the comparison of FY 1994–FY 2000 with the DSARC years.

consistent with those stated above in two respects: (1) There were no significant differences across the six acquisition periods in the central portions of the distribution (4th through the 7th deciles), and (2) the McNamara-Clifford and AR periods had significantly fatter right tails. It also is interesting to note that there is some evidence that the left tails of these two periods were somewhat fatter than those of other periods; that is, McNamara-Clifford had higher highs and perhaps higher lows.

Finally, we considered the pattern in average APUC growth across the six acquisition periods if the 13 extremely high cost growth programs are removed. The means of the truncated distributions are presented in Table 4. Pair-wise tests found the average APUC growth for the AR years (without the extremely high cost growth systems) to be significantly lower than the averages for the McNamara-Clifford and DSARC periods. None of the other differences was statistically significant and a test of the table as a whole did not reveal significant differences.[16] It appears, then, that the significant differences in average APUC growth reported in the previous section (Statistical Analysis of Average Cost Growth) stem from the significantly higher proportion of extremely high cost growth systems during the McNamara-Clifford and AR periods.

Table 4. Average APUC Growth by Acquisition Regime for Bust Funding Climates, Excluding Extremely High Cost Growth Programs

Acquisition Regime	Period (FY)	Average APUC Growth*
McNamara-Clifford	1964–1969	0.43 (16)
DSARC	1970–1980	0.39 (53)
Post Carlucci DSARC	1987–1989	0.34 (11)
DAB	1990–1993	0.32 (11)
Acquisition Reform	1994–2000	0.18 (20)
DAB post-AR	2001–2002	0.40 (5)

Note. Numbers in parentheses are the number of observations in the cell.
* Normalized for changes in quantity.

Appendix E of McNicol et al. (2016) presents an analysis of the boom case that parallels that of this and the preceding section for the bust case. There was no indication of significant association between acquisition period and average APUC growth and no indication of statistically significant differences across the acquisition regimes in the boom periods with the proportion of MDAPs in the right tail of the distributions.

Interpretation of the Statistical Results

The conclusions of the preceding section add a level of detail to the interpretation of the APUC growth data offered in the earlier section titled Statistical Analysis of Average

[16] Two-tail t-test of the differences of the means of two independent samples. ANOVA for the table as a whole yielded P = 0.45. K-S found four of the distributions to be normal. The exceptions were those for FY 1964–FY 1969, which K-S found to only marginally satisfy the test for normality, and FY 2001–FY 2002, which had too few data points to test.

Cost Growth. Packard's radically new acquisition phases and his more highly structured process were almost completely successful in preventing instances of extremely high cost growth and, for this reason, significantly reduced average APUC growth. The relaxation of OSD oversight of MDAPs during the AR era saw a return of a significant number of extremely high cost growth systems and, for that reason, average APUC growth returned to nearly its 1960s level. In sum, the Packard reforms of late FY 1969 worked well in essentially eliminating instances of extremely high cost growth and in that way reduced average APUC growth; they were not significantly improved upon in this respect through the early 2000s; and the relaxation of OSD-level oversight of the AR years was associated with a significant number of extremely high cost growth programs and, therefore, of higher average APUC growth.

The DAB process is a mechanism the Under Secretary of Defense for Acquisition, Technology, and Logistics can use to bring MDAPs into conformance with acquisition policy at MS II/B. Among other things, programs should have use the appropriate contracting mechanism, should have a sound test plan, should not proceed until the technologies to be employed are reasonably mature, should rest on realistic programmatic assumptions, and should be fully funded to a realistic cost estimate. It is not surprising, then, to find that (except in the AR years when OSD-level oversight was relaxed) the DSARC process and its successor, the DAB process, largely eliminated instances of extreme cost growth. This might be due to direct OSD-level modification of particular MDAPs. Alternatively, the certainty of reviews by the DSARC/DAB might have prompted the Services to avoid in the programs they proposed the characteristics that cause high cost growth. The best way to gain a deeper insight into the matter probably is to compare closely the AR period with the DSARC period and to examine the extremely high cost growth programs.

It is surprising that the statistically significant differences are found only for the extremely high cost growth systems. The description of the process certainly suggests that it also should have an effect on programs with smaller but still very substantial cost growth. This finding, however, does not necessarily imply that the OSD-level process has no effect. Instead, the statistical finding as such is that the fairly rudimentary OSD-level process of the McNamara-Clifford years did as well as its more elaborate successors except on extremely high cost growth systems.

It is, finally, important to note that this paper has been concerned almost entirely with cost growth of MDAPs that passed MS II/B in bust periods. A complete summary also would need to take into account parallel analyses for the boom periods and the comparisons of cost growth in bust and boom periods for a given acquisition regime. That task, however, is postponed to a subsequent study.

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Preparing to Be Wrong

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Abstract

Senior national security leaders face a diverse set of threats and greater uncertainty than in the past. They have called for adaptable or agile organizations and weapon systems to address this uncertainty. We focus on what this means for weapon system acquisition in terms of design, threats, and processes. Additionally, we show how metrics can be quantitatively used to help leadership understand the costs and benefits of adaptable and non-adaptable weapon systems.

Introduction

> *The United States is going to maintain our military superiority with armed forces that are agile, flexible, and ready for the full range of contingencies and threats.*
>
> —President Obama, January 5, 2012

Background

The imperative for U.S. forces to be adaptive to changing circumstances is driven by uncertainty regarding potential threats and operational environments, coupled with likely reductions in force structure and modernization accounts.[1] In many disciplines, time and time again, it has been demonstrated that expectations regarding the future are often wrong—sometimes very wrong, resulting in severe consequences. The Department of Defense (DoD) has not been immune from this tendency. The modesty these failures should engender is manifested in the importance accorded the idea of adaptability in recent pre-eminent strategic guidance documents.[2] Senior leaders are directing the DoD to prepare to be wrong. This perspective raises several questions: What is an appropriate conceptual definition of adaptability for the DoD? How does that definition apply to the different functions of the Department? And how could you operationalize and measure it in those functions? The first two questions have received some attention, the latter far less.

Not surprisingly, the concept of adaptability has recently been scrutinized and considered within a DoD context. An enterprise-level definition used by the Defense Science Board (DSB; 2011) is "the ability and willingness to anticipate the need for change, to

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[1] For example, now and in the future, there are no fewer than five interdependent domains for warfare: land, sea, air, space, and cyberspace. It has been rare in history for a new domain to be added to the short list of environments for warfare, and yet two such new domains, space and cyberspace, were added only recently (Gray, 2008–2009).
[2] See, for example, Office of the Secretary of Defense (2012) and Dempsey (2012).

prepare for that change, and to implement changes in a timely and effective manner in response to the surrounding environment" (p. viii). With this definition in hand, the DSB (2011, p. 30) reviewed the DoD enterprise and offered several recommendations, two of which motivated this paper: first, the call to align processes to the pace of today's environment—more specifically, to employ dynamic trade space analysis; and second, to reduce uncertainty through better awareness. Regarding the second, however, the approach taken here assumes that the DoD will make little progress in this regard and, therefore, should place equal if not more emphasis on explicitly accounting for uncertainty in its capability development and acquisition processes.

In Operation Iraqi Freedom and Operation Enduring Freedom, U.S. forces encountered an agile enemy adapting quickly in the tactical arena. In such operational environments, *survival* requires a local response. *Success*, however, depends on rapid response at all DoD enterprise levels (DSB, 2011, p. viii). In some instances, changes in the way our warfighters engage the adversary—modifying tactics, techniques, and procedures (TTPs) or concepts of operations (CONOPSs)—is the fastest, but not necessarily the most effective, response. In many cases, success depends on the introduction of new equipment, technology, or weapon systems.

The objective of this paper is to support warfighters in the achievement of success on the battlefield by enabling the DoD to assess the adaptability of current, in-design, and in-development weapon systems; determine how modernization upgrades may enhance or degrade adaptability; and design future weapon systems to be adaptable. In so doing, it seeks to offer an answer to the question: How do you operationalize adaptability in the DoD's technical capability base and its capabilities development process, and measure the degree to which the weapon systems resulting from those processes are adaptable (DSB, 2011, p. 36)?[3]

There are several incentives for focusing on weapon systems. Unlike other potential sources of adaptability (e.g., TTPs and CONOPSs), systems are long-gestation, long-lived assets whose design constraints prevail for decades. And these assets are costly—Research, Development, Test, & Evaluation (RDT&E) and procurement accounts combined are approximately one-third of the DoD's budget ($170 billion in 2013). Weapon systems are analytically tractable and amenable to rigorous examination and assessment, as they are subject to physical laws. Such analyses and assessments could serve as valuable inputs into strategies for developing adaptive TTPs, CONOPSs, skills, and organizations. For example, exposing operators to unutilized technical capabilities in current systems could encourage creative uses of the same.[4] Additionally, an assessment of current and in-

[3] The DSB recommended that development and acquisition planning include adaptability as a specific requirement metric.

[4] How many of us understand the technical capabilities of our smartphones? If more did, it is reasonable to expect that heretofore unknown novel uses would be identified. Consider the extraordinary number and types of apps that have been developed by the iPhone and Android user communities, for example.

development systems that finds a lack of adaptability might suggest that a cost-effective investment strategy for achieving adaptability *now* may lie in those other arenas.[5]

This paper presents a set of concepts, working definitions, a framework, and a quantitative approach for evaluating adaptability in current, in-design, and in-development weapon systems and for supporting dynamic trade space analyses to enable the design of adaptive future systems.[6] It proceeds with a discussion of three distinct but related concepts: responsiveness, flexibility, and adaptability.

Concepts and Working Definitions

These concepts are not new to the physical systems analytical community. Their discussion here, however, is novel in that the lens through which they are considered is that of the defense of the nation. The concepts of responsiveness, flexibility, and adaptability are taken from the dynamic system and control theory fields and modified for use by the DoD.

- *Adaptability* is a measure of the change in the state variable of interest.
- *Flexibility* is a measure of the effort required to transition from state x_0 to x_1.[7] It is inversely related (or negatively correlated) to the effort required to transition to a new state. A system that is flexible requires less effort to be reconfigured to reach state $x_{1.}$
- *Responsiveness* is a measure of the time required to transition from state x_0 to x_1. Responsiveness is inversely related (or negatively correlated) to the time required. A system that is responsive requires less time to transition between states.

Considering these concepts within the context of the paper's objective, working definitions for assessing against and designing to adaptability are as follows:

- *Adaptability* is a measure of the potential set of missions (or possible states within a mission space) that can be supported.[8]
- *Flexibility* is an inverse measure of the costs of adapting (effort, capability tradeoffs, and dollar costs); the greater the costs to adapt, the less flexible the weapon system.
- *Responsiveness* is an inverse measure of the time required to adapt (i.e., transition within a mission space or between missions).

These definitions are distinct but related and apply equally well to weapon systems and their physical subsystems. The acquisition community will likely see a relationship

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[5] For a study on skills development, see Burns and Freeman (2010). Alternative assessment approaches might be more appropriate for alternative acquisition strategies. Other strategies could be grounded in procuring larger quantities of single-purpose platforms or based on a systems-of-systems approach to capability development.

[6] The Joint Requirements Oversight Council (JROC) recently sent a memorandum to all DoD Components and Agencies to encourage requests for Key Performance Parameter (KPP) relief if KPPs appear out of line with cost-benefit analysis. A dynamic trade space analysis methodology would be a useful tool for informing such requests. See Joint Requirement Oversight Council (2013).

[7] For alternate definitions, see Ferguson, Siddiqi, Lewis, and de Weck, 2007.

[8] For a discussion of possible states within the same mission space, see Conley and Tillman, 2012.

between these terms and the traditional acquisition parlance of performance (*potential*), dollar cost, and schedule.

Assessing and Designing for Adaptability

Weapon systems and platforms typically remain in service for long periods, during which change often occurs—some of which is manageable and some not. Routinely dynamic international, operational, and fiscal environments should encourage the DoD to assess the adaptability of its current and planned weapon systems and ensure that future systems are designed to facilitate adaptation to changing circumstances.

Assessing and designing for adaptability should not be confused with doing so for robustness.[9] Even though each concept refers to the ability of a system to handle change, the nature of the change as well as the system's reaction to it in each case is very different. Adaptability implies the ability of a design to satisfy *changing requirements*, whereas robustness involves satisfying a *fixed set of requirements* despite changes in the system's operating environment (Saleh, Hastings, & Newman, 2003). An adaptable design is an active way to deal with future mission and/or operating environment uncertainty, as it includes core design resource margins assessed as most likely to be relevant across a wide range of potential futures. This approach is intended to minimize risks and maximize opportunities. Conversely, a robust design is passive, as it focuses on a system performing a fixed set of requirements satisfactorily regardless of the future environment (de Neufville & Scholtes, 2011, pp. 6, 39).

Framework for Assessment and Design

Designing for adaptability requires discussions—early in the capability development process—of mission requirements (i.e., capabilities), design resources, technical limitations, operational constraints, dollar costs, and their coupling to physical and engineering relationships. These factors comprise a high-order framework that can also be used for assessing the adaptability of current and in-development systems. Why these factors? System capabilities (e.g., range, speed, payload, force protection, probability of kill) depend on how design resources (e.g., internal volume, weight, power) are consumed and supplied by physical subsystems (e.g., engine, armor, fuel) and operational constraints (e.g., transportability weight limit, high hot limits) and are further bounded by fiscal constraints. These factors, while few in number, comprehensively describe a system from both a user and technical perspective. Their relationships are illustrated in Figure 1.

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[9] Designing for adaptability should also not be confused with designing for an incremental acquisition approach to support an evolutionary acquisition (EA) strategy. In EA, a fixed requirement is met over time by developing several increments, each dependent on available mature technology. See Enclosure 2 of OUSD(AT&L), 2008.

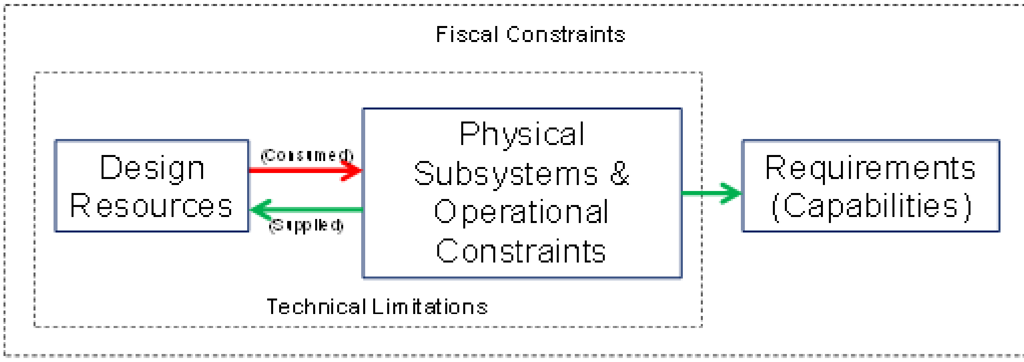

Figure 1. Relationships Comprising the Framework

Capability envelopes and adaptability draw from the same reservoir, (i.e., design resources and operational constraints). Consider, as an example, the potential adaptability and flexibility of a nominal infantry fighting vehicle (IFV) initially developed to support a cross-country terrain mission. The measure of adaptability will be the number of potential missions the vehicle could support, with a specific focus on assessing adaptability for urban operations. The measure of flexibility will be the dollar costs and tolerability of capability trades required in order to adapt.

Because this nominal vehicle was intended to traverse quickly across wide-open terrain, its original design sacrificed force protection for speed and range. Using the vehicle in urban operations would require significantly more force protection, thus requiring up-armoring. It is assumed that there are numerous bolt-on armor kits available at reasonable dollar cost that would satisfy this need; however, utilizing such kits would, in turn, consume additional *weight* and *power* design resources. That consumption would then result in reduced vehicle speed and range (capability tradeoffs).

The vehicle in this example could be assessed as adaptable, flexible, and responsive with regard to urban operations missions:

- Adaptable: the vehicle had unutilized design resources (*weight* and *power*) that enabled up-armoring to provide additional force protection required for a new mission (urban operations).
- Flexible: the dollar cost and capability tradeoff cost of adapting—force protection for speed and range—were reasonable and tolerable.
- Responsive: applying bolt-on armor is not a time-intensive activity.

The example highlights the fact that assessing adaptability is necessary, but not sufficient, for making decisions regarding potential system modifications/reconfigurations or initial designs. Flexibility and responsiveness should also be considered. Note that when adaptability requires capability tradeoffs, it should not necessarily be construed as negative, as the trades may be considered tolerable or even desirable. In the example, the loss of speed and range was deemed tolerable given the urban operating environment.

Focus on Design Resources

The framework suggests that design resource margins are the appropriate focus for both assessing and designing for adaptability. Why a margins-based approach when others have argued that modularity is the best route for "buying" adaptability? The focus on resource margins was not motivated by analytical or engineering preference; rather, it was driven by current defense strategic guidance and a review of the DoD's recent capability development and acquisition history.

Current guidance calls for developing "cutting edge" technical capabilities. This is not new guidance, as DoD has historically developed systems with the objective of achieving superior technical performance. But its implications are significant from an engineering perspective. Superior technical performance comes from integral designs, not modular ones. There is wide agreement on this point across engineering communities. Modularity comes with technical performance costs; it tends to favor "business performance" over technical performance (Holtta-Otto & de Weck, 2007; Whitney, 2004). It is not surprising, then, that a review of recent MDAPs (including some in the design phase) showed an overwhelming majority of the programs were/are being designed as highly complex, highly capable, integrated-architecture systems—for example, the F-22, F-35, DDG-51 Flight III, and GCV.

From an assessment perspective, then, the systems populating the assessment sample are almost entirely—if not entirely—integral rather than modular. From a design perspective, since it is assumed that the objective of retaining "cutting edge" capability will not be relaxed any time soon, integral designs will likely persist. Design resource margins are the most appropriate metric for measuring adaptability in integral systems and, therefore, are the focus of this approach.

With all of that being said, systems can certainly be designed as integral-modular hybrids. Even in that type of design, however, a focus on design resource margins is most appropriate for assessing or embedding adaptability. It is instructive to consider recent comments on the subject by Chief of Naval Operations Admiral Greenert (2012). In promoting payload modularity, Greenert argued the design of future platforms "must take into account up front the volume, electrical power, cooling, speed, and survivability needed to effectively incorporate new payloads throughout their service lives" (p. 4). Stated differently, the platforms *must be designed with margins* sufficient to handle future payloads.

The remainder of this paper applies the concepts, working definitions, and framework introduced above to the tasks of assessing the adaptability of current and planned weapon systems and supporting dynamic trade space analyses to enable the design of future adaptive systems.

Enhancing or Degrading Adaptability

As mentioned previously, capabilities and adaptability draw from the same reservoir of design resources, and those resources can either be consumed or supplied by physical subsystems. When assessing or designing for adaptability, uncertainty should be considered on the supply side (e.g., the state or trends of technology) as well as the demand side (e.g., the operating environment). On the supply side, it may be that future technological advancements in physical subsystems could supply future design resources to current platforms. For example, lighter armor could supply *weight* margin, and more efficient batteries could supply both *weight* and *internal space* margins. Considering the supply side enables assessments of the contributions that system upgrades would make to the adaptability of the system. Upgrades that consume design resources degrade future adaptability, while those that supply resources enhance it.

Proofs of Concept

Assessing the adaptability, flexibility, and responsiveness of current and in-development systems requires an understanding of mission requirements, key design resources and their utilization, physical subsystems, operational constraints, costs, and their interactions and relationships. In this section, several proofs of concept are offered to illustrate the assessment and design methodologies.

Designing and Dynamic Trade Space Analysis: Proofs of Concept

The approaches to designing for adaptability and supporting dynamic trade space analysis are nearly identical, absent the first item listed below:

- Decide whether the system will be developed to be generally or specifically adaptable. This requires explicit recognition of the level of uncertainty associated with the missions and/or environments in which the system is intended to operate.
- Identify the capabilities desired (and, more directly, the physical subsystems that will provide them) and the associated design resources that are either supplied or consumed by them.
- Develop a physics-based understanding of the interaction between capabilities desired, physical subsystems, and design resources.
- Identify operational constraints that limit performance.
- Identify costs.

In this section of the paper, a nominal IFV will be used to present two proofs-of-concept. The first example will demonstrate how adaptability can be rigorously considered in the design of a system. It will also highlight an important issue not yet addressed in our design discussion—strategic value versus tactical cost. The second example will illustrate a more complex dynamic trade space analysis. These proofs-of-concept offer stark examples of how adaptability and capability draw from the same reservoir (i.e., design resources and operational constraints). Table 1 details basic performance and technical assumptions that will be used in both proofs. The cells labeled “Trade space” in the Capabilities (Desired) column will be the focus of the dynamic trade space analysis.

Table 1. Nominal IFV Performance and Technical Assumptions

Performance		Capabilities (Desired)	Design Resource	Analytical Implication
Force Protection	Ballistic	Trade space	Weight	Integral ballistic armor must be able to passively defeat ballistic threats.
	Explosive	Survive an X class of IED and a Y RPG	Weight	Supports 45 pounds/square foot (psf) of integral underbody armor and 95 psf of add-on EFP armor.
Passenger Capacity		Trade space	Volume (length)	Interior volume scales based on human factors and number of passengers (32 cubic ft/person and 450 lbs/person).
Full Spectrum	Weight	Desire system to be reliable	Weight	Structure, engine, transmission, etc. must be sized to support add-on EFP armor.
	Power	Increased exportable power	Power, Weight, Volume	Has a 50-horsepower generator for electrical power.
Mobility		Speed of X up a grade of Y	Weight, Volume	Uses an Abrams-like track and has 15 horsepower/ton of engine power up-armored. Uses currently producible armor materials, engines, etc.
Lethality		Lethal to a similar class of vehicles	Weight, Volume	Has a manned turret. Reserved 2.1 tons for non-armored turret weight and 120 cubic feet of volume. Also, 2.5 tons for ammunition and fuel.
Electronics and Sensors		Similar to Abrams and Bradley	Power, Cooling, Volume (internal)	Has sensors/electronics similar to Abrams and Bradley.
Transportability (Operational constraint)		Transportable by C-17	Weight restriction	Combat weight limited to 130,000 lbs and must fit inside compartment E of C-17.
Adaptability		Proof 1: Specific Proof 2: General	Weight, Power	Proof 1: Embed design margin to allow vehicle to increase/change payloads in future without degrading current performance criteria. Proof 2: Embed design margin to support dynamic tradespace analyses for emergent future capabilities.

Designing for Specific Adaptability: Force Protection

This proof explores potential vehicle designs that could enable future increases in ballistic force protection, thereby ensuring the IFV will remain operationally effective in increased-threat environments. It is assumed that a number of alternative futures have been assessed, resulting in a bounded range of potential force protection requirements—STANAG Level 4 to STANAG Level 5.

For any potential design considered in this proof, the performance objectives listed in Table 1 (e.g., mobility and reliability) must not be compromised if/when future upgrades to the vehicle occur. A design that supports adaptability to increase passive armor in the future must ensure now that the *weight* design resource is properly calibrated and supplied to enable this future addition. The primary physical subsystems that supply the *weight* resource are suspension and structure (see the Full Spectrum row in Table 1). *Weight* also interacts with the mobility requirement and drives the engine size.

Referring back to the bulleted items that constitute the approach to designing for adaptability, the first three have been satisfied: specific adaptability was selected; desired capabilities and their associated physical subsystems and design resources were identified; and the interactions between them were understood. The remaining two items are addressed as follows: it is assumed that the C-17 will remain the heavy airlift vehicle for the foreseeable future; therefore, the transportability *weight* limit of the C-17 will be considered an operational (and, therefore, design) constraint. Regarding cost assumptions, see Patel and Fischerkeller (2013).

Two vehicle designs were considered, to illustrate the relationships between their relative adaptability, flexibility, and responsiveness. One ("Optimized Vehicle") represents a vehicle designed optimally to support the lower bound force protection requirement—STANAG 4—with no margin incorporated for bolt-on armor upgrades to increase the force protection level. The other ("Adaptable Vehicle") represents a vehicle designed (with regard to suspension and structure) to supply the maximum possible weight design margin to support the addition of future force protection capability; in effect, it was designed to support bolt-on steel armor upgrades to increase force protection to the upper bound force protection requirement—STANAG 5. Table 2 shows the comparisons.

Table 2. Performance and Relative 100th Unit Procurement Costs ($K of BY2012)—Optimized vs. Adaptable Designs

Operating Environment Force Protection Level Requirement	Optimized Vehicle Performance	Adaptable Vehicle Performance	Optimized Vehicle Cost Δ	Adaptable Vehicle Cost Δ
STANAG 4	Nominal	Nominal	Reference Vehicle	$897
STANAG 4 + 10% STANAG 5	Nominal	Nominal	$959 + RDT&E	$1,051
STANAG 4 + 20% STANAG 5	Nominal	Nominal	$1,784+RDT&E	$1,204
STANAG 4 + 30% STANAG 5	Nominal	Nominal	$2,502+RDT&E	$1,358
STANAG 4 + 40% STANAG 5	Nominal	Nominal	$3,133+RDT&E	$1,511
STANAG 4 + 50% STANAG 5	Nominal	Nominal	$3,691+RDT&E	$1,665
STANAG 4 + 60% STANAG 5	Nominal	Nominal	$4,188+RDT&E	$1,819
STANAG 4 + 70% STANAG 5	System failure	Nominal	N/A	$1,972
STANAG 4 + 80% STANAG 5	System failure	Nominal	N/A	$2,126
STANAG 4 + 90% STANAG 5	System failure	Nominal	N/A	$2,279
STANAG 5	System failure	Nominal	N/A	$2,432

The performance columns in Table 2 show that both vehicles perform equally well up through an operating environment requiring a force protection level of STANAG 4 + 60% STANAG 5. They do so, however, through very different means. While both vehicles carry steel armor at STANAG 4, the Optimized Vehicle's force protection capability is increased by replacing steel with titanium armor. This must be a zero-sum weight exchange because the optimized vehicle was not designed to carry additional weight. Conversely, the Adaptable Vehicle was designed to carry additional weight and has its force protection capability increased through additional bolt-on steel armor. At STANAG 4 + 70% STANAG 5, the maximum weight the Optimized Vehicle can carry is exceeded, resulting in system failure. This is not the case for the Adaptable Vehicle. Not only can it still operate effectively in that environment, it can also accommodate additional bolt-on steel armor to operate effectively up to STANAG 5.

Flexibility is captured in the chart via the relative (Δ) cost columns. At STANAG 4, the Optimized Vehicle has a lower relative unit procurement cost, however, as requirements increase, costs increase sharply relative to the Adaptable Vehicle because more expensive titanium armor is needed to maintain desired mobility and reliability. Embedding adaptability made for a more flexible vehicle, as its upgrade costs are less sensitive to changes in requirements.

Finally, inferred but not captured directly in this chart is responsiveness. Steel armor must be stripped before titanium armor is applied to the Optimized Vehicle. This is far more time-intensive than bolting on steel to the Adaptable Vehicle. The Adaptable Vehicle, then, is more responsive.

Designing for General Adaptability: Dynamic Trade Space Analysis

This general adaptability proof illustrates a far-wider range of possible system adaptations and their dependencies. The technical and cost assumptions presented for the nominal IFV (Table 1) will again be used in this proof. This analysis will assume that an adaptable IFV is designed with a 20% *weight* margin, 100% *electrical power* margin, and a 33% *power* margin relative to the optimized design, to support future unspecified capabilities for currently unknown missions and operating environments. *Weight* and *power* were selected because they dominate the design, as can be seen in their relevance to nearly every capability desired in Table 1. *Power*, in particular, was selected because experience tells that it can be traded in the future to support many different types of capabilities either directly or indirectly. As such, it is a core design resource that supports adaptability to many potential futures. As before, the performance objectives highlighted in Table 1 (e.g., mobility, reliability, and transportability) must not be compromised in any potential design.

In order to illustrate one iteration of a dynamic trade space analysis, Figure 2 shows the cost, force protection, number of dismounts carried, and urban accessibility (percent of urban areas accessible) trade space for a vehicle designed with a 20% *weight* margin. This is a high-order analysis, a level at which adaptable design analyses should commence. The models behind this analysis are typically called *screening models* and represent simple, transparent, and readily understandable representations of the physical interactions of the physical subsystems.[10] Screening models allow numerous iterations, to consider potential adaptable designs relatively quickly. They provide the ability to explore the art of the possible with minimal expense (time and dollars). The time for more complex, engineering point models is later in the design phase, not sooner (de Neufville & Scholtes, 2011).

This dynamic trade space analysis illustrates a number of opportunities for consumption of that 20% *weight* margin in the future. For example, high urban accessibility would come at the cost of squad size and force protection.

[10] The Institute for Defense Analyses has created a suite of screening models for GCV analysis. They were the basis for analyses presented in Figure 1.

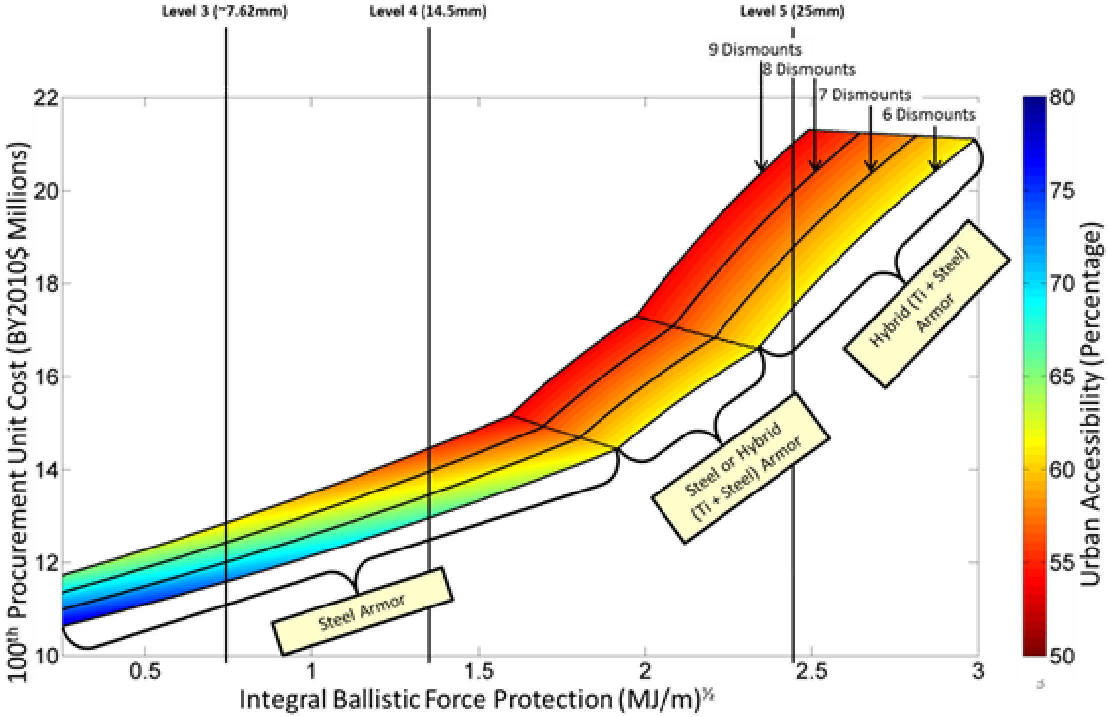

Figure 2. Dynamic Trade Space Analysis Supported by General Adaptability Design

Additional high-order analyses are also possible. Perhaps the 100% *electrical power* margin could be used for additional sensors and electronics. Would that affect internal volume available for dismounts? Would that additional weight consumption constrain future armor choices? Should mobility or transportability be traded? And so on. The multitude of questions one could ask is, again, a strong motivation for using these low-resolution analytical tools iteratively at the outset of the design process.

Strategic Value Versus Tactical Cost

The above analysis introduces an important aspect of designing for adaptability—*strategic value* versus tactical cost (i.e., nominal program costs). Equating the two, especially when planning for an uncertain environment, is a mistake. While the relative costs of the Optimized Vehicle at STANAG 4 are less, should future emergent threats demand higher force protection, the costs of up-armoring (and concomitant capability tradeoffs) arguably decrease its strategic value compared to that of the Adaptable Vehicle.[11]

As with insurance, the *strategic value* of a system should be assessed in terms of its contributions over all possible futures. Insurance and adaptability are justified by the value

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[11] Our example assumed a smooth design and development process. Often, however, requirements are changed post-Milestone B, which leads to cost growth. This cost is not considered in the example. In reality, then, it may very well be that tactical costs for optimized and adaptable platforms are often comparable as changes in requirements could more easily be addressed by adaptable designs (see GAO, 2011, pp. 14–15; Bolten et al., 2008).

they bring when relevant events occur, not by their continual use (de Neufville & Scholtes, 2011, p. 11). If we consider a "relevant event" as a future circumstance that requires the specification of new system requirements, several such events inevitably occur over the service lives of systems as new technologies or new threats emerge. At the right price, we willingly buy insurance as a hedge against uncertain future events. So, too should DoD as it faces an uncertain future. But how can decision-makers determine whether the price for adaptability is reasonable? Figure 3 illustrates a decision support chart that was constructed using the optimized and adaptable vehicle cost data presented in Table 2.

Selecting either an adaptable or optimized system is a "bet" on future trends rather than any one specific outcome. For this example, selecting adaptability is a "bet" that future adversaries will employ capabilities that would require significantly more force protection than is required in current systems. Conversely, selecting an optimized design is a "bet" that future adversaries will not employ capabilities that would require significant changes to current force protection levels.

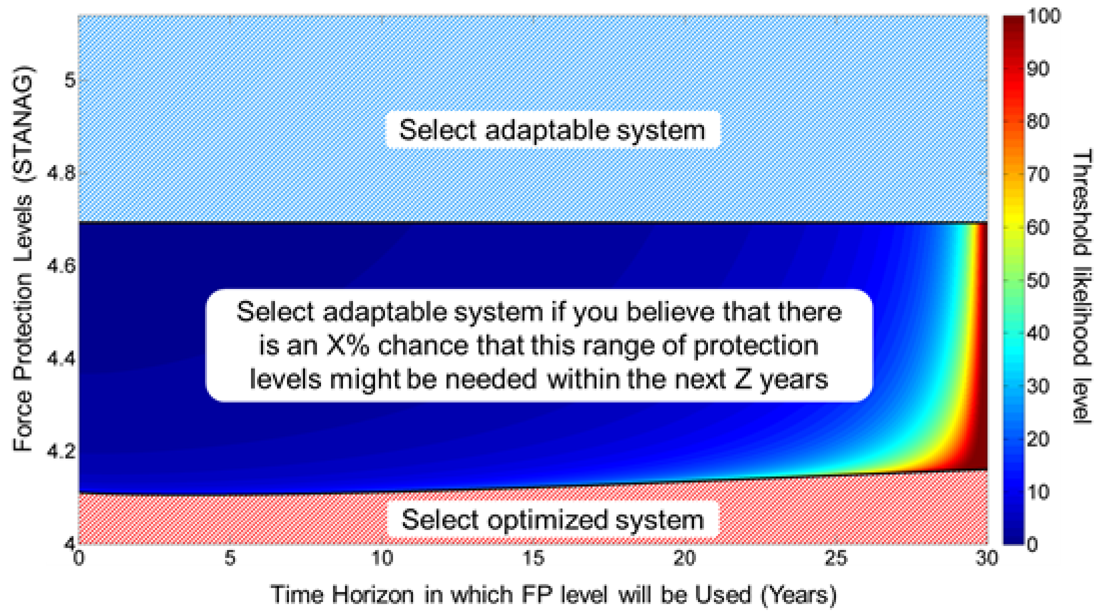

Figure 3. Capability Development and Acquisition Decision Support Chart

The following examples, constructed from referencing Figure 3, illustrate how the chart can *quantitatively* inform capability development and acquisition decisions. Specifically, we can describe the "bet" that leadership is making in more quantitative and rigorous terms.

An *adaptable* system provides the greatest strategic value if:

- Leadership is *confident* there is *at least a small chance* that adversaries will employ capabilities that would require force protection levels above STANAG 4.1, or
- The weight margin can be utilized for other emergent requirements.

An *optimized* system provides the greatest strategic value if:

- Leadership is *confident* that there is a *high chance* that adversaries will not employ capabilities that would require force protection levels above STANAG 4.1.

Costs from Table 2 are embedded in Figure 3 via a present value (PV) analysis of the optimized and adaptable systems. The Confidence Level contours (color code) represent the minimum annualized probability at which the adaptable system provides more value (e.g., lower PV).

The approach taken to create Figure 3 can be replicated to create similar capability development and acquisition support tools for other systems. It enables decision-makers to explicitly account for uncertainty in their choices and review the consequences of that accounting. While preferably brought to bear sooner, such an approach would be very beneficial at the Analysis of Alternatives decision point.

Which Resource Margins and How Much?

Effective implementation of a margin-based approach to designing adaptability into weapon systems requires *choosing which design resources* should be allocated margin (or not) and *calculating the size* of that margin such that additional system value in future uncertain environments could be realized by consuming (or supplying) them in those environments.

The designing-for-adaptability process presented previously informs resource margin decisions. In the proofs-of-concept, the capabilities were fixed values and the type and value of margin were known (the design resource of *weight* with the percentage of 20). In actual dynamic trade space analysis, all should be considered potential variables whose values (and also types, in the case of margins) would be determined for a final design through numerous exploratory analyses. Numerous iterations allow the analysts, operators, and other stakeholders opportunities to consider many different approaches to a design that satisfies known requirements and enables adaptability for unknown future requirements. The creative value of multiple iterations cannot be overstated and again, highlights the importance of using low-resolution screening models early in the design process.

As trade space within and across capabilities and margins is being explored, Key Performance Parameters (KPPs) grounded in long-term forecasts in which confidence is moderate to low should be considered first for trade as the design team seeks to embed a margin for potential future requirements. One need only perform a cursory review of a handful of System Threat Assessment Reports (STARs) to see several examples of moderate and low confidences being cited. Returning to a point made earlier, routine failures to accurately forecast futures should engender modesty. That modesty can be operationalized as design margins to increase the potential strategic value of a platform. A similar perspective could be taken when reviewing KPP threshold (required) and objective (desired) values. To the degree the differences in those values are based on different levels of confidence in near- vs. long-term forecasts, that delta should be considered trade space—plan for the relative certainty, prepare for the uncertainty.

This approach can and should, where appropriate, be complemented by experience. For example, the Navy incorporates power margins on ships as part of their service life allowances based largely on historical experience. Similarly, based on mission experience, the National Aeronautics and Space Administration (NASA) incorporates into all flight systems a 10% margin for power and 5° C thermal design margin to respond to post-launch uncertainties associated with the mission and environment, respectively (NASA, 2009, pp. 13, 82).

Conclusion

Adaptability, flexibility, responsiveness—these terms need not be empty descriptors of the force desired by the White House and the DoD. They can be operationalized as metrics against which the force can be assessed and towards which it can be designed. Current operational and fiscal realities call for an approach to enable those efforts. Absent one, the DoD risks stumbling forward into an uncertain strategic and operational future, possibly making significant force structure, modernization, and future weapon system design decisions that, at a minimum, do nothing to enhance the force's adaptability and could, quite possibly, facilitate its degradation.

A general utilization assessment of the current force's major systems' design margins would offer insights into the potential for adaptability to emergent circumstances in an uncertain future environment. A more focused look at those margins deemed most relevant to future missions and operating environments in which high confidence exists also would yield valuable and actionable insights.

Designs for incremental modernization programs or entirely new weapon systems, which are expected to be in the field for decades, should explicitly incorporate adaptability. When considering upgrades or new designs, the perspective of strategic value vs. tactical cost should rule the day. It was noted previously that the DSB recommended an adaptability requirement for all future systems. The DoD enterprise is populated by systems engineers, operators, and other stakeholders who are both intelligent and fallible; consequently, unanticipated threats and opportunities often emerge late in the course of development (post-Milestone B) and long after initial fielding. But changes in requirements need not be as cost-imposing as they often are; adaptable designs could provide opportunities to apply those costs toward achieving greater strategic system value by enabling systems to be modified to execute currently unknown missions and operate in currently unknown environments. Where uncertainty is abundant, an adaptability requirement should be non-negotiable—it must be a "need-to-have," not a "nice-to-have."

Preparing for an uncertain future is not an insurmountable challenge for the DoD. Significant RDT&E and procurement decisions that take adaptability into account can be informed by rigorous analyses and assessments. We hope this paper has offered useful concepts, working definitions, and approaches to inform an intelligent path forward that enables the DoD to prepare to be wrong.

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Panel 6. Considerations in Software Modeling and Design

Wednesday, May 4, 2016	
1:45 p.m. – 3:15 p.m.	**Chair: John Zangardi,** Deputy Assistant Secretary of the Navy for Command, Control, Communications, Computers, Intelligence, Information Operations, and Space ***Achieving Better Buying Power for Mobile Open Architecture Software Systems Through Diverse Acquisition Scenarios*** Walt Scacchi, Senior Research Scientist, Institute for Software Research, UC Irvine and Thomas Alspaugh, Project Scientist, Institute for Software Research, UC Irvine ***Architecting Out Software Intellectual Property Lock-In: A Method to Advance the Efficacy of BBP*** Maj Chris Berardi, USAF; Bruce Cameron, Lecturer, MIT; Daniel Sturtevant, CEO, Silverthread, Inc.; Carliss Baldwin, Professor, Harvard Business School; and Edward Crawley, Professor, MIT ***Navy Mobile Apps Acquisition: Doing It in Weeks, Not Months or Years*** Jacob Aplanalp, Assistant Program Manager, My Navy Portal, PEO EIS; Dave Driegert, Senior Technical Advisor, PEO EIS; Kevin Burnett, Technical Manager, PEO EIS; and Kenneth Johnson, Technical Director, PEO EIS

John Zangardi—was appointed as Deputy Assistant Secretary of the Navy, Command, Control, Communications, Computers, Intelligence, Information Operations, and Space (DASN C4I/IO and Space) in March 2011. In support of the Assistant Secretary of the Navy (Research, Development, & Acquisition), Dr. Zangardi is the principal Department of the Navy advisor for C4I, IO, space (including space-related acquisition), business enterprise acquisition, and information technology and resources management. In his oversight role, he coordinates with key stakeholders to maximize alignment with Navy and Marine Corps needs. He is a native of Scranton, PA, and a graduate of the University of Scranton. Dr. Zangardi was awarded a Master of Science degree from the Naval Postgraduate School and a doctorate from George Mason University. Commissioned through the Aviation Officer Candidate School, he was awarded Naval Flight Officer wings in 1983. Operationally he served with Patrol Squadron 6, USS *Abraham Lincoln* (CVN-72), Patrol Squadron 8, and Patrol Squadron 26 as Commanding Officer. Ashore, his assignments include Patrol Wings Pacific, Joint Staff (J6) as Lead Budget Analyst, Navy Staff (N78) as Assistant for Programming and Budget, and Navy's Office of Legislative Affairs as Director for Naval Programs. After leaving active duty, he was employed by BAE Systems Electronics and Integrated Systems operating group, Arlington, VA. He was assigned as Director for Maritime Systems and Requirements. In January 2008, Dr. Zangardi was selected for appointment to the Senior Executive Service (SES) with assignment as Deputy Director for Warfare Integration Programs (N6FB), within the Directorate for the Deputy Chief of Naval Operations Communications Networks (N6). With the stand-up of the Deputy Chief of Naval Operations Information Dominance (N2/N6), he was assigned as Director for Program Integration and as Deputy to the Director for Concepts, Strategy, and Integration.

Achieving Better Buying Power for Mobile Open Architecture Software Systems Through Diverse Acquisition Scenarios

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Abstract

The U.S. Defense community denotes an ecosystem of system or software component producers, system integrators, and customer organizations. For a variety of reasons this community now embraces the need to utilize open source software (OSS) and proprietary closed source software (CSS) in the system capabilities or software components it acquires, design, develops, deploys, and sustains. But the long-term transition to agile and adaptive capabilities that integrate bespoke or legacy, OSS and CSS components, has surfaced a number of issues that require acquisition-research-led approaches and solutions. In this paper, we identify and describe six key issues now found in the Defense software ecosystem: (1) unknown or unclear software architectural representations; (2) how to best deal with diverse, heterogeneous software IP licenses; (3) how to address cybersecurity requirements; (4) challenges arising in software integration and release pipelines; (5) how OSS evolution patterns transform software IP and cybersecurity requirements; and (6) the emergence of new business models for software distribution, cost accounting, and software distribution. We use the domain of command and control systems under different acquisition scenarios as our focus to help illuminate these issues along the way. We close with suggestions for how to resolve them.

Introduction

The U.S. Defense community, which includes the military services and civilian-staffed agencies, is among the world's largest acquirers of commodity and bespoke (custom) software systems. The Defense community further extends its reach and influence on a global basis through national treaties and international alliances through enterprises like NATO. The Department of Defense (DoD), other government agencies, and most large-scale business enterprises continually seek new ways to improve the functional capabilities of their software-intensive systems while lowering acquisition costs. The acquisition of open architecture (OA) systems that can adapt and evolve through replacement of functionally similar software components is an innovation that can lead to lower cost systems with more powerful functional capabilities. OA system acquisition, development, and deployment are thus seen as an approach to realizing Better Buying Power (BPP) goals for lowering system costs, achieving technical excellence, enabling innovation, and advancing the acquisition workforce (Kendall, 2015).

Bespoke software systems are produced and integrated within the Defense community. In addition Defense system acquisition or procurement enterprises also obtain wares from most non-Defense industry providers of software systems, applications, or services (i.e., the mainstream software products or services industry). The acquisitions often entail software procurement or development contracts valued in the millions to hundreds-of-millions of dollars (Myers & Obendorf, 2001). At this scale of endeavor and economic value, certain kinds of software engineering (SE) research problems arise that are not visible or are insignificant in smaller scale SE R&D efforts.

In this paper, we focus attention to the slice of this world that focuses on the development and deployment of *software-intensive command, control, communication, cyber and business systems* (hereafter, C3CB). We further limit our focus to the most general software elements found in C3CB system capabilities; for example, software infrastructure components, common development technologies supporting app/widget development, and mission-specific apps/widgets, in particular widgets produced with the Ozone Widget Framework (Conley et al., 2014). OWF (now called the Ozone Platform or OZP) was initially developed by the NSA, though is now identified as Government OSS (GOSS) and supported by a third-party contractor. It is widely used within the Defense and Intelligence community. The growing importance of OZP within the Defense community has directed focus to the production and integration of C3CB system capabilities to be assembled using it. This focus drives open discussion of and broad exposure to emerging research issues that arise from the production and integration (or software engineering—SE) of software components, and these in turn raise challenges for acquisition management and personnel. Specifically, we draw attention to issues surrounding the development, integration, and deployment of *multi-version* and *multi-variant software systems* composed from various open source software (OSS) and proprietary (CSS) software elements or remote services (Scacchi, 2002, 2010), eventually including recent efforts to support Web-compatible services and/or mobile devices in C3CB. This focus also provides exposure to future C3CB system capabilities composed from apps acquired through various acquisition regimes, including apps downloaded from different Defense community app stores (George, Morris, O'Neil, et al., 2013; George et al., 2014).

Recent Scenarios for Acquisition of OA Software Capabilities

Interest in open source software (OSS) within the U.S. Department of Defense (DoD) and military services first appeared more than 10 years ago (Bollinger, 2003; Scacchi & Alspaugh, 2008). More recently, it has become clear that the U.S. Defense community has committed to a strategy of acquiring software-intensive systems across the board that require or utilize an "open architecture" (OA) which may incorporate OSS technology or OSS development processes that can help Defense customer organizations to achieve better buying power (Kendall, 2015). Why? Among the reasons identified is the desire to realize more choices among software component producers or integrators, as producers and integrators often act in ways that lock their customer organizations into overly costly and sometimes underperforming and difficult to sustain systems. One approach being explored focuses attention to agile and adaptive OA software components that are acquired and assembled (integrated) as C3CB system capabilities (assembled capabilities or AC) that are acquired and shared by multiple parties via independent "lines of efforts" acting within an ecosystem of producers, integrators, and consumer organizations (Reed et al., 2014; Scacchi & Alspaugh, 2015). The goals of the AC approach include a shorter delivery and update cycle for mission components and an improved cybersecurity posture. We explain this approach as follows.

The AC approach contemplates independent acquisition lines of effort for different types of OA software components that can be acquired from independent providers:

- *Mission Components* enable C3CB processes and present common operating picture data to end-users. Mission components may be realized as apps/widgets that may be deployed on mission-specific platforms, including those operating on secured Web/mobile devices.
- *Common Development Technology* provides AC development tools and common run-time applications servers that support the mission components. The servers are bundled with Shared Infrastructure, as follows.
- *Shared Infrastructure Components* combine local/remote application servers and data repositories with networking services and platforms.

Assembled capabilities therefore represent alternative configurations of mission-specific components that are produced with common development technology for deployment on shared infrastructure technology platforms.

Independent Lines of Effort (LOEs) by single or multi-party acquisition for mission components, common development technologies, or shared infrastructure components, are expected to greatly accelerate development and fielded deployment. This acceleration entails tradeoffs in increased dependency and risk management. Independent LOEs enable at least three alternative scenarios for acquiring OA C3CB system capabilities.

1. *Use current strategy and acquisition capabilities*. Here there is no focus on AC that utilizes mission components, common development technologies, or shared infrastructure components.
2. *Augment deployed systems with mission components and common technologies*. Augmentation is either for (a) new mission functionality; (b) modernization "in place" so that part of the original system is deprecated as the new mission components are delivered; or (c) infrastructure replacement over parts of original system that may be combined with modernization efforts.
3. *Focus efforts on production, integration, security assurance, and deployment of mission components that use common technologies and shared infrastructure, and that can be assembled into different ACs*. This can entail production, integration, and delivery of all mission components in one contract vehicle; or alternatively, the delivery of mission components partitioned across multiple acquisition contract vehicles, so as to spread and manage risk, while insuring multi-party buy-in commitment.

The following efforts provide examples where these alternative C3CB acquisition scenarios can be considered. First, the Air Force's Theater Battle Management Core System–Force Level (TBMCS-FL), which manages air tasking orders and airspace management, among other things, is being harvested for current operational capabilities. These capabilities can then be encapsulated and delivered as mission components for other C3CB systems, using OZP widgets and supporting common technologies. The C2AOS C2IS acquisition scenario also intends to deliver harvested functionality as mission components. Air Force AOC (Air Operations Center) is planning to include C2AOS C2IS as the replacement for TBMCS-FL, and will use the Navy ACS (hence indicating the need for multi-party acquisition agreements). This in turn implies the need for Joint C2, and needs to be copied to all Services. It represents an opportunity to reduce duplicate activities for producing equivalent C3CB system capabilities. Second, the Army's Distributed Common Ground System (DCGS-A) currently uses mission components for visualization (over 300 widgets available). DCGS-A will incorporate metadata mission components that utilize the DCGS Integration Backbone (DIB). Third and last, the Navy is deploying CANES and ACS (Agile Core Services) shared infrastructure to its fleet as a modernization effort (Guertin, Sweeney, & Schmidt, 2015).

There are now a number of policy directives within the Defense community that formally recognize that OSS system elements can be treated as commercial-off-the-shelf (COTS) components, and that bespoke software system development projects will utilize an OA, unless otherwise justified and approved. Thus, developing contemporary C3CB that incorporate both OSS and new/legacy CSS elements are "business as usual." However, many legacy Defense community system capability producers are hesitant about how best to engineer such OA/OSS systems. For example, does an OA system imply/require that its software architecture be explicitly modeled, be accessible for sharing/reuse (e.g., as a Reference Model), and be modeled in a form/notation that is amenable to architectural analysis and computational processing ("Software Architecture," 2016)? Therefore, we can begin to identify what kinds of SE research issues can be observed and investigated within the Defense community associated with its transition to OA systems and OSS software elements, specifically for Web and Mobile devices within the realm of C3CB.

OA, Open APIs, OSS, and CSS

OA C3CB system capabilities are assembled with mission components, common development technologies, and infrastructure. *Infrastructure components* are broadly construed to include non-mission specific software functionality or operations. Such components can include computer operating systems, Web servers, database management systems, cloud services, mobile device management middleware, and others, along with desktop, mobile, or smartphone-based Web browsers, word processors, email and calendaring, text/voice chat, and end-user media players. Example infrastructure components include the U.S. Army's Common Operating Environment (COE), the Navy's Consolidated Afloat Networks and Enterprises Services (CANES) Afloat Core Services (ACS) (Guertin, Sweeney, & Schmidt, 2015), and similar elements in the Joint Intelligence Environment.

Common development technologies are common software development tools, libraries, or frameworks used to implement the necessary software functionality so that new or legacy mission components can be integrated into mission-specific software capabilities. Software technology frameworks (or common implementation libraries) like Oracle Java 8, Ozone Platform, OpenJDK (OSS Java Development Kernel for Android app development), and the NASA World Wind Java SDK; programming languages like Java or C++; and scripting languages like Javascript may be utilized as common development technologies for developing mission components. Other software production capabilities like the Navy Tactical Cloud and CANES integrate both infrastructure and common development tools like Hadoop, MapReduce, and other mission data analysis tools for the Tactical Cloud, and the Agile Core Services and Java for CANES.

Mission components represent a hybrid assortment of (a) *simple widgets*—small, thin apps similar in spirit to those acquired and downloaded from online app stores (like a clock, calculator, dictionary, sticky note, or unit converter); (b) *singular widgets*—more substantial functional components either created new (bespoke) or extracted from legacy systems that must run on a specific local computing platform (e.g., shipboard fire control system); or (c) *compound widgets*—hosted in a cloud and run as a remote cloud service over a single/multi-tiered client-server software architecture (e.g., Google Maps, NASA World

Wind), and thus potentially accessible and usable on a Web/mobile computing platform (Google Chrome Web browser running on a secure Android mobile device).

OA seems to simply suggest software system architectures incorporating OSS/CSS infrastructure, common development technologies, and mission components that all utilize open application program interfaces (APIs). But not all software system architectures incorporating OSS/CSS components and open APIs will produce an OA, since whether an architecture is an OA depends on (a) how/why OSS/CSS and open APIs are located within it; (b) how OSS/CSS and open APIs are implemented, embedded, or interconnected within it; (c) whether the copyright (Intellectual Property) licenses assigned to different OSS/CSS components encumber all/part of the architecture into which they are integrated; and (d) choices among alternative architectural configurations and APIs that may or may not produce an OA (cf. Scacchi & Alspaugh, 2008). This can lead to situations in which acquisition contracts stipulate a software-intensive system with an OA and OSS/CSS components, but the resulting software system may or may not embody an OA. This can occur when the architectural design of a system constrains the system requirements: if not all requirements can be satisfied by a given system architecture, if requirements stipulate specific types or instances of OSS/CSS (e.g., Web browsers, content management servers), if an architecture style (Bass, Clements, & Kazman, 2003) is implied by given system requirements, or if requirements are implied by the choice to incorporate legacy software capabilities with one architectural style that are to be wrapped within mission-specific widgets with a different architectural style.

Application domain of interest: C3CB with Web/Mobile Devices Utilizing Widgets C3CB are common information system applications that support modern military operations at a regional, national, or global level. These applications may be focused to address common military mission planning, mapping, resource status tracking and scheduling, mission performance, and monitoring activities through application sub-systems. However, closely related C3CB systems applications are also in common use within civilian/public safety agencies, public infrastructure/utility operations, live television and sports event broadcasting, massively multi-player online game operations centers, and even in international motorsports racing competition events like Formula 1. So the study of software production and system integration issues arising in the Defense community can inform awareness of similar issues in other non-Defense software system domains, and vice versa.

Modern C3CB applications are increasingly expected/planned to be composed from best-available software components, whether OSS or CSS, utilizing bespoke or legacy software capabilities. Furthermore, as smartphones, tablets and laptop computers are being brought into the workplace, so too is interest increasing within the Defense community in supporting the acquisition and development of Web-compatible widgets and mobile apps, provided through an emerging ecosystem of component producers and system integrators, for configuration into secure OA C3CB software system capabilities (George et al., 2014; Reed et al., 2012; Reed et al., 2014; Scacchi & Alspaugh, 2013a; Scacchi &Alspaugh, 2015). Common software elements for such systems include Web browsers open to extensions like custom mission-specific Map widgets, and remote content servers, email and calendaring, word processing, local/networked file servers, and operating systems. The data processed by the software may be of high-relevance to military missions/operations, or may just be the daily grind of data manipulated by “productivity” applications which most of us use routinely to perform/enact our work assignments. Security has been mostly addressed through system isolation or “air gaps” to the outside world due, for example, to airborne or afloat capability deployments. But this is no longer common practice, and cybersecurity concerns have risen to the top of functional and non-functional requirements for all such

C3CB applications. New OA systems are now required to be secure by design, by implementation, and through release, deployment and evolution, as well as subject to independent testing and certification. Secure OA designs can then entail different schemes for encapsulating different (sets of) components, use of virtualization schemes, shims and wrappers, encrypting data transfers and storage, and configuring multi-level system access capabilities. But we have found examples in which different OA system designs and configurations propagate security obligations, and privacy protections and access rights are either mediated or nullified by different software component IP licenses or system updates.

OA Ecosystems Within the Defense Community

In our view, a software ecosystem is a network of software component producers, system integrators, and customer organizations. In the Defense community, producers and integrators are commonly industrial entities (defense contractors), while customer organization are military program offices. Figure 1 presents an abstract view of a software ecosystem that associates software components or apps with their producers, system architectures with system integrators, and delivered component or integrated application systems with their customers. We also add annotations to indicate that each component or app has its own software IP license, and that integrated systems delivered to customers come with some composition of IP license obligations and rights propagated through the system's OA.

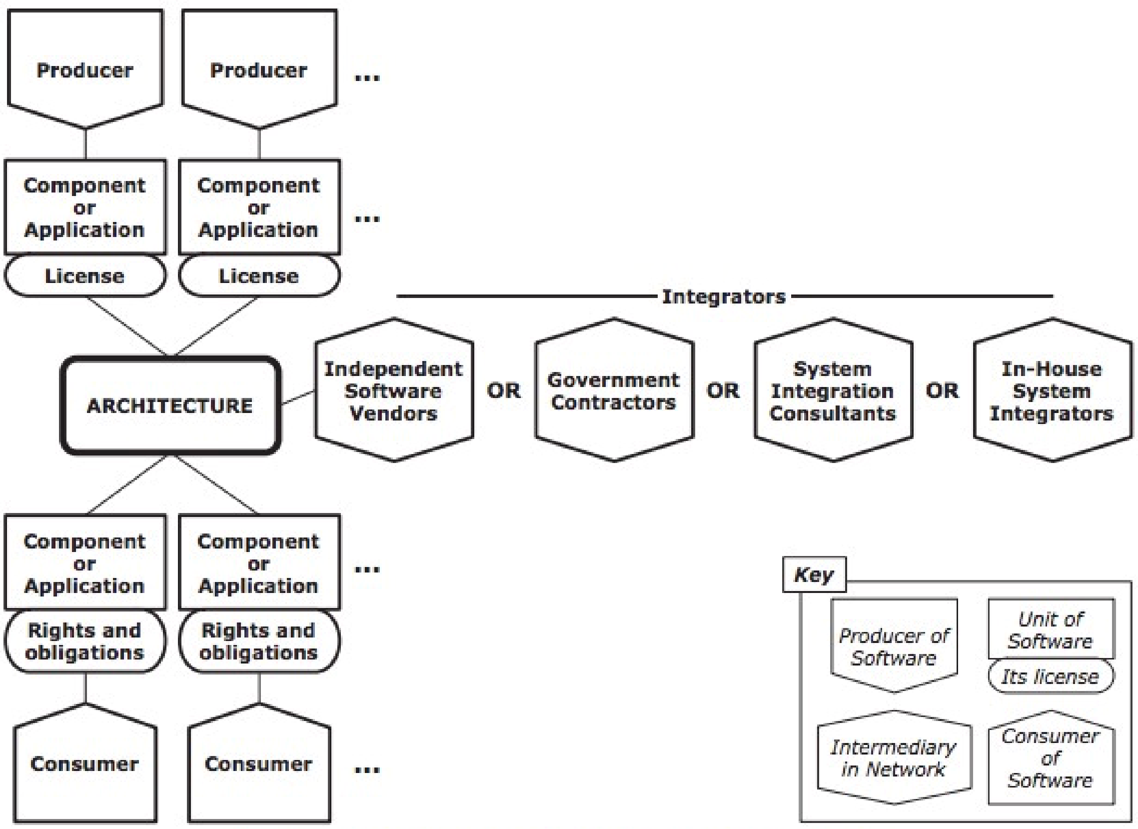

Figure 1. An Abstract Software Ecosystem Rendered as a Network of Software Component Producers, Integrators of Systems/AC, and End-User Consumer Organizations

There is growing interest within the Defense community in transitioning to acquiring complex software system capabilities via an agile and adaptive ecosystem (Reed et al., 2012; Reed et al., 2014; Scacchi & Alspaugh, 2015), where components may be sourced from alternative producers or integrators, allowing for more competition, and ideally lowering costs and improving the quality of software elements that arise from a competitive marketplace (Kendall, 2015). But this adaptive agility to mix, match, reuse, mashup, swap, or reconfigure integrated systems, or to accommodate end-user architecting (Garlan et al., 2012) as in-house integrations of mission components, requires that systems be compatible with or designed to utilize an OA. Consequently, we can identify six kinds of emerging research challenges or issues for software capability acquisition that we have observed within the U.S. Defense community as they move to produce, integrate, deploy and evolve OA systems for C3CB system capabilities that utilize contemporary OSS and bespoke/legacy CSS components. These issues center around (1) unclear representations of OA software system capabilities, (2) how best to accommodate diverse intellectual property licenses when combining bespoke/legacy OSS/CSS mission components, (3) how to accommodate diverse and complicated cybersecurity requirements, (4) technical challenges arising from alternative ways to integrate and deploy diverse software components, (5) how to accommodate many different paths within the Defense community that drive software component evolution, and (6) how to estimate and manage the costs of acquiring, deploying, and sustaining diverse software-based mission components and C3CB system capabilities. These are examined in the next section.

With this background and sets of concepts for understanding a simplified view of the world of C3CB software systems, we now turn to identify and examine a set of issues that are now recurring in the acquisition, design, development, and deployment of such systems.

Emerging Issues in Developing and Deploying OA C3CB Systems Within Different Acquisition Scenarios

There are at least six kinds of emerging research challenges or issues for software capability acquisition that we have observed within the U.S. Defense community as it moves to OA systems for C3CB system capabilities.

Unknown or Unclear OA Solutions

An OA entails a documented representation of software capability described in an architectural description language that specifies component types, component interconnections and connector types, open APIs, and their properties and interrelationships. The common core of a C3CB system OA resembles most enterprise business systems, as C3CB are a kind of management information system for navigating, mapping, tracking resources; scheduling people and other resources; producing plans and documentation; and supporting online email, voice, or video communications. Figure 2 depicts an OA representation that can also serve as a "reference model" for a C3CB software product line (Womble et al., 2011). Figure 3 further expands the sub-architecture of software components that denote configurations of mission-specific components as widgets. Thus, C3CB system capabilities can compose or reuse multiple or nested OA reference models.

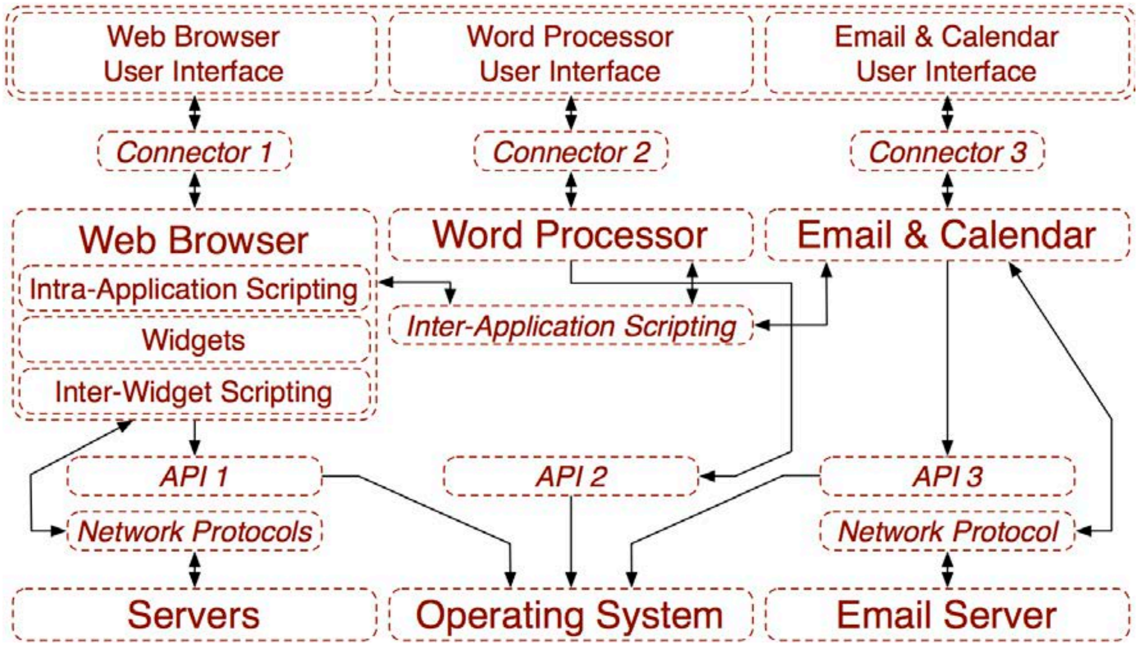

Figure 2. OA Reference Model for Common Software Component Types
Note. This is an OA reference model for common software component types including widgets interconnected within integrated C3CB system capability. Components come from producers that are assembled into OA C3CB capabilities by system integrators.

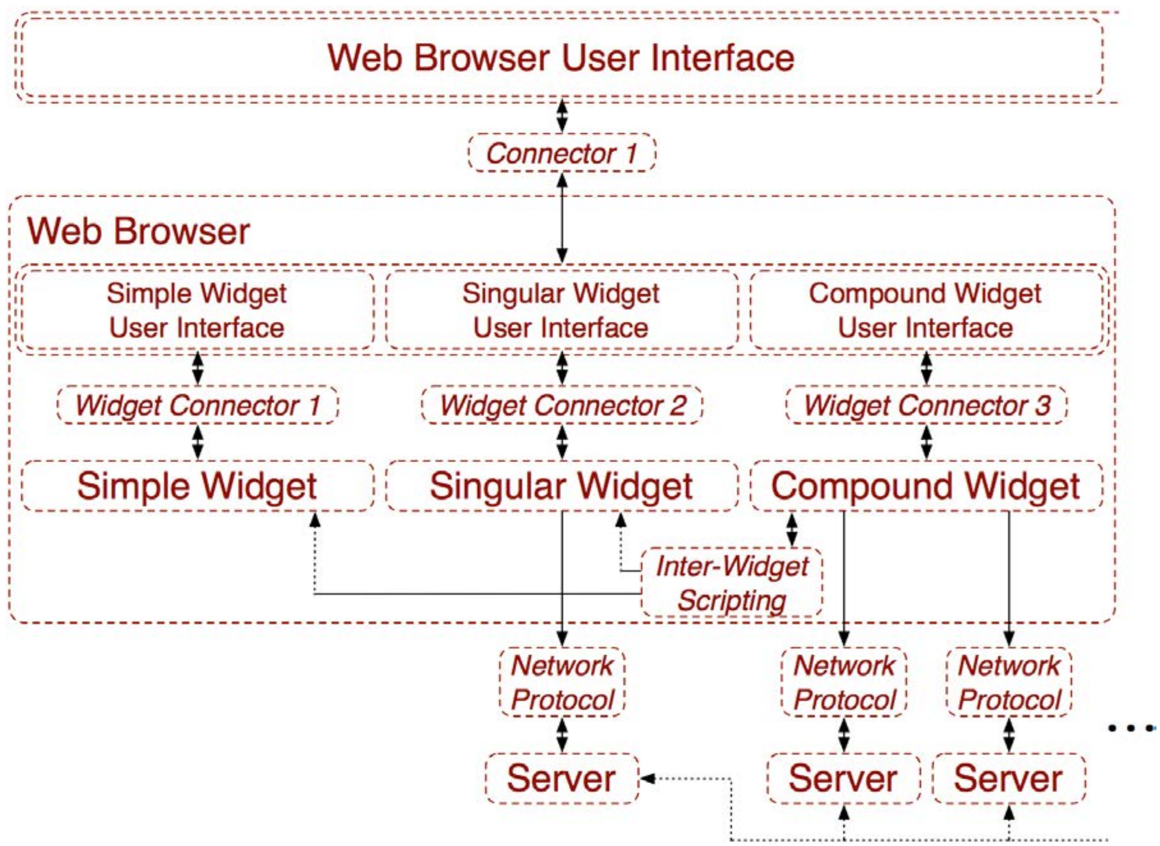

Figure 3. OA Reference Model for Common Types of Software Widget Components

Note. This figure is an OA reference model for common types of software widget components that can be connected and integrated to realize mission-specific C3CB system capabilities, within the overall OA shown on the left-side in Figure 2. Servers may be secured Web content servers, app servers, databases, or file system servers/repositories.

The next piece of the OA challenge we are studying is the envisioned transition with the Defense community to C3CB system capabilities being composed by end-user system integration architects (Garlan et al., 2012) working within/for customer organizations, or potentially extended by end-users deployed in the field. This is the concept that surrounds the transition to discovering software components, apps, or widgets in Defense customer organization app stores (George et al., 2013; George et al., 2014). These app stores are modeled after those used in distributing and acquiring software apps for Web-based or mobile devices, operated by Apple, Google, Microsoft, and others. How the availability of such Defense mission capability app stores will transform the way C3CB systems are produced, or even if legacy Defense industry contractors will produce them, remains to be seen. Said differently, how app stores transform OA software ecosystem networks, business models, and cybersecurity practices is an emerging challenge for acquisition and SE research in the Defense community.

Another kind of challenge arises when acquiring new or retrofitting legacy C2 software system applications that lack an open or explicit architectural representation identifying major components, interfaces, interconnections and remote services (if any). Though OA reference models and architectural description languages are in use within the SE research community, contemporary C3CB generally lack such descriptions or representations that are open, sharable, or reusable. This may be the result of legacy business practices in the Defense community that see d*etailed software architecture representations as proprietary IP* rather than as open, sharable technical data, even when OSS components are included or when applications sub-systems are entirely made of OSS code. An alternative explanation reveals that complex software systems like common Web browsers (Mozilla Firefox, Google Chrome, Apple Safari, Microsoft Internet Explorer) have complex architectures that integrate millions of SLOC that are not well understood, and that entail dozens of independently-developed software elements with complex APIs and IP licenses that shift across versions (Scacchi & Alspaugh, 2012). For such systems the effort to produce an explicit OA reference model is itself a daunting architectural discovery, component/sub-system extraction, restructuring/refactoring, and continuous software evolution task (Choi & Scacchi, 1990; Kazman & Carriere, 1998). Thus, new ways and means for extracting software components interconnections and interfaces and transforming them into higher-level architectural representations of mission-specific apps/widget configurations are needed.

Harvesting legacy source/executable binary code entails many software engineering challenges that constrain acquisition efforts. First, legacy code provides too much technical detail and comparatively little abstraction of overall system configuration, composition, components and interconnection/dependencies. Second, incongruent computational system models (e.g., legacy data-flow versus publish-subscribe widgets) or hybrid OA AC arise when transitioning legacy system software elements into new widget-based mission components. Third, there is a general inability to visualize or analyze (test, selectively execute, translate into another programming language, etc.) overall system configurations, interconnections, or interfaces. Fourth, lacking these three, the potential for general software reuse is limited to executable code reuse, which is the lowest common denominator for reuse. Such reuse results in substantial blocks of unused code that cannot be easily removed due to indiscernible interdependencies. Last, when configuring mission components that entail legacy C2 software applications wrapped for integration as widgets, different architectural styles can inadvertently be mixed (e.g., dataflow architecture for legacy C2 software, and publish-subscribe architecture for configured mission widgets), which in turns raises the potential for architectural mismatches (Velasco-Elizondo et al., 2013) that may be difficult to determine or detect during system integration, especially when such integration activities are performed by end-user/consumer organizations.

Heterogeneously Licensed OA Software Capabilities

OSS components are subject to widely varying copyright, end-user license agreements, digital civil rights, or other IP protections. The Open Source Institute recognizes dozens of OSS licenses are in use, though the top 10 represents more than 90% of the open source ecosystem (Scacchi & Alspaugh, 2012). This is especially true for OSS components or application systems that incorporate source code from multiple, independent OSS development projects, such as found in contemporary Web browsers like Firefox and Chrome which incorporate components from dozens of OSS projects, most with diverse licenses (Scacchi & Alspaugh, 2012). This means that C3CB system capabilities that entail configuration of OSS/CSS components are subject to complex software IP obligations and rights that may defy tracking, or entail contradictory legal obligations or rights (Alspaugh, Scacchi & Asuncion, 2010). Determining overall IP obligations for such systems is generally beyond the scope of expertise for software developers, as well as most corporate lawyers. Furthermore, we have observed many ways in which IP licenses interact within an OA software system, such that different architectural design choices that configure the same set of software components result in different overall system obligations and rights. Understanding multiple license interaction and IP mismatches is far too confusing for most acquisition professionals and Program Office decision-makers and a source of legal expense, or alternatively expensive indemnification insurance policies by the software producers or system integrators.

One complication that can be anticipated here arises when component types are replaced with versioned component instance alternatives (Scacchi & Alspaugh 2012). Consider the situation where a Web Browser (e.g., *Firefox 40.0.3* or *Chrome 47.0.2526.111 (64-bit);* etc.) component has a specific IP license (e.g., *Mozilla Public License 2.0* or *GPL 3.0*) associated with the versioned instance, which in turn may be viewed by system integrators as enabling/limiting an integrated system's architectural design, depending on how different components are interconnected in ways that may or may not propagate (un-) desirable IP obligations and rights—a concern that arises frequently when using components subject to the GPL (Scacchi & Alspaugh, 2008). As we have learned in practice, corporate lawyers employed by Defense contractors or in government agencies do not have solutions for how to resolve such complexities, except via costly overall liability indemnification schemes, and efforts to distribute integrated systems with many IP obligations and few rights that effectively make an integrated open source system closed. This in turn can defeat the potential opportunities and benefits for commitment to OA systems that integrate OSS components.

Bespoke/legacy software components for OA AC design, integration and delivery within widgets will be subject to their bespoke/legacy IP obligations. This may include limits on the right to extract, restructure, or reengineer their architecture (cf. Choi & Scacchi, 1990; Kazman & Carriere, 1998) into open source formats. Similarly, IP licenses associated with OSS or new CSS components may impinge on their integration with these legacy components, or may limit disclosure of their interfaces that would allow more open integration of alternative software AC configurations developed by different Defense community component producers (Scacchi & Alspaugh, 2012).

Nonetheless, in our view, OA software ecosystems are defined, delimited, and populated with niches that locate specific integrated system solutions (Scacchi & Alspaugh, 2012). Furthermore, we see that these niches effectively have *virtual IP licenses* that must be calculated via the obligations and rights that propagated across integrated system component licenses via union, intersection, and subsumption relations among them (Alspaugh & Scacchi, 2012). Such calculation may appear to be daunting, and thus begs for a simpler, tractable, and computationally enforced scheme that can scale to large systems composed from many components, as well as be practically usable by C3CB system capability producers, integrators, and acquisition professionals. In such a scheme, OSS/CSS licenses could formalize IP obligations as operational requirements (i.e., computationally enforceable, at the integrated system level) instantiated by system integration architects (Alspaugh, Scacchi, & Asuncion, 2010; Alspaugh & Scacchi, 2013). Similarly, customer/user rights are then non-functional requirements that can be realized and validated as access/update capabilities propagated across the integrated system (Alspaugh & Scacchi, 2013).

Cybersecurity for OA Software Capabilities

Cybersecurity is a high priority requirement in all C3CB systems, applications, AC, and platforms (Scacchi & Alspaugh, 2013c; Scacchi & Alspaugh, 2013d). No longer is cybersecurity something to be addressed after C3CB systems are developed and deployed—cybersecurity must be included throughout the design, development, deployment, and evolution of C3CB. However, the best ways and means for addressing cybersecurity requirements are unclear, and oftentimes somewhat at odds with one another depending on whether cybersecurity capability designs are specific to a C3CB platform (e.g., operating system or processor virtualization; utilization of low-level operating system access control or capability mechanisms); component producer (secure programming practices and verification testing); system integrator (e.g., via use secure data communications protocols and data encryption); customer deployment setting (mobile: airborne or afloat; fixed: offices, briefing rooms, operations centers); end-user authentication mechanisms; or acquisition policy (e.g., reliance on third-party audit, certification, and assurance of system cybersecurity). However, in reviewing these different arenas for cybersecurity, we have found that the cybersecurity requirements or capabilities can be expressed in much the same way as IP licenses: using concise, testable formal expressions of obligations and rights. Some examples follow (capital letters are placeholders that denote specified system, service, or component contexts):

- The obligation that a user must verify his/her authority by password or other specified authentication process.
- The obligation that all components connected to specified component C must grant it the capability to read and update data in compartment T.
- The obligation to reconfigure a system in response to detected threats, when given the right to select and include different component versions, or executable component variants.
- The right that a user or software component may read and update data in compartment T using the licensed component.
- The right that may allow replacement of a specified component C with some other vetted component.

These examples show how cybersecurity requirements can be expressed or paraphrased in restricted natural language (e.g., using a domain-specific language) into composite specifications that denote “security licenses” (Alspaugh, Scacchi & Asuncion, 2010; Alspaugh & Scacchi, 2012). In this way, it should be possible to develop new software analysis tools whose purpose is to interpret cybersecurity obligations as operational constraints (executable) or provided capabilities (access control or update privileges), through mechanisms analogous to those used for analyzing software licenses (Alspaugh, Scacchi & Asuncion, 2010; Alspaugh & Scacchi, 2012), and show how component or sub-system-specific obligations and rights can be propagated across a system’s architecture.

We similarly envision the ability for OA system capabilities to be produced and integrated according to different cybersecurity requirements, depending on where and how they are deployed (Scacchi & Alspaugh, 2013d). For example, in Figure 4 we show one possible layout of software components that confines different sub-configurations within different virtual machines. These virtual machines may also be hierarchically nested, as is the case when mission-specific widgets that entail legacy C2 applications must be securely confined at run time in order to access remote servers, in contrast to a secured Web browser running on a secured mobile device.

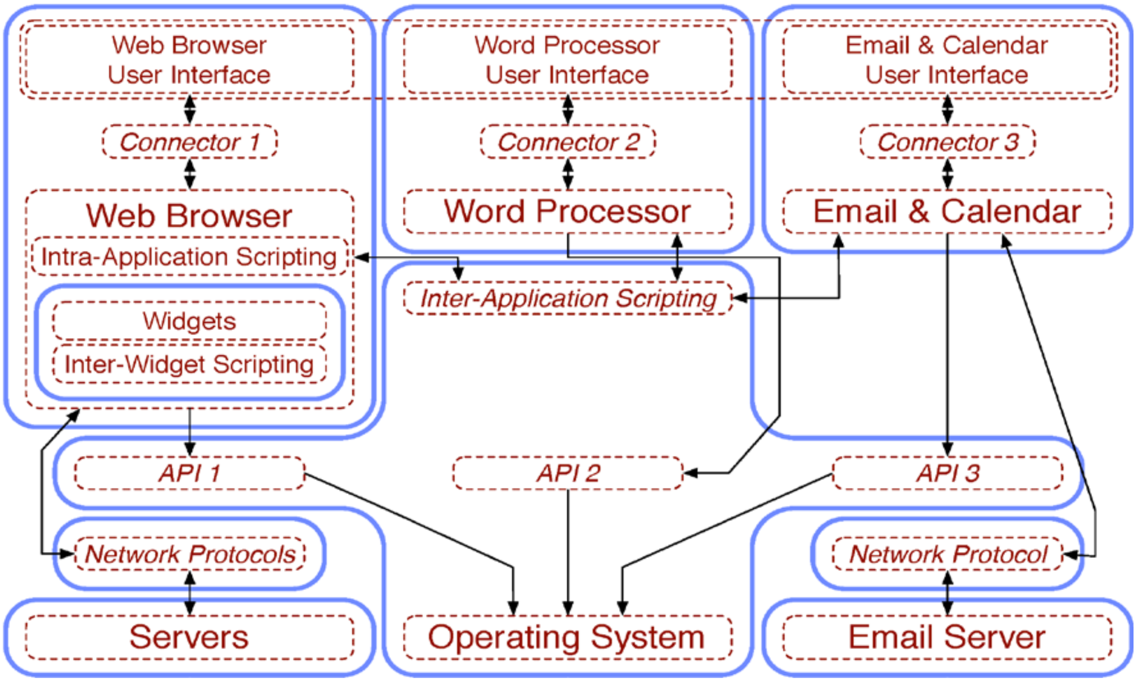

Figure 4. A Configuration of Security Confinement Vessels that Encapsulate Infrastructure Software Components and Mission-Specific Widgets for the OA Shown in Figures 2 and 3

Last, the inclusion of OSS or new CSS components within future OA C3CB software systems or AC will be amenable to current approaches to cybersecurity assurance, as we have outlined before (Scacchi & Alspaugh, 2013d). Mission components can be assessed for cybersecurity characteristics, and assembled, without triggering reaccreditation. Similarly, evolutionary support for field-deployed AC can allow rapid substitution of mission components that enable rapid, agile response to cybersecurity issues in mission components. However, legacy CSS components which were developed and deployed before current cybersecurity assurance challenges will need to rely on "air-gap" interfaces at deployment time that may be vulnerable to aggressive exploits delivered through mobile devices.

Consequently, we believe that cybersecurity can be addressed in the future using explicit, computational OA representations that are attributed with both IP and cybersecurity obligations and rights.

Software Component Build, Release, Deployment (BRD) Processes

C3CB applications represent complex software systems that are often challenging to produce, especially when conceived as bespoke systems. To no surprise, acquisition of these systems often requires a development life cycle approach, though some system elements may be fully-formed components that are operational as packaged software (e.g., commercial database management systems, Web browsers, Web servers, user interface development kits/frameworks). C3CB development is rarely clean-sheet and less likely to be so in the future. As a result, component-based system development approaches are expected to dominate, thus relegating system integrators (or even end-users) to perform any residual source code development, inter-app integration scripting, or intra-app extension script development. But software process challenges arise along the way (Scacchi & Alspaugh, 2013b).

First is again the issue noted earlier of whether there is an explicit, open-source OA design representation, preferably one that is not just a diagram, but instead is expressed in an architectural design language. With only a diagram or less, then is little or no guidance for how to determine whether a resulting software implementation is verifiable or compliant with its OA requirements or acquisition policies, such as provision or utilization of standardized, open APIs to allow increased software reuse, selection of components from alternative producers, or post-deployment extensions (Kendall, 2015).

Second is the issue arising from system development practices based on utilization of software components, integrated sub-systems, or turnkey application packages. These software elements come with their own, possibly unknown requirements that are nonetheless believed to exist and be knowable with additional effort (Alspaugh & Scacchi, 2013). They also come with either OSS code or CSS executables, along with their respective APIs. These components must be configured to align with the OA specification. Consequently, software tool chains or workflow automation pipelines are utilized to build and package internal/external executable, version-controlled software releases. We have found many diverse automated software process pipelines are used across and sometimes within software integration activities (Scacchi & Alspaugh, 2013b). These pipelines take in OSS code files, dependent libraries, or repositories (e.g., GitHub) and build executable version instances that are then subjected to automated testing regimes that include simple “smoke tests” and extensive regression testing. Successful builds eventually turn into packaged releases that may or not be externally distributed and deployed as ready-to-install executables. While this all seems modest and tractable, when one sees the dozens of different OSS tools used in different combinations across different target platforms it becomes clear that what is simple when small becomes a complex SE activity when the scale of deployment increases.

Another complication, which is now beginning to be recognized within and across BRD processes and process automation pipelines, arises in determining when and how different BRD tool chain versions/configurations can mediate cybersecurity requirements in the target system being built. We have seen cases in which software builds and deployed releases are assumed to integrate to functionally equivalent CSS components, but which are then not included in releases due to IP restrictions. We have also observed and reported how functionally equivalent variants as well as functionally similar versions may or may not be produced by BRD tool chains, either by choice or by unintentional consequence. This, in our opinion, gives rise to the need for explicit open-source models of BRD process automation pipelines that can be analyzed, tested, reused, and shared to determine whether release versions/variants can be verified and/or validated to produce equivalent/similar releases that preserve prior cybersecurity obligations and usage rights.

Last, mixing new OSS and CSS components with legacy apps wrapped within widgets will complicate build and release processes and obscure deployment processes. Legacy apps encapsulated within mission-specific widgets will commonly need to dynamically link executable binary components, which in turn increases the challenges in their testing and cybersecurity assurance, both during development and during field deployment. In order to mitigate these technical challenges while enabling more agile software component system integration, multi-component OA configurations should explicitly declare pre/post conditions on acceptable input/output parameter values, along with exceptional values, that in turn can be independently verified or validated.

Software Component Evolution Practices Transmitted Across the OA Ecosystem

Software evolution is among the most-studied of SE processes. While formerly labeled as “software maintenance,” a profitable activity mediated through maintenance contracts from software producers to customers, the experience of OSS development projects and practices suggest a transition to a world of continuous software development—one that foreshadows the emergence of continuous SE processes, or software life cycles that just keep cycling until interest falters or spins off into other projects. OSS development projects rely on OSS tools that themselves are subject to ongoing development, improvement, and extension, as are the software platforms, libraries, code-sharing repositories, and end-user applications utilized by OSS developers to support their development work. Developers entering, progressing, or migrating within/across OSS projects further diversify the continuous development of the most successful and widely used OSS components/apps. This dynamism in turn produces many ways for OSS systems or OA systems that incorporate OSS components to evolve.

Figure 5 portrays different software evolution patterns, paths, and practices we have observed arising with new C3CB applications (Scacchi and Alspaugh 2012). Here we see paths from a currently deployed, executable system release, to a new deployed release—something most of us now accept as routine as software updates are propagated across the Internet from producers, through integrators, to customers and end-users.

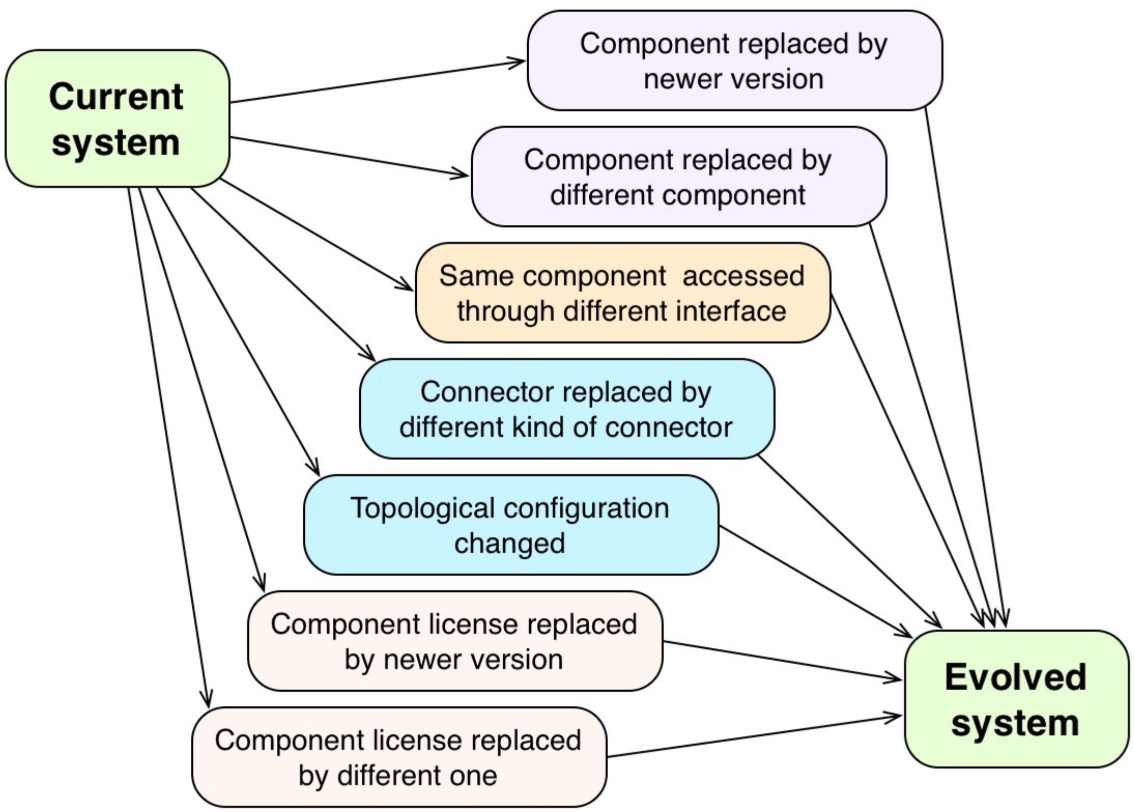

Figure 5. Different Paths and Mechanisms Through Which OA Software Systems Can Evolve
(Scacchi & Alspaugh, 2012)

Integrated OA systems can evolve through upgrades of functionally equivalent component variants (patches) as well as through substitution of functionally similar software components sourced from other producers or integrators. In Figure 6, we show a generic situation that entails identifying how an OA consistent with that depicted in Figure 2 may accommodate the substitution and replacement of a locally installed word processor application with a remote Web-based word processing software services (for example, Google Docs or Microsoft Office 365). This capability is a result of utilizing an OA that constitutes a reference model aligned with a vendor-neutral software product line. This is also a capability sought by customer organizations, and sometimes encouraged by software producers to accommodate their evolving business models (discussed below). While the OA remains constant, the location of the component has moved from local to remote/virtual, as has its evolutionary path. Similarly, the cybersecurity of the local versus remote component has changed in ways that are unclear, and entail a different, evolved assurance scheme.

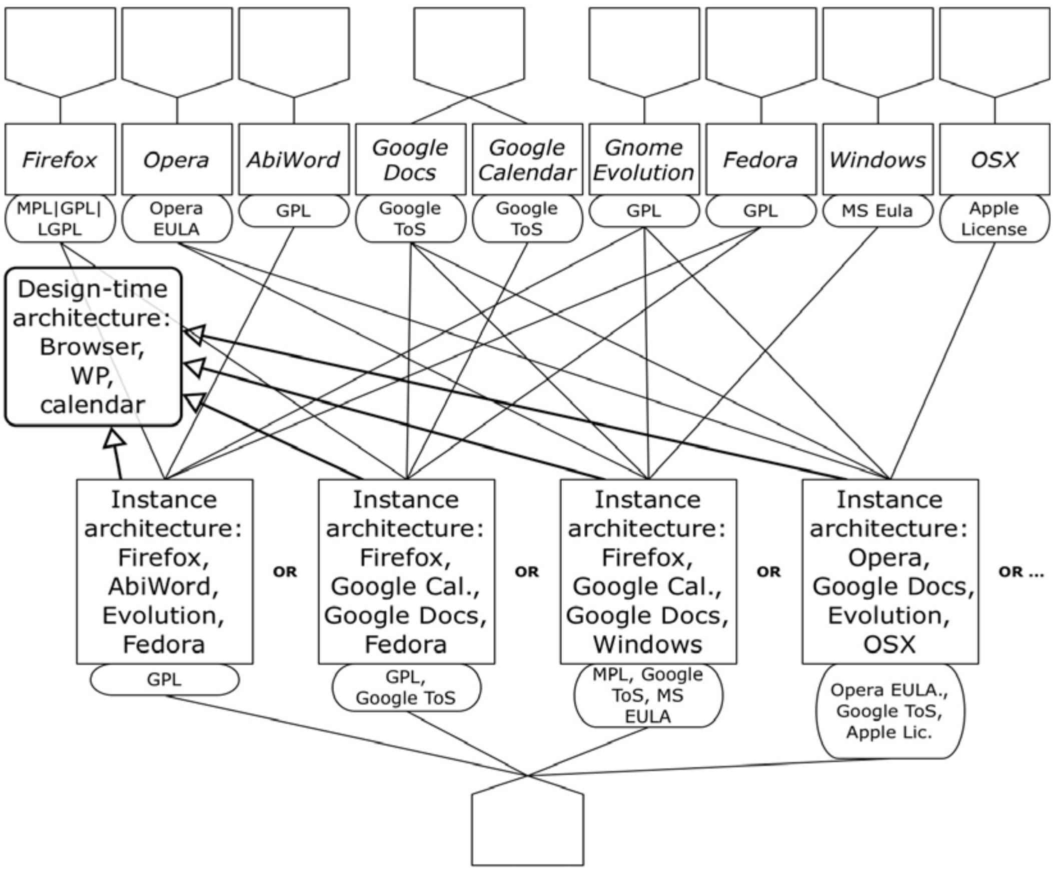

Figure 6. Alternative Configurations of Integrated Instance Releases of Components Consistent With the OA in Figure 2 That Are Treated as Functionally Equivalent by Customer Organizations
(Scacchi & Alspaugh, 2012)

Next, any common development technology used to support production or integration of mission components with shared infrastructure components must recognize that these technologies and components are all subject to independent, mostly autonomous evolution practices within the Defense community. For example, OZP is currently undergoing evolution, including its migration to Java 8 sourced by Oracle, and this move will may disrupt the correct operation of widgets already produced using Java 7 common development technologies. Similarly, new OSS and CSS components will evolve due to practices arising in the competitive marketplace, while legacy mission components wrapped within widgets will have obscure or opaque evolution practices that are locked into legacy Defense community component providers. Legacy components will also limit how their encapsulating widgets evolve, potentially due to architectural mismatches or dependencies to legacy systems that are no longer supported, operational, or compatible with current platform technologies (Velasco-Elizondo et al., 2013).

Overall, the evolution of software components, component licenses, component interconnects and interconnections, and interconnected component or AC configurations are now issues that call for research efforts to help make such patterns, paths, and practices more transparent, tractable, manageable, and scalable within an OA software ecosystem, as well as customers seeking the benefits of openness, sharing, and reuse.

New Business Models for Acquisition of Software Components and Widgets

The last issue we address is the newest in this set of six for consideration for new acquisition research. While the field of acquisition research and practice has long paid attention to software economics, the challenges of software cost estimation are evolving in light of new business models being put into practice by software producers and system integrators. In the past, software development projects were often managed by a single contractor responsible for both software production and system integration. Costs could be assessed through augmentation to internal business accounting practices (e.g., budgeting, staffing workloads, time-sheet reports, project schedules, etc.). But a move to OA ecosystems means that multiple producers can participate, and OA schemes accommodate switching among providers while a system is being integrated, deployed, or evolved in the field. This in turn coincides with new ways and means to electronically distribute software updates, components, or applications, as well as new ways to charge for software. OSS components may be acquired and distributed at “no cost,” but their integration and evolution are charged as service subscription, or as time-effort billings.

We have already seen other alternatives for costing or charging for software that include franchising; enterprise licensing; metered usage; advertising supported; subscription; free component, paid service/support fees; federated reciprocity for shared development; collaborative buying; donation; sponsorship; free/open source software (e.g., Government OSS—GOSS); and others. So how are customer organizations, especially in the Defense community where software cost estimation practices are routine, supposed to estimate the development or sustaining costs of the software components or integrated systems they acquire and evolve, especially when an OA system allows for producers whose components come with different costing/billing schemes? This is an open problem for both acquisition research and software engineering practice.

Overall, new OSS and CSS components are experiencing a rapid diversification of acquisition cost models and practices, while legacy components are generally tied to single-source contractors as a result of utilizing legacy components as a cost-avoidance practice. All of the preceding five factors further obfuscate how to estimate or measure software component/AC development costs, schedules, or time to delivery/usage. So acquisition costs of systems that mix and match new OSS and bespoke CSS components, together with legacy CSS components, will be difficult to cost-estimate or cost-manage. This in turn will limit the efficacy of BBP 3.0 practices for such systems.

Discussion and Conclusions

Our study reported in this paper identifies a set of technical issues and risks that can dilute the cost-effectiveness of Better Buying Power efforts. It similarly suggests that current acquisition practices aligned with BBP can also give rise to acquisition management activities that can dominate and overwhelm the costs of OA system development. This adverse condition can arise through app/widget vetting, new software business models, opaque and/or underspecified acquisition management processes, and the evolving interactions of new software development and deployment techniques. Unless proactive investment in acquisition research and development can give rise to worked examples, open-source models, and new acquisition management system technologies, the likelihood of acquisition management dominating agile development and adaptive deployment of component-based OA C2 system capabilities is unsettling.

Our research identified and analyzed how new software component technologies like OSS infrastructure components, common development technology components, and mission-specific widgets for Web-based and/or mobile devices, along with their intellectual property (IP) license and cybersecurity requirements, engineering and evolution processes, and cost estimating practices interact to drive down (or drive up) total system costs across the system acquisition life cycle. The availability of such new scientific knowledge and technological practices can give rise to more effective expenditures of public funds and improve the effectiveness of future software-intensive systems used in government and industry. Thus, a goal of this paper was to explore new ways and means for achieving cost-sensitive acquisition of OA software systems, as well as identifying factors that can further decrease or increase the costs of such systems.

We identified and examined six areas for research arising at the intersection of software engineering and acquisition that now confront the Defense community (and perhaps other industries as well). These six issues areas include (1) the lack of architecture representations and schemes for discovering or specifying OA system designs; (2) OA systems that integrate components or applications subject to diverse, heterogeneous IP licenses; (3) how to manage the cybersecurity of OA systems during system design, development, and deployment; (4) software process challenges and evolving disruptions in seemingly mundane process automation pipelines; (5) software evolution patterns, path, and practices in OA ecosystems; and (6) how new business models are upending software cost estimation practices and outcomes. All of these research areas are readily approachable, and research results are likely to have significant practical value, both within the Defense community and beyond.

These issue areas were investigated and addressed in the domain of command, control, communication, cyber and business systems (C3CB). We believe all are tractable, yet dense and sufficient for deep sustained research study, as well as for applied research in search of near-term to mid-term practical results.

In related work (Scacchi & Alspaugh, 2015), we have called for specific R&D investments into the development of open source, domain-specific languages for specifying open architecture representations (or architectural description languages) that are formalizable and computational, as well as supporting annotations for software license obligations and rights. While ADLs have been explored in the SE research community, the challenges of how software architectures mediate software component licenses and cyber security requirements are an open issue, with practical consequences. Similarly, ADL annotations that assign costs or cost models in line with new software business models are an open problem area. We have also called for R&D investment in new SE tools or support environments who purpose is to provide automated analysis and support of OA systems IP and cybersecurity obligations and rights, as new requirements for industrial practice in large-scale software acquisition, design, development, deployment, and evolution. Such environments are the automated tools that could be used to model, specify, and analyze dynamically configurable, component-based OA software systems expressed using the open source architectural representation schemes or ADLs noted here.

Our research identifies and analyzes how OA CBC3 system capabilities can utilize software components and mission-specific widgets, with diverse IP license and cybersecurity requirements, and how new software business models can interact to affect total system costs across the system acquisition life cycle. The availability of such new scientific knowledge and technological practices can give rise to more effective expenditures of public funds and improve the effectiveness of future software-intensive systems used in Defense community, as well as elsewhere within government and industry. Hopefully, this paper serves to help throw light into how software engineering and acquisition research can inform and add benefit to software practices within the Defense community through ways and means that further advance Better Buying Power opportunities and outcomes.

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Architecting Out Software Intellectual Property Lock-In: A Method to Advance the Efficacy of BBP

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Abstract

This paper works to understand Department of Defense (DoD) contracting trends since the beginning of Better Buying Power (BBP). By using data publicly available from the Governmentwide Point of Entry (GPE), this paper concludes that there are no clear trends in the levels of competition in the DoD, as measured by ratios of Justifications and Approvals (J&A) to contract awards, as a result of BBP. However, this is not to say that BBP is ineffectual, but that methodologies are still needed to implement the guidance outlined in BBP. To that end, this paper proposes a methodology to identify salient data rights in computer software. Our aim is to provide a means for program managers to understand which data rights are most important to ensure future sustained competition.

Introduction

Over five years have passed since the first version of Better Buying Power (BBP) was introduced by Secretary of Defense Aston Carter, formerly Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]; Carter, 2010). In that time, two updated versions of BBP were released by the current USD(AT&L) Frank Kendall: BBP 2.0 (Kendall, 2013) and BBP 3.0 (Kendall, 2015). Since the initial BBP, many authors offered critiques of the BBP strategies (examples include Hasik, 2014; Hill, 2013; Huitink, 2014; Hunte et al., 2015; Layden & Arndt, 2012) with varying sentiments of approval or disapproval. However, within these critiques are two reoccurring patterns. First, the majority of critiques are made using qualitative methods. These analyses are important, but represent a somewhat one-sided story without any accompanying quantitative analyses.

Second, many lament that BBP is akin to a management philosophy that lacks any insight into implementation, but very few critics offer methods to aid in implementation. One example is Hasik's (2014) review, "Carter effectively introduced a slew of new rules into the Pentagon's bureaucracy, but he and his successor have developed few mechanisms for affecting the behavioral change beyond issuing a memorandum" (p. 17).

Consequently, our work herein endeavors to serve two purposes. First, to analyze data from the Governmentwide Point of Entry[1] (GPE) to identify any trends in levels of DoD competition since the introduction of BBP. We will not, however, tread into complicated tests of statistical significance with the hope of identifying minute changes in competition. Rather, our goal is to look for broad changes in DoD competition patterns, after which we will devote the second half of this paper to explain a methodological approach to aid in the realization of three BBP initiatives.

State of Competition

The 2015 Annual Report of the *Performance of the Defense Acquisition System*, released annually by the office of the USD(AT&L), argues that competition is starting to rise. To substantiate this statement, the report uses a fractional measure of contracts competitively awarded by dollar amount. The most recent measures show that 58.3% of fiscal year (FY) 14 contracts, by dollar amount, were competitively awarded, which is up from 57% in FY13 (USD[AT&L], 2015). However, this methodology is sensitive to an outlier bias, where a few large contracts awarded competitively (i.e., contracts on the order of magnitude in the $100s of millions) overshadow the many smaller contracts awarded using other than full and open methods. In this scenario, there may be competition amongst a small number of large contractors on big contracts, but little to no competition amongst the many hundreds, if not thousands, of contractors on the small contracts. This results in metrics that reflect a large quantity of competition by dollar amount, but little change in the actual number of competitive contracts awarded. Unfortunately, no methods were used to control for this bias in either the quantitative analysis or the interpretation of results. We make no argument that the data presented by the USD(AT&L) is overestimated or underestimated, only that more analyses are needed to triangulate the actual effects.

Given these methodological choices, it is difficult to determine, with any certainty, whether competition in DoD contracts is increasing or decreasing. This makes determining the efficacy of BBP equally difficult. Consequently, we propose an independent study using data from the GPE to triangulate the results in the 2015 *Performance of the Defense Acquisitions System* report. The GPE is an online repository for U.S. Government business opportunities, which is accessible by the public. This is an ideal source of data because DoD agencies are required by Federal Acquisition Regulation (FAR) 5.201 to post synopses of contracting actions above $25,000.[2] Furthermore, the contract notices on the GPE cover the

[1] "Governmentwide point of entry (GPE) means the single point where Government business opportunities greater than $25,000, including synopses of proposed contract actions, solicitations, and associated information, can be accessed electronically by the public. The GPE is located at http://www.fedbizopps.gov" (48 CFR 2.101—Definitions).

[2] FAR 5.202(a) outlines 14 exceptions to the mandatory contract synopsis policy outlined in 5.201. The exceptions are too lengthy to enumerate in detail herein; however, the 14 exceptions are sufficiently specific to ensure the maximum amount of information is available to the public.

spectrum from a vehicle maintenance contract at an Air Force base in South Dakota in the tens of thousands of dollars to ACAT-type programs in the tens of millions of dollars. From these posted contract notices, we can quantify the overall DoD procurement activity per fiscal year.

In addition to contract notices, other types of contracting actions are also posted. Of particular interest are Justifications and Approvals (J&A),[3] which is a document released to the public when the DoD uses a procurement strategy other than full and open competition.[4] The February 17, 2009, revision of FAR 6.302 mandated that all J&A documents are posted to the public.[5] Each J&A notice on the GPE is an artifact which reflects a lack of competition in DoD acquisition. Consequently, the frequency of J&As relative the overall number of contract awards provides a separate indicator of competitiveness within the DoD marketplace that is not sensitive to outlier bias.

Data Collection

Although the data is electronically available to the public, it is made available through a web interface. Consequently, to retrieve the data a web scraper was built, tested, and employed to obtain the data for all DoD-related agencies. These agencies and their respective number of contract notices on the GPE are outlined in Table 1.

Web scraping is a time-consuming process which is costly to both the provider of information, in terms of increased website traffic, and the scraper, in terms of bandwidth and data size. In an effort to minimize the impact of scraping, only seven variables were collected for each notice posted on the GPE: name, contract number, class code, agency, procurement organization (within the agency), date of notice, type of notice, and the URL for each specific notice page.

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[3] "Justification and Approval (J&A) is a document required to justify and obtain appropriate level approvals to contract without providing for full and open competition as required by the Federal Acquisition Regulation (FAR)" (Defense Acquisition University, 2015).
[4] For those unfamiliar with DoD jargon, "other than full and open competition" is defined as any sole source or limited competition contract action that does not provide an opportunity for all responsible sources to submit proposals.
[5] Similar to the FAR 5.202(a) exception, there are also exceptions for Justifications and Approvals outlined in FAR 6.305(b) and (c).

Table 1. Number of Notices Collected by Agency

AGENCY	NOTICES
DEFENSE LOGISTICS AGENCY	675,041
DEPARTMENT OF AIR FORCE	219,025
DEPARTMENT OF ARMY	322,139
DEPARTMENT OF NAVY	274,984
OTHER DEFENSE AGENCIES[6]	27,756
TOTAL	1,518,945

In addition to the approximately 1.5 million contract notices collected, additional details specific to each J&A were also scraped. Similar to the contract notices, the scraping only gathered a parsimonious collection of variables for each J&A: name, contract number, contract award date, FAR authority, service, command, program management office, classification code, and North American Industry Classification System (NAICS) code. The results of this secondary scrape are outlined in Table 2.

To control for threats to internal validity from instrumentation error, the total number of notices was cross checked against the number displayed on the GPE. In all cases, the number of notices collected by the web scraper match the number of entries in the GPE archive. This ensures no portion of the data was errantly omitted from the sample. Additionally, to control for lagging policy effects caused by the February 17, 2009, revision of the FAR, which mandated J&A public disclosure, all data before FY10 was omitted. The resulting data covers FY10–FY15. Additionally, three contract notices contained dates with years greater than 2016, and 66 of the J&As did not contain a FAR authorization. These data were excluded from the final sample analyzed below.

Data Analysis

There is some seasonality in both the contract award and J&A data, which is centered around the end of each fiscal year, see Figure 1(a). This result is expected, given the race to obligate funds before the end of the fiscal year. However, what is unexpected is the difference in seasonality between contract awards and J&As in both FY12 and FY13 (see Figure 1(a)). This phenomenon is most likely explained by the Budget Control Act of 2011, commonly referred to as "sequestration," which required nine annual sequesters of $109 billion. The first of the annual sequesters took effect in March 2013 (Van Hollen, 2015), likely stymying the number of contracts awarded both before and after. Interestingly, there appears to be no sequestration effect on the number of J&As during the same time periods. Additionally, we see no substantive reduction in the absolute number of J&As in the six fiscal years under study.

We also considered the fraction of J&As relative to contracts awarded (see Figure 1(b)). This measure shows a ratio of uncompetitive contracts to competitive contracts. In this

[6] Examples of Other Defense Agencies include: Defense Advanced Research Projects Agency (DARPA), Uniformed Services University of the Health Sciences (USUHS), U.S. Special Operations Command (SOCOM), Department of Defense Education Activity (DoDEA), Defense Commissary Agency (DCA), United States Transportation Command (TRANSCOM), Defense Finance and Accounting Service (DFAS), etc.

data we see spikes in the fractional measure at the end of FY11 and during FY13. As previously discussed, the FY13 numbers are most likely explained by sequestration. However, the spike during the initial quarter of FY12 appears to be a result of low number of contracts awarded. In fact, the contract awards during the first quarter of FY12 are the lowest out of any quarter between FY10–FY15. This is likely explained by the five successive Continuing Resolutions appropriations in FY12. Interestingly, there seems to be no obvious connection between the introduction of BBP initiatives[7] and the fraction of J&As to contract awards. If we look at the six-month exponentially weighted moving average (EWMA) of the fractional measure, we see that even after three iterations of BBP DoD levels of competition are similar. This is not to suggest that BBP was ineffectual or that there was no impact on competition, but that no obvious conclusion can be made based on the data in the GPE.

Lastly, we examined a moving cross correlation between contract awards and J&As (see Figure 1(c)). The data have a static correlation of 0.55 $(p = 5.9e - 7)$. Furthermore, for the large majority of the months spanning FY10–FY15, there is a positive six-month moving cross correlation, sometimes as high as 0.96. As with Figures 1(a) and 1(b), there is some variability in the outcomes, but those are largely explained as lagging effects from the events previously discussed. We believe this to be an important measure of competition because if competition rates were truly improving, we would expect to see the correlation between contract awards and J&A move closer to 0, or no effect. While the data from the GPE do demonstrate some periods of no correlation between J&A and contract awards, 94% of the points in the sample have a positive six-month moving cross correlation.

[7] BBP initiatives are dated using the stamp dates from the USD(AT&L) memorandums which directed implementation. The respective dates are as follows: BBP 1.0—June 28, 2010; BBP 2.—April 24, 2013; and BBP 3.0—April 9, 2015.

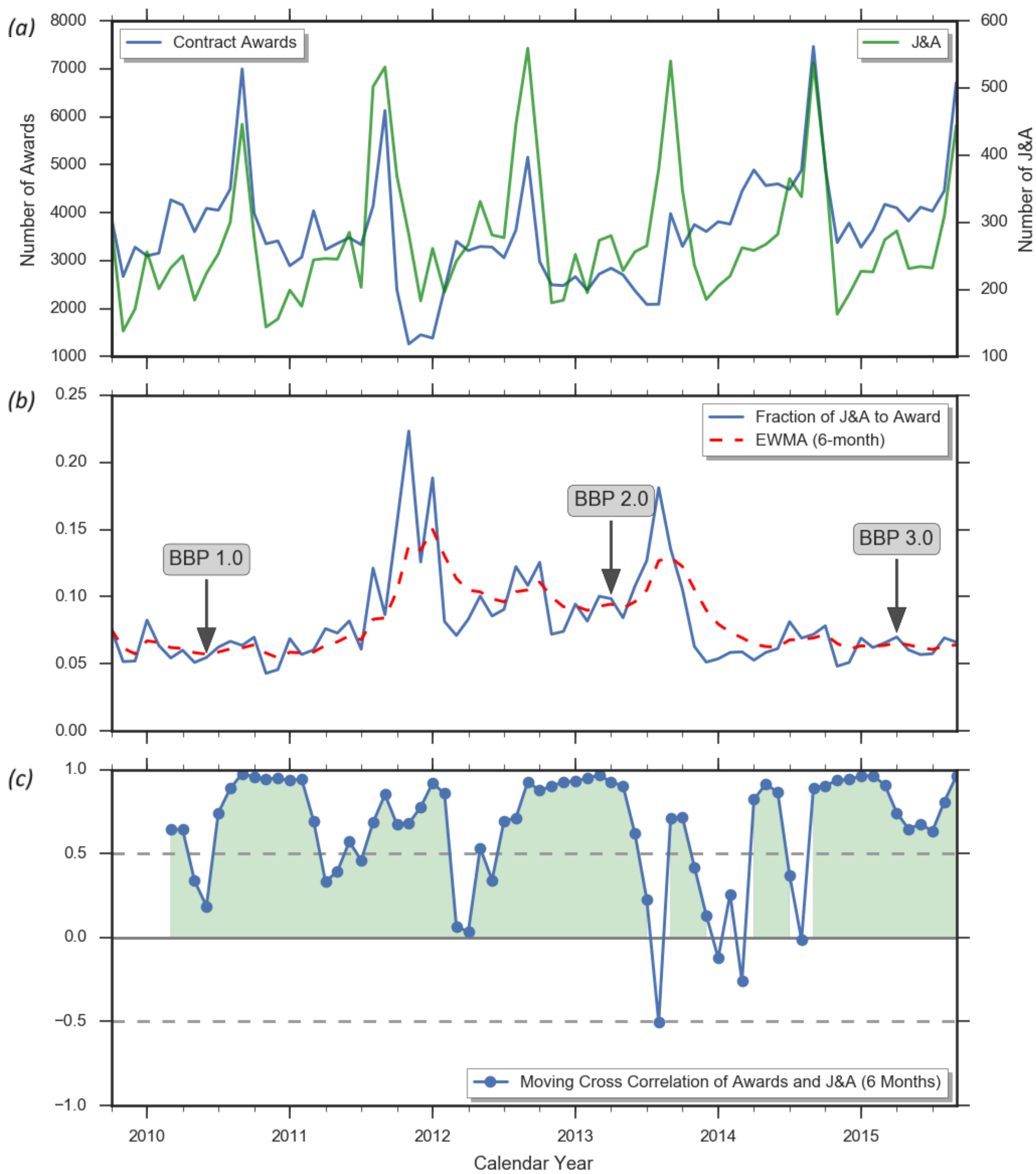


Figure 1. Contract Awards and J&As

Note. All subplots in Figure 1 are drawn using a calendar year x-axis, not a U.S. Government Fiscal Year x-axis. (a) Shows the frequency of contract awards (left y-axis) and J&As (right y-axis) as a time series sampled on a monthly frequency. (b) Shows the fraction of J&A to contract awards. Callouts on (b) denote when each of the three versions of BBP were mandated by USD(AT&L). To remove some seasonality from the fraction, the red dashed line shows a six-month exponentially weighted moving average (EWMA). (c) Shows a six-month moving cross correlation between contract awards and J&As.

Discussion

The aforementioned results do not demonstrate any facts with statistical certainty; however, they do illustrate that the data are noisy and influenced by multiple exogenous events. Additionally, the independent analysis of GPE data do not necessarily support the clear-cut conclusions in the 2015 edition of the *Performance of the Defense Acquisition System* report. The numbers may be improving by proportion of dollars competitively awarded, but an examination of the frequency of uncompetitive contracts to competitive contracts shows no clear improvement.

Those familiar with J&As and FAR Part 6 will rightly point out that not all J&As are equal in their ability to indicate a lack of competition. This is true; there are seven different categories of J&As (the GPE uses eight categories, adding a subcategory for 6.302-1). Table 2 enumerates the different types of J&As and their frequency in the GPE during the period FY10–FY15.

Table 2. GPE Justifications and Authorization Types and Respective Frequency

J&A AUTHORIZATION	COUNT
FAR 6.302-1 - *Only One Responsible Source (Except Brand Name)*	13,922
FAR 6.302-1(C) - *Brand Name*	2,155
FAR 6.302-2 - *Unusual and Compelling Urgency*	1,748
FAR 6.302-3 - *Industrial Mobilization; Engineering, Developmental or Research Capability; or Expert Services*	138
FAR 6.302-4 - *International Agreement*	59
FAR 6.302-5 - *Authorized or Required by Statute*	607
FAR 6.302-6 - *National Security*	5
FAR 6.302-7 - *Public Interest*	671
TOTAL	19,305

The J&A authorized by FAR 6.302-2 is for other than full and open competition in cases of "unusual and compelling urgency." This category does not accurately reflect the DoD's inability to implement a competitive process, but a choice to exclude competition in the interest of exigent circumstances. This same argument could be made for all J&A types, except FAR 6.302-1. However, FAR 6.302-1 is by far the most prevalent type of J&A, accounting for approximately 83% of all the J&As in the GPE (see Figure 2(a)). Across FY10–FY15 we see that the average rate of 6.302-1 J&As is approximately 83%, with the percentage trending somewhat higher in FY12 and FY13. Consequently, it is safe to argue that 6.302-1 J&As are by far the most frequently used across the fiscal years examined and that by removing the remaining 17% from the sample would only have a marginal effect on the analyses presented in Figure 1, as the ratio of 6.302-1 J&As removed would be nearly uniform for each fiscal year. Interestingly Figure 2(a) does not show any trends in J&A type, as a percentage of total number, across six fiscal years. Prior to this analysis we hypothesized that the impact of BBP (1.0–3.0) would have had some noticeable impact on the quantity and type of J&As used. From the data presented in Figure 1 and Figure 2, there are no easily observable results that would support this hypothesis.

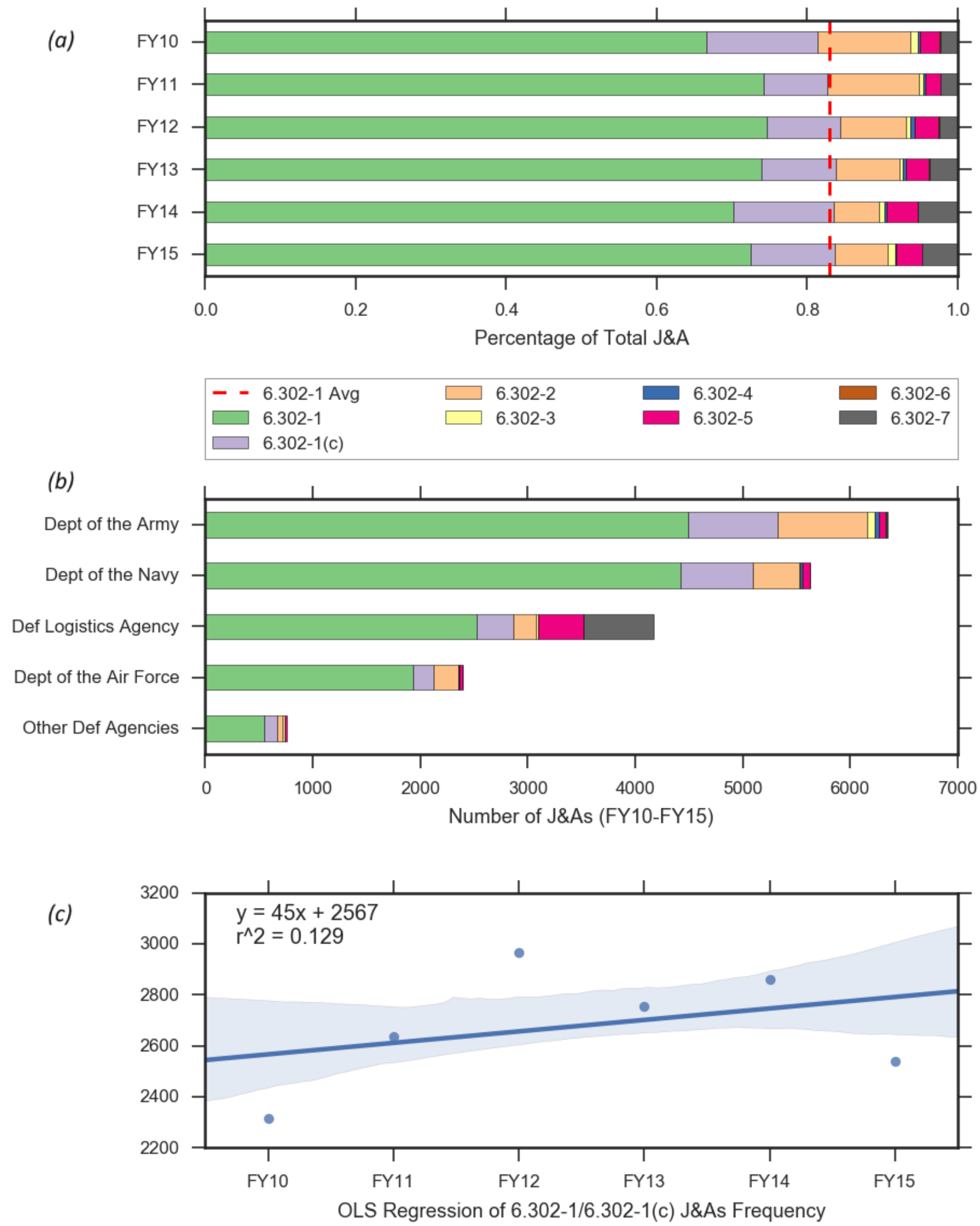


Figure 2. J&As Data

Note. All subplots in this figure have different x axes, which differs from Figure 1 which used a common x axis. (a) Depicts the percentage of each J&A type by fiscal year. The dashed red line shows the average number of 6.302-1 and 6.302-1(c) J&As across all fiscal years. (b) Depicts the total number of each J&A type by service from FY10 through FY15. (c) OLS regression of the total number of 6.302-1 and 6.302-1(c) J&As from FY10 through FY15. Although FY15 showed a reduction in 6.302-1 and 6.302-1(c) J&As, the overall trend is slightly positive with a coefficient of 45 and an intercept of 2,567. The shaded area represents a confidence interval of 58, which corresponds with the standard error of the estimate.

The nature of the information stored in the GPE allows us to also understand which Service is generating the most 6.302-1 J&As (see Figure 2(b)). Prior to undergoing this analysis, we hypothesized that all services would be roughly equal in the number of J&As. However, the data at Figure 2(b) illustrate a different picture. For the sample period examined the Army and Navy are, by a large margin, the biggest producers of 6.302-1 J&As (e.g., the Army generated approximately 150% more 6.302-1 J&As than the Air Force in the sample period). However, it is important to remind the reader that these numbers do not control for the size, in terms of dollars, of each J&A. As a somewhat hyperbolic example, each of the Air Force's J&As could be for a $1 billion space system and the Army's J&As could be for a $1,000 rifle. Therefore, there are limitations on the conclusions which can be drawn from the data outlined in Figure 2(b). Also interesting, the Defense Logistics Agency seems to be the sole user of the FAR 6.302-7, Public Interest, J&A, accounting for 97% of all the 6.302-7 J&As issued across six fiscal years. Given the universal nature of the FAR, we did not expect one service to dominate the use of a particular type of J&A.

The J&A data thus far demonstrates that 6.302-1 is the most prevalent type as a percentage of the total number of J&As, but is there a trend in the use of 6.302-1 J&As across the fiscal years in the sample? To address this question, we fit an Ordinary Least Squares (OLS) regression to the number of 6.302-1 J&As across the six fiscal years under examination (see Figure 2(c)). Given the small number of samples the OLS regression model would not be useful as a predictor of future values of 6.302-1 J&As; however, it is a rough indicator of a positive trend in the number of 6.302-1 J&As. If the levels of competition, measured as number of contracts competed, were increasing, we would expect a negative or downward trend in the number of 6.302-1 J&As over the sample period. That being said, the standard error for the OLS estimator is 58, which indicates it is possible, but perhaps not probable, that there is a slightly negative trend in the data.

Given that we now know 6.302-1 is the most prevalent type of J&A and that 6.302-1 use is likely increasing, it is worth discussing this specific FAR authorization in more detail. The FAR does not enumerate all possible uses of 6.302-1, but it does provide guidance on application of the regulation. In doing so, it provides four situations in which the authority in 6.302-1 may be appropriate. It is important to note that this list is not intended to be all inclusive. These four situations are as follows:

> (1) When there is a reasonable basis to conclude that the agency's minimum needs can only be satisfied by —
>
> (i) Unique supplies or services available from only one source or only one supplier with unique capabilities; or,
>
> (ii) For DoD, NASA, and the Coast Guard, unique supplies or services available from only one or a limited number of sources or from only one or a limited number of suppliers with unique capabilities.
>
> (2) The existence of limited rights in data, patent rights, copyrights, or secret processes; the control of basic raw material; or similar circumstances, make the supplies and services available from only one source (however, the mere existence of such rights or circumstances does not in and of itself justify the use of these authorities) (see Part 27).
>
> (3) When acquiring utility services (see 41.101), circumstances may dictate that only one supplier can furnish the service (see 41.202); or when the contemplated contract is for construction of a part of a utility system and the utility company itself is the only source available to work on the system.
>
> (4) When the agency head has determined in accordance with the agency's standardization program that only specified makes and models of technical equipment and parts will satisfy the agency's needs for

additional units or replacement items, and only one source is available. (FAR 6.302-1(b))

These four situations are relatively generic with the exception of 6.302-1(b)(2) and 6.302-1(b)(3), the former of which governs the application of 6.302-1 for situations where intellectual property issues or data rights limit competition, and the ladder towards a narrow situation where utility services are acquired. These guiding situations pose an interesting question: Are there certain categories of goods or services for which 6.302-1 is used more frequently than others given the specificity in 6.302-1(b)(2)? To obtain an approximate measure of this we examine the procurement classification codes[8] of each 6.302-1 J&A. These are considered an approximate measure, as the contracting official has final authority on which procurement classification code the J&A will use; therefore, there is some variance in which types of effort fall into which procurement classification code. Consequently, the GPE encourages interested bidders to search across similar classification codes (e.g., a bidder interested in *15–Aircraft and Airframe Structural Components* should also search in *16–Aircraft Components and Accessories*). However, unless the two codes are similar in domain or type then the procurement classification codes provide a good guideline (i.e., it would be difficult to argue there is overlap between *24–Tractors* and *14–Guided Missiles*). Table 3 outlines the top 10 Product Service Codes (PSC) and Federal Supply Codes (FSC) by number of 6.302-1 J&As.

Table 3. Top 10 Product Service Codes (PSC) and Federal Supply Codes (FSC) by 6.302-1 J&A

Products	Count	Services	Count
16 -- Aircraft components & accessories	1,720	R -- Professional, administrative, and management support services	981
70 -- General purpose IT equipment	1,107	Q -- Medical services	920
20 -- Ship and marine equipment	725	D -- Information technology services, including telecommunications services	813
58 -- Communication, detection, & coherent radiation equipment	666	J -- Maintenance, repair & rebuilding of equipment	677
65 -- Medical, dental, veterinary equipment & supplies	611	A -- Research & Development	339
15 -- Aircraft & airframe structural components	560	S -- Utilities and housekeeping services	297
59 -- Electrical and electronic equipment components	525	U -- Education & training services	197
99 -- Miscellaneous	506	V -- Transportation, travel, & relocation services	142
66 -- Instruments & laboratory equip	463	Z -- Maintenance, repair, and alteration of real property	136
28 -- Engines, turbines & components	326	L -- Technical representative services	100

[8] Procurement classification codes are truncated versions of both the Federal Supply Codes (FSC) and Product Services Codes (PSC). For example, instead of using the four-digit Federal Supply Code 1620–*Aircraft Landing Gear Components*, the procurement classification code uses only the first two digits *16–Aircraft Components and Accessories*.

Table 3 shows some interesting patterns in the type of goods and services procured using 6.302-1 J&As, namely the largest number of product J&As belongs primarily to aircraft related PSCs (16,15, and 28) and the second most appears to be electronic equipment PSCs (70, 58, 59, and 66). Viewing these results under a Williamsonian Transactional Cost Economics lens, these results are somewhat intuitive based on the language in FAR 6.302-1(b)(2). Products with a high asset specificity are expected to carry some mode of safeguard, in this instance, intellectual property protection to defend against transactional hazards (Williamson, 1981). Said differently, products built specifically for a single purpose with little opportunity for dual-use in the commercial market (e.g., aircraft landing gear on a F-16 or IT equipment designed to process UAV full motion video) are expected to carry intellectual property safeguards to protect the manufacturers' ideas and investments. Failure to protect such intellectual property would lead to a situation where competitors could easily reproduce the original manufacturer's goods, a transactional hazard. Therefore, we can expect these types of products are often procured under a 6.302-1 J&A. Although not a revelatory conclusion, this loose connection between intellectual property and 6.302-1 J&As adds credence to many of the intended changes suggested in BBP.

Improving Competition

The most recent iteration of Better Buying Power, BBP 3.0, outlines three strategies which confront the issue of intellectual property in DoD procurement. The first, *Remove Barriers to Commercial Technology Utilization,* argues that the DoD should capture private sector innovation by using commercially available technologies and products, but directs further analysis of the implications on intellectual property. The second strategy, *Increase the Productivity of Corporate Independent Research and Development (IRAD),* targets the misuse of IRAD funds by defense contractor on "*de minimis* investments primarily intended to create intellectual property" (Kendall, 2015) to secure a competitive advantage in future DoD contracts. The final strategy, *Use Modular Open Systems Architecture to Stimulate Innovation*, argues that the DoD must control relevant interfaces to ensure competitors with superior products are not occluded from competition due to intellectual property restricted interfaces.

The commonality across these three strategies is the management of intellectual property. This is not a new concept in DoD procurement. In fact, there is a statutory requirement for the DoD to manage intellectual property in the John Warner National Defense Authorization Act for Fiscal Year 2007, which "require[s] program managers for major weapon systems and subsystems of major weapon systems to assess the long-term technical data needs of such systems and subsystems and establish corresponding acquisition strategies that provide for technical data rights needed to sustain such systems and subsystems over their life cycle" (Mazour, 2009, citing 10 U.S.C. § 2320(e)). This is a difficult statute to comply with because it asks members of the DoD acquisition community to predict what data rights are needed in the future. Being that there is no readily agreed upon method for accomplishing data rights forecasting, Eli Mazour (2009), in his article *for Public Contract Law Journal*, correctly points out that the easiest way to comply with this law "is to acquire as many rights as possible in as much technical data possible" (p. 681). The logic being, if one acquires all possible data rights, then one is certainly prepared to sustain a weapon system over its life cycle. Mazour's comments are illustrative of the problem with both statutory requirements and with the BBP strategies; neither offer a means for program managers to accomplish what is required. This brings us to a major question confounding the DoD procurement community—how do program managers determine which data rights to purchase?

In the second half of this paper we endeavor to provide a means for understanding intellectual property in computer software and determining which data rights should be purchased to increase the likelihood of sustained future competition. The choice of software, versus a physical system (e.g., aircraft components), is critical for three reasons. First, our analyses of J&As herein identifies electronic equipment, which all host software, as an area where items are often procured using other than full and open competition. Second, the increased DoD emphasis on acquiring open source software and open architectures is driving the acquisition of software systems with a complex web of open source and closed source intellectual property regimes (Carter, 2010; Kendall, 2013, 2015). Understanding the interactions between these vastly different intellectual property regimes is instrumental for future policy decisions. Third, there is a steady increase in the functions performed by software in major DoD weapon systems. Consider the juxtaposition of two generations of aircraft: In 1970s aircraft (e.g., F-111), around 20% of its functions were performed by software, whereas for aircraft in the early 2000s (e.g., F-22), 80% of its functions are performed by software (Ferguson, 2001). The role of software and the intellectual property of software are becoming increasingly important across all future DoD acquisitions.

Intellectual Property Lock-In

Before discussing our methods in detail, it is important to understand the intellectual property mechanisms that prevent competition. Specifically, *intellectual property lock-in* occurs "when switching costs outweigh the benefit of adopting a superior new product [and] a consumer is locked in to her incumbent supplier" (Breuhan, 1997, p. 2). This switching cost could be the cost of a new product itself, the redesign of a system, or the licensing costs of any new intellectual property. Described in a narrative manner, lock-in often occurs when companies vie for a share in a new market. In this situation, companies compete hard for early adopters in a given technology, oftentimes with penetration pricing (Farrell & Klemperer, 2007). An organization becomes locked-in when the cost of switching to another technology outweighs the benefit of adopting a superior, sometimes cheaper, product.

Taking it one step further, the concept of switching costs is based on the substitutability of a new technology or component. If a new piece of technology is easily substitutable, in terms of time and money, into a legacy system, then we argue there is a relatively low switching cost. Conversely, if a piece of technology is not easily substitutable, we argue that with this lack of substitutability comes a high switching cost and subsequently a high potential for lock-in. What defines intellectual property lock-in, as opposed to technological lock-in, are switching costs determined by rights to intellectual property (defined in the DoD lexicon as "data rights").

Previous work on the evolution of software design and modularity provide a means to assess the substitutability of files in software with little *a priori* knowledge on the functionality of the software itself (MacCormack, Rusnak, & Baldwin, 2007). This work builds from previous theory on the architectural design (Baldwin & Clark, 2000) and research on quantifying modularity in software (MacCormack, Rusnak, & Baldwin, 2006). Specifically, previous work studied the evolution of software over a series of sequential versions to identify the most important factors in component survival, "which is an indicator of the degree to which components can be removed or substituted" (MacCormack et al., 2007, p. 4) and shows that tightly-coupled components have a higher probability of survival as software evolves, making them "harder-to-kill." Since this measure of hardness-to-kill is a proximal measure for substitutability, it should also serve to identify those components which have high switching costs and, ergo, a large potential for lock-in.

Method

Our selected method applies a Design Structure Matrix (DSM) approach to analyze the relationships between different entities in a software system. The basic approach relies on the following four steps (MacCormack et al., 2006, 2007):

1. Capture a network representation of software source-code using dependency extraction tools.
2. Find all the paths (direct and indirect) between files in the network by computing transitive closure.
3. Calculate visibility scores to each file, which represent a file's reachability from other files or ability to reach other files in the network.
4. Organize files into one of four canonical groups based on visibility scores.

We will enumerate the basics of each step beginning with network extraction. There are two basic choices regarding the application of DSMs to software: (1) the level of unit analyzed, and (2) the type of dependency between units. Regarding the unit analyzed, it is possible to analyze software at the directory, source file, and function levels. In this methodological approach the source file is used as the unit of analysis, which is also supported by prior work on software design (Cataldo et al., 2006; Eick, Graves, & Karr, 2001; Sturtevant, 2013). There are also choices in the dependency type between these source files. Keeping with previous literature (MacCormack et al., 2006; Rusovan, Lawford, & Parnas, 2007) we use the function call. A function call is an instruction in the software code that requests a specific task be executed, sometimes making the request internally or of another source file. When one source file executes a function call that requests a task to be completed by another source file, we characterize this as a directional dependency between the two source files. For example, if a function call in file X calls a function call in file Z, we would say that file X depends on file Z. It is important to note that this is a directional dependency and just because file X depends on file Z, it does not imply file Z depends on file Z. This first order dependency extraction is accomplished using a commercial call extractor, specifically *SciTools Understand*.[9]

To illustrate the output of step 1 and the process of step 2, we point your attention to Figure 3. In this toy example we have extracted the dependencies from a piece of software that contains four source files (i.e., D, C, A, and B). Upon completing the extraction, we see that D calls C and C calls both A and D. This is a direct, or level 1, connection between the files. The resulting DSM is an illustration of the same connections in the network graph, except arrayed as a matrix. The DSM is read from right to left. For example, starting at row C from left to right, we see that two blue dots denote file C is connected to both A and B. The next step in the methodology calls for identifying all the direct and indirect paths through the software. This full set of paths is known as visibility or transitive closure. To identify the visibility of each source file we use matrix multiplication.[10] Specifically, by raising the DSM to successive powers of n, we obtain the direct and indirect dependences that exist for each successive path length n. Summing these n matrices yields the visibility matrix, which shows both direct and indirect dependencies between source files for all possible path lengths up

[9] See www.scitools.com for more details.
[10] Note that we choose to include the matrix for n = 0 when deriving the visibility matrix, implying that an element will always depend on itself.

to the maximum. If we draw our attention to the visibility matrix in Figure 3, we now see two new entries for source file D. This is because file D originally connected to file C, but file C also connected to files A and B. Therefore, in the visibility matrix we have captured this second order connection between D to A and D to B.

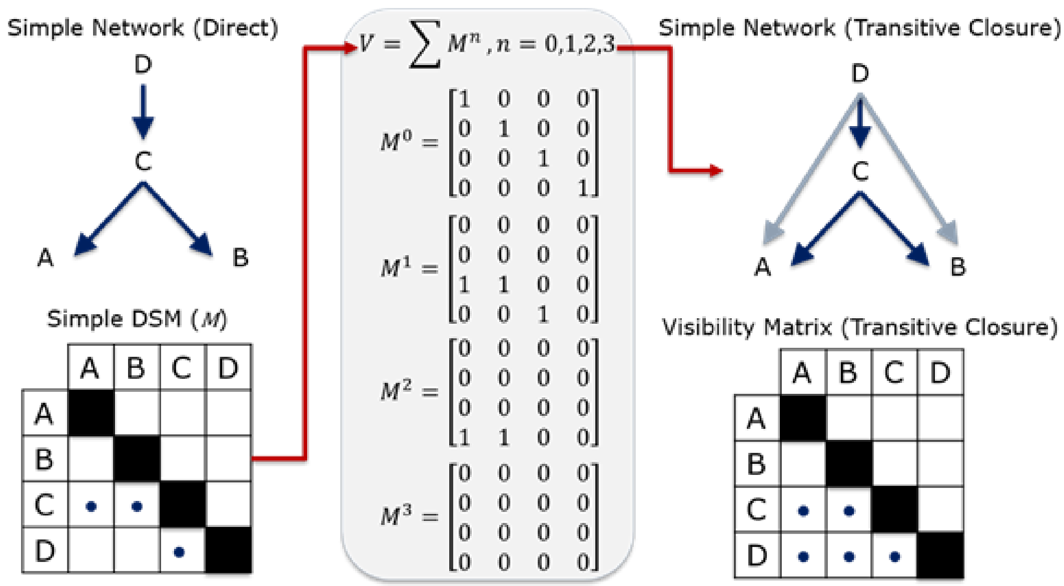


Figure 3. Example Level 1 DSM, Example Transitive Closure Calculations, and Example Visibility Matrix

The penultimate step is to calculate the visibility scores for each file in the software. The measures of visibility are derived directly from the visibility matrix (Figure 4 uses the same visibility matrix from Figure 3). Visibility fan-out (VFO) is calculated by summing all the dependencies along each row of the matrix, including the diagonal. For example, file C has a VFO of 3, which means that it depends on 75% of the files in the software either directly or indirectly. Visibility fan-in (VFI) is calculated similarly, instead by summing down the columns of the visibility matrix. Continuing the example, file C is seen by both itself and file D.

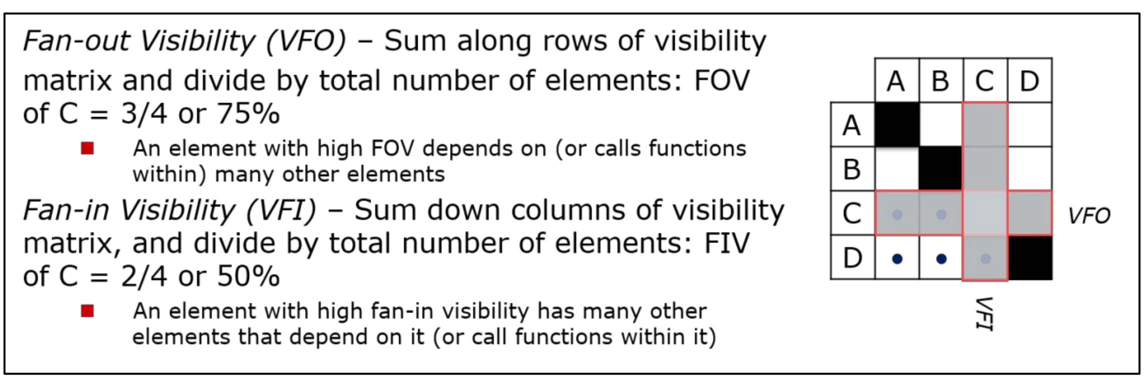
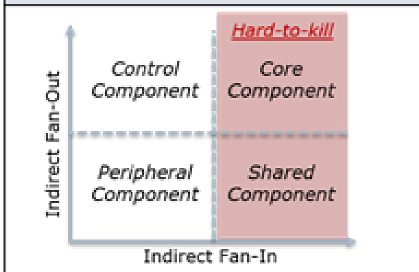


Figure 4. Calculations for Fan-Out Visibility and Fan-In Visibility

With visibility scores calculated, we now organize each file into one of four types of files (see Figure 5). This step is critical because previous work suggests files with high VFI and high VFO are statistically significant indicators of hardness-to-kill (MacCormack et al., 2007). However, high VFO by itself was not uniformly significant across all samples in previous research, suggesting that high VFI is more dominant in explaining survival. Intuitively this makes sense; files with a high VFI score imply they are relied upon extensively by other files in the software. Substituting a file which is relied upon extensively by other files is difficult, whereas substituting a file which relies upon others (i.e., high VFO) is relatively easier. Consequently, we conclude the two types of components which are both more survivable and least substitutable fall into the “shared” and “core” classes (highlighted in red on Figure 5).

Four Canonical Types Of Components



Core Components:	Core files are “seen by” many files and “see” many files.
Shared Components:	Shared files provide functionality to many parts of the system. These files are “seen by” many files, but do not “see” many files.
Peripheral Components:	Peripheral files are neither “seen by” many files nor “see” many files.
Control Components:	These files “see” many other files, but are not “seen by” many files.

Figure 5. Four Canonical Types of Files
(adapted from Lagerström et al., 2013)

Case Study

To illustrate the utility of this methodology, we will examine a piece of DoD developed software and gain an understanding of which files have high switching costs and could result in intellectual property lock-in. Specifically, we will examine a flight simulator software currently under sustainment at Air Force Materiel Command. The end goal of this case study is to show how the method above can be utilized to identify a list of files for which the data rights should be secured to ensure future sustained competition.

This particular piece of software is comprised of 6,362 files primarily written in C++ and Java. Using the methodology described above, calls were extracted, visibility metrics calculated, and each file was organized into one of the four groups in Figure 5. The results are depicted in DSM at Figure 6. Recall from Figure 5 that the most important groups to determine substitutability and hardness-to-kill were the “shared” and “core” groups. These two groups are organized in the upper left corner of Figure 6 and are labeled accordingly. The files that fall into either shared or core comprise approximately 18% software, as a percentage of total files.

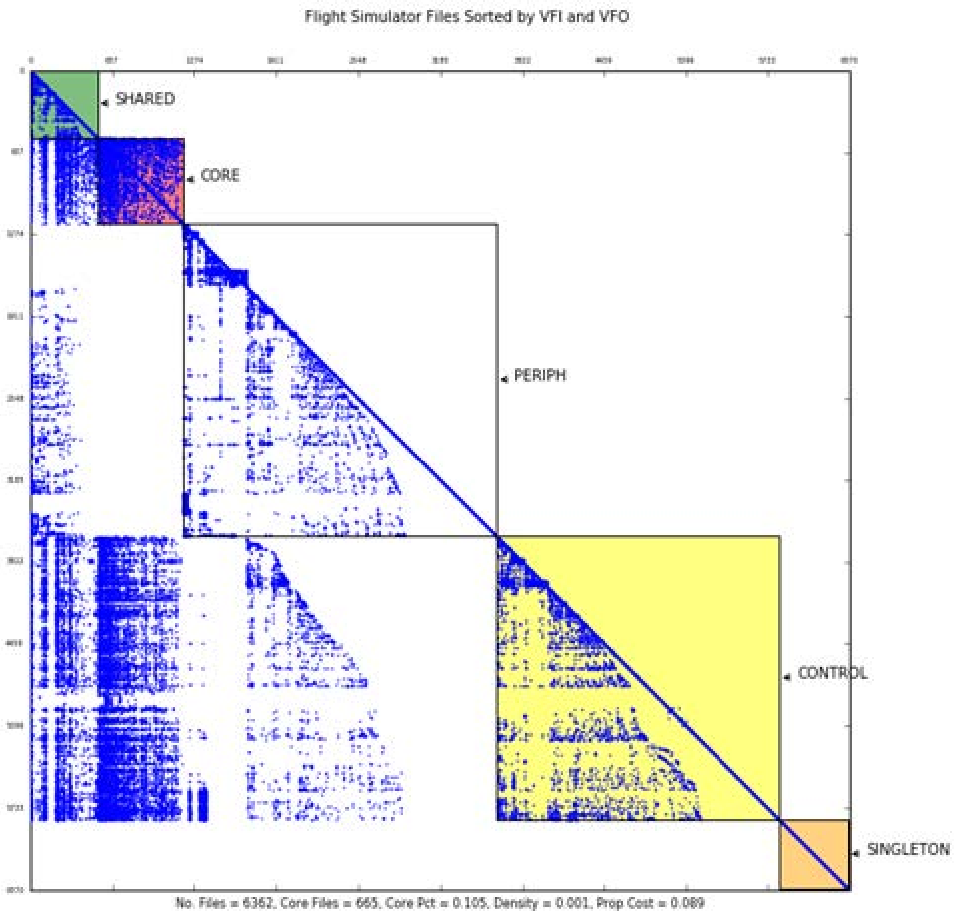


Figure 6. Flight Simulator Files Sorted by Visibility Fan-In and Visibility Fan-Out

We argue that this visual output and categorization of files should assist program managers in determining which data rights to purchase. Without this method the program manager would have had to decide which data rights in the 6,362 files were instrumental for future competition. Further exasperating the problem, there is a low likelihood that the program manager has any formal training in computer science or software development. The attractiveness of our methodology is that it allows for the prioritization of data rights without any understanding of the actual lines of code in each file. The program manager does not need to understand the function calls in any given file or even the purpose of each; he or she must only understand that one file calls another. From this we can identify the files which are difficult to separate from the software at large and are likely to survive in the software throughout multiple versions. In acquiring the rights to just this small percentage of files, we argue that it increases the likelihood of future sustained competition because the DoD has rights to the subset of files which are hardest to operate the software without.

Future Work/Conclusion

We have shown that there are no clear trends in the levels of competition in the DoD, as measured by ratios of J&As to contract awards, as a result of BBP. However, this is not to say that BBP is ineffectual, but that methodologies are still needed to implement the guidance outlined in BBP. To that end, we proposed a methodology to identify salient data rights in computer software, thus providing a means for program managers to understand which data rights are most important to ensure future sustained competition.

That being said, there are limitations to our proposed method. First, we make no attempt to account for the effects of file specific licenses on the prioritization of data rights. In the files identified in the flight simulator example, there could be open source files which carry varying license types[11] (e.g., General Public License, Lesser General Public License, Creative Commons, BSD, MIT, etc.). The presence of one or more of these licenses in the software could change which files the government is entitled data rights. Further work is needed to combine the license information at the file level into the methodology discussed herein. However, with more research we argue this obstacle is solvable.

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[11] The Free Software Foundation (FSF) lists 125 different open source copyright licenses. However, only 93 of the 125 are considered "free software" by the FSF definition, which is roughly "the users have the freedom to run, copy, distribute, study, change and improve the software" (Free Software Foundation, 2015). However, the standards of what qualifies as "free software" or open source software differ between organizations.

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Navy Mobile Apps Acquisition: Doing It in Weeks, Not Months or Years

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Abstract

Private industry and the Military both recognize the need to develop mobile applications (apps) to meet the growing demand for delivering content in a way that supports end-users' needs and preferences. The U.S. Navy has been examining all the conceivable strategic, policy, and security issues surrounding mobile application development and deployment, but limited Navy commands have had success implementing a policy and development methodology for meeting widespread end-user needs.

One exception has been the Program Executive Office (PEO) for Enterprise Information Systems (EIS), a U.S. Navy Program Executive Office whose mission is developing and sustaining business Information Technology (IT) systems for the Navy. One of their primary customers, the Chief of Naval Personnel, challenged PEO EIS to develop a strategy and development methodology for quickly developing mobile applications to meet a variety of Navy Human Resource (HR) needs.

PEO EIS, through a designation to one of its Program Management Offices (PMOs)—PMW 240, or the "Sea Warrior" Program—employed an innovative approach for design, development, and acquisition of mobile applications that has allowed it to field multiple mobile applications in just 8–12 weeks per application given strong customer engagement. To date, PMW 240 has fielded eight applications in the past year with dozens more in the planning and development phases.

This paper will share the innovative methodology, Systems Engineering Technical Review (SETR) process, and Federal Acquisition Regulation (FAR) insights that have allowed PMW 240 to field mobile apps rapidly. It will also discuss some of the challenges and next steps to expanding the Navy HR mobile application capabilities. Since PMW 240 is an acquisition executor, all processes, innovations, and insights will be presented from a practitioner perspective in hopes of benefiting other practitioner organizations that require mobile application deployment for their end-users.

Background

There has been an unprecedented level of interest across the U.S. Navy to rapidly investigate and enhance existing mobile technology capabilities, primarily due to their familiarity, convenience, ease of use, and productivity benefits. This investigation is considering implementations that leverage Government Furnished Equipment (GFE) and "Bring Your Own Device" (BYOD) models.

As the lead organization for Navy Enterprise mobility, the Deputy Chief of Naval Operations for Information Warfare held a Mobility Summit in October 2014, which laid the path to develop a holistic view of Navy enterprise mobility efforts—supporting afloat, ashore, and forward deployed operating environments. As a result, the Enterprise Mobility Integrated Product Team (EMIPT) stood up in January 2015 to serve as the Navy's designated advisory and action group for all matters pertaining to Navy enterprise mobility efforts. The team defined Enterprise Mobility as

> the suite of technologies and solutions that provides Navy personnel access to information any time, any place, and from any device. Access may be provided via government and/or commercial infrastructure utilizing multiple device capabilities, and related network and applications capabilities. (Department of the Navy, 2012)

Notwithstanding the demand for mobile application availability, there are significant information assurance and other technical and policy issues being actively addressed across the Navy. Leveraging existing guidance, Navy Manpower, Personnel, Training, and Education (MPT&E) leadership initiated its Mobile Application Management effort using the support of the Program Executive Office for Enterprise Information Systems (PEO EIS)/PMW 240 Sea Warrior Program to develop and deploy mobile applications for the MPT&E domain. A key element of the PMW 240 tasking is to build on government and commercial best practices, document its business and technical management processes, and lay out a path for institutionalizing MPT&E mobile application management practices. This tasking is being performed by the MPT&E Mobility Team, staffed by PMW 240.

The PMW 240 Mobility Team develops, oversees IA accreditation, tests, deploys, and supports mobile applications based on requirements from the MPT&E user community. The PMW 240 Mobility Project allows for the rapid development and deployment of mobile applications to meet both end user and Navy leadership demand signals, with the unique focus of providing these applications on BYOD versus GFE platforms and devices.

PMW 240's specific involvement in mobile application development began when the Chief of Naval Personnel (CNP) challenged PMW 240 to build two Navy lieutenants' mobile application concept for Division Officers. Six months later, PMW 240 not only delivered the eDIVO (electronic Division Officers; see Figure 1) application, but also the framework for all future MPT&E mobile applications. PMW 240 has delivered eight more information and training mobile applications since eDIVO, achieving a normal time to deliver from concept approval in less than four months, with the development pipeline queue filled with mobile applications from Sailors and functional business owners.

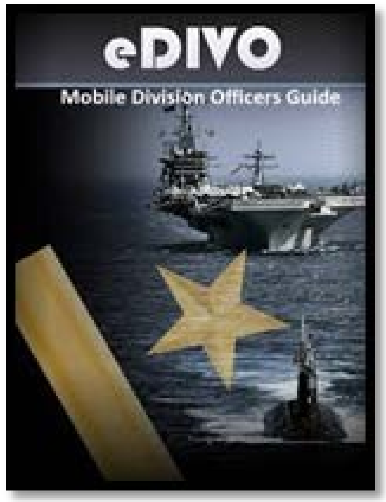

Figure 1. eDIVO Guide

Problem Statement

PMW 240 was tasked with quickly developing and delivering MPT&E mobile applications to Sailors on their personal mobile devices. However, unlike most commercial mobile leaders who can define and streamline their own procurement processes, a specific mobile application acquisition process did not exist separately from the standard weapon system acquisition processes that PMW 240 could leverage. Using the standard processes which were developed for large-scale Department of Defense (DoD) weapon systems would have returned lengthy development schedules and increased costs, which was unacceptable to the Chief of Naval Personnel and PEO EIS.

Innovative Solutions Approach

To address the challenges articulated by the problem statement, PMW 240 recognized it had to acquire mobile applications quickly and inexpensively. To achieve this goal, PMW 240 decided to use a robust framework provided by an acquisition process already tailored for IT—the Abbreviated Acquisition Programs (AAP) and Non-Designated Program process. This IT acquisition process was a necessary first step, but PMW 240 also recognized that it needed to "fine tune" and adapt that existing framework into one that could successfully deliver lightweight and secure mobile applications to their end users within months of initial conception without compromising the appropriate quality control and security checks inherent in the current process. Figure 2 illustrates how PMW 240 innovatively tailored the standard weapon system acquisition process to address its mobile application delivery challenge.

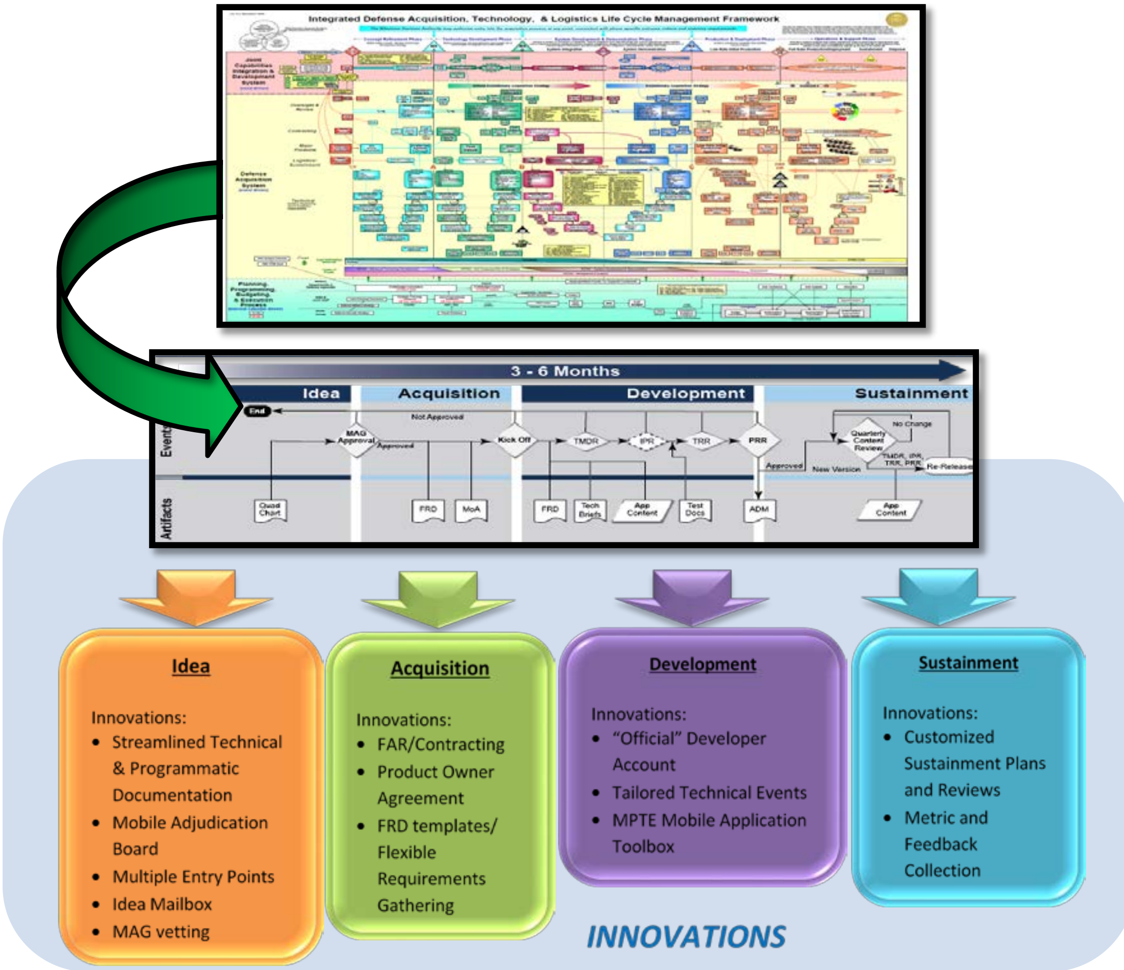

Figure 2. Robust DoD IT Acquisition Lifecycle Process Tailored to the PMW 240 Mobile Application Process and Innovations

PMW 240 has now successfully implemented the acquisition lifecycle process outlined in Figure 2. The remainder of this section will outline specific activities of the Idea, Acquisition, Development, and Sustainment phases of this process, identify core principles upon which mobile application acquisition is being executed, and discuss specific acquisition-related innovations in each of the four phases of the Figure 2 lifecycle process (Cochrane & Brown, 2010).

Mobile Acquisition Lifecycle Overview

The High-Level Operational Concept graphic in Figure 3 depicts the streamlined process the PMW 240 Mobility Team uses to identify mobile application requirements, then progressively lead those requirements through a series of executable systems engineering and project management phases and decisions to a fully functioning and sustainable mobile application (PMW 240 Sea Warrior Program, 2015b).

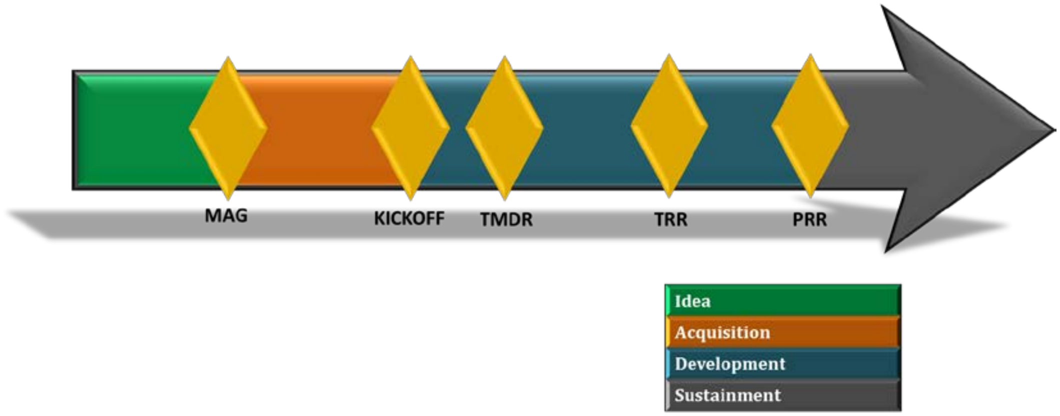

Figure 3. PMW 240 Mobile Application Development Process

The entire mobile application development process flows from left to right through the Idea, Acquisition, Development, and Sustainment phases, with specific and important activities involving both functional owners (customers) and PMW 240 in each phase.

The process starts in the Idea phase with the generation of ideas for new apps being presented to and evaluated by the Mobile Application Group (MAG), a governance body that prioritizes mobile application development. MAG approved applications are assigned to the PMW 240 Mobility Team for acquisition (PMW 240 Sea Warrior Program, 2015e).

The Acquisition Phase starts when approved ideas are more formally defined through the generation of acquisition documents and data. Through PMW 240's streamlined acquisition process and document templates, the team is able to rapidly move on these application ideas. The PMW 240 team then identifies an acquisition strategy, works with the application product owner (Navy subject matter expert organization who will own the content of the application after development) to create a functional requirements document (FRD), executes a Product Owner Agreement (POA) with that owner, and conducts a project kick-off with application product owners to ensure their understanding and support of the application's readiness for development.

After project kickoff, PMW 240 enters the Development phase by conducting a series of tailored systems engineering technical review (SETR) events that guide the project through requirements refinement, design, development, test, and production readiness decisions before the app is deployed for use. Those SETR events will be described in more detail later in this paper. Applications may be developed internally by Navy software developers, by PMW 240 contracted software developers, or externally by third party developers who are sponsored by Navy MPT&E functional leads or independent submitters. The outputs of the Acquisition/Development Phase are a fielded mobile application published on designated application stores.

In the Sustainment Phase, the Product Owner provides updated content as needed to the developer who updates the mobile app for publication via the app store. Both the Product Owner and the PMW 240 Mobility Team monitor feedback on content, functionality, usability, and user experience to determine upgrades or retirement for the app.

Mobile Application Core Principles

In addition to the overarching acquisition lifecycle and development process it developed and is following, PMW 240 recognized that it needed to identify and follow some core principles to also guide its mobile application acquisition efforts. These core principles provide a solid strategic foundation on which PMW 240 bases its mobile application acquisition and ensure that certain performance and compliance requirements are met (PMW 240 Sea Warrior Program, 2015a). These principles are

- Simplicity and Rapid Deployment—Mobile application projects should be designed with rapid deployment and simplicity in mind, wherever possible.
- Performance—The application must follow standard iOS and Android development practices to ensure a normal level of memory consumption.
- Security—The application must adhere to requirements and specifications outlined in the Cybersecurity Mobile Application Checklist, Fortify scans, and their respective references.
- Compliance—The application must comply with standard mobile platform vendor development guidelines outlined in official licensing and distribution agreements.
- User Documentation and Training—The application should make all documentation, lifecycle management, and training information publically available as needed. Application tutorials are a preferred method for training users of mobile applications how to perform necessary functions to utilize the application effectively.
- Maintenance/Sustainment—Mobile application projects should be designed to reduce the burden of maintenance and other sustainment actions. Before using any feature or supporting software, a developer must first search for reports indicating software and support will not sunset in the near future. Also, the developer must compare alternatives with respect to proven software and support longevity, and reputation for ease of maintenance.
- Feedback—The user must have the capability to email feedback directly to the NAVY 311 helpdesk. In addition, mobile application projects will use a Commercial Off the Shelf (COTS) capability to capture feedback within the application and subsequently collate, tag, and send that data to NAVY 311 when appropriate.
    - Each application will be issued its own email address to facilitate communication between the COTS software and NAVY 311.
    - The COTS software also provides the capability to capture feedback from various App Stores, Facebook, Twitter, and other social media resources, creating tickets from the feedback it discovers.

Idea Phase Innovations

Although the Idea phase of the lifecycle is relatively short and simple, PMW 240 has applied innovative guidance and tools to both accelerate and simplify this phase.

Streamlined Technical and Programmatic Documentation

Agile Mobility Plan

PMW 240 developed the Agile Mobility Plan (AMP) to provide technical information related to the development, cybersecurity, testing, deployment, and sustainment of PMW 240 mobile applications. The information contained in the document represents what is common to all PMW 240 mobile application investments. The AMP is the blueprint for the technical conduct and control of PMW 240 mobile applications from inception through sustainment. As a lightweight, tailored version of the PMW 240 Systems Engineering Plan (SEP), this 25-page document (innovatively short and concise) highlights only the aspects of systems engineering that are prevalent to the mobile application lifecycle. This allows for a purposeful, pointed document resulting in the rapid development and deployment of mobile applications to meet both end user and Navy leadership demand signals (PMW 240 Sea Warrior Program, 2015b).

Agile Mobility Management Plan

PMW 240 also developed the Agile Mobility Management Plan as a companion document to the AMP. The Agile Mobility Management Plan provides for management and governance of PMW 240 mobile application investments. The document specifies and delegates the Mobility Project Decision Authority (MDA) from the PMW 240 Program Manager down to a lower level, the Principal Assistant Program Manager (PAPM), for expedited decisions and more availability. Through delegation of this authority within the program office, project milestones, management policies, and governance decisions occur at a more rapid pace, permitting the PMW 240 team to deliver more applications in less time (PMW 240 Sea Warrior Program, 2015a).

Mobile Adjudication Board

PMW 240 established the Mobility Adjudication Board (MAB) to manage requirements, defect resolution, and other mobile application project issues as required; it is also a forum used to implement the fundamental change management process of configuration control during planning, development, deployment, and sustainment. The Mobility Adjudication Board Charter (MABC) enables a disciplined approach and visibility for the approval, disapproval, and prioritization of new or existing requirements. It is a critical component to maintaining the known configuration and ensuring all changes are approved prior to implementation.

The MABC has the Scope of Authority (SoA) for mobile app changes to the configuration baseline during the planning, development, deployment, and sustainment phases of the program. Mobility projects normally progress at a higher rate of speed than standard web application endeavors. For this reason, a single, very lightweight governing structure handles configuration management oversight during development (normally, more cumbersome Program Review Board [PRB] or Configuration Control Board [CCB] structures in full IT system acquisitions). This innovatively lightweight structure ensures issues are handled in a timely manner by the appropriate oversight and combines two traditional processes—PRB and CCB—into a single efficient review team (PMW 240 Sea Warrior Program, 2015d).

Multiple Entry Points

PMW 240 receives mobile applications that fall under various states of maturity within the lifecycle and allows for all to enter into its lifecycle process. Most applications are proposed in the form of less mature ideas, but some are maturing and already in some phase of a development state, or are fully built and ready to be published into the application store. To conserve resources and recognize the lifecycle maturity of these various applications, PMW 240 considers the current state of the application to determine where and how to categorize it. This allows for a customized yet expedited entry into the application store while verifying the application meets the proper exit criteria for deployment.

Idea Mailbox

PMW 240 acquires application ideas through a variety of sources, including leadership direction, command interest, and line of business owner ideas. PMW 240 also utilizes a digital mailbox advertised on Navy media. This innovative mailbox, seen in Figure 4, navyapps@navy.mil, receives ideas for new applications from both civilians and Sailors and is checked on a weekly basis to ensure new and fresh ideas for applications from practitioners are in the forefront of application development consideration. This mailbox is an innovative approach to soliciting mobile application ideas directly from the end-users who will benefit from them.

Figure 4. PMW 240's Application Mailbox

Mobile Action Group Review and Approval

On a quarterly basis, PMW 240 briefs the collected application ideas to the Mobile Application Group (MAG) for investment approval. If an application is not chosen for immediate investment, an informational quad chart detailing salient information for each application idea is entered into the Mobility Team's application backlog and will be reconsidered by the MAG at the following quarterly meeting. If the MAG approves an application idea, the PMW 240 Mobility Team performs required contracting actions which signal the beginning of the acquisition phase. Using a quarterly time-driven review period keeps the investments current and provides PMW 240 with regular direction on applications to best align with the leadership and end-user interest. Such frequent review of requirements and prioritization is innovative for IT acquisition, to say nothing of standard DoD 5000 weapon systems prescribed processes (PMW 240 Sea Warrior Program, 2015e).

Acquisition Phase Innovations

The acquisition phase of anything the DoD procures is not generally considered to be a space where innovation can flourish. However, PMW 240 has implemented innovative approaches to allow agility in acquiring new mobile applications.

FAR/Contracting

Per the Federal Acquisition Regulation (FAR), contract negotiation and execution can require extensive effort and wait time for an initial contract award and additional time for follow-on task order awards against an Indefinite Delivery/Indefinite Quantity (ID/IQ) or Multiple Award Contract (MAC) vehicle. To support rapid mobile application development, PMW 240 quickly recognized it needed a very flexible and responsive contracting strategy and associated vehicle that FAR-prescribed competitive or negotiated contracting procedures might not allow.

As a result of the unique MNP mobile app development needs, PMW 240 conducted market research to identify industry standard timelines and costs for developing the types of mobile apps under consideration. Based on that data, PMW 240 alpha-negotiated an ID/IQ contract vehicle with an economically-disadvantaged woman-owned small business. That vehicle contained Firm-Fixed Price (FFP) Contract Line Item Numbers (CLINs) for small, medium, and large application development, as well as for maintenance tasking on an app by app basis. The CLIN values were based on the industry standard costs and allow PMW 240 to award new task orders (TOs) selecting the needed CLINs in a matter of days. That

TO award speed significantly decreases the overall acquisition phase time requirements (PMW 240 Sea Warrior Program, 2015a).

Product Owner Agreement

Prior to beginning any development, the Mobility Team works with the Product Owners to negotiate the Product Owner Agreement (POA). The POA is a lightweight document comparable to a larger program's Memorandum of Agreement (MOA) that explains the responsibilities of the Product Owner and PMW 240 throughout the application lifecycle and ensures that an application is maintained following publication into the application stores. The POA explains that the Product Owner is responsible for any content-related changes, including notifying the PMW 240 team of any policy, link, or material updates, and the PMW 240 team is required to handle any technical changes, such as bug fixes and operating system updates. This document is negotiated and signed by the two participating teams and reposed under configuration control. The lightweight nature of the POA is innovative in that it allows signature at a lower organizational level, so it requires less oversight, allowing the development on the application to begin sooner (PMW 240 Sea Warrior Program, 2016a).

FRD Templates/Flexible Requirements Gathering

In addition to the POA, PMW 240 requires a Functional Requirements Document (FRD) to be completed and signed before beginning development. The Mobility Team has three FRD templates depending on the type of the application to be built: an aggregated content application, a training application, and a hybrid application (content and training). The most fitting template is then customized through a series of rapid meetings with the PMW 240 team and the Product Owners and reviewed by the development team for any needed clarification. Once all parties are confident that the FRD captures the vision for the application, the document is signed out and the development phase can begin with the Tailored Mobile Design Review (TMDR). This innovatively rapid requirements gathering and clarification process using these pre-defined templates generally requires no more than 10 business days, which is an extremely short timeline compared to standard IT and weapon systems acquisitions timelines for similar activities (PMW 240 Sea Warrior Program, 2015c).

Development Phase Innovations

The Development phase of the lifecycle is usually the longest phase of any acquisition, and it is for PMW 240 mobile applications as well. To decrease required development time as much as possible, PMW 240 has implemented innovative guidance and oversight.

"Official" Developer Account

With a diverse set of product owners working with PMW 240 to develop the applications, it is important to adhere to specific standards and meet certain thresholds when it is time for production. PMW 240 established developer accounts for the public application stores (Apple and Google) and is the clearing house for all official Navy MPT&E mobile applications. The streamlined process for publication and production ensures each application meets the exit criteria for the PMW 240 process and the entrance criteria for these public application stores. The efficiency of this singular clearing house point provides a structured process and effective release methodology.

Tailored Technical Events

The PMW 240 Technical Event Process (TEP) guidebook provides guidance for planning Systems Engineering Technical Reviews (SETR) events. However, that document generally guides development through a waterfall approach that requires months and even years of technical events to deliver working software. PMW 240 innovatively tailored the SETR guidance to match the agile methodology it has implemented to deliver MPT&E mobile apps in weeks and months instead of years. The following are the critical tailored technical events required to track progress for each mobile application. Each of the four technical events listed below are one hour in length and require participation from the Product Owners, PMW 240, the development team, and representatives from Cybersecurity, the Public Affairs Office (PAO), Enterprise Change Management (ECM), Configuration Management (CM), Test, and Logistics.

- **Kickoff Meeting (KO)**—After a mobile app project receives MAG approval, a Kickoff meeting is held to introduce team members from different competencies and stakeholders to establish the expectations for development/deliver, general procedures to be followed, priorities, schedule, and clear assignment of roles and responsibilities.
- **Tailored Mobile Design Review (TMDR)**—The TMDR is a tailored combination of three standard technical reviews: System Requirements Review (SRR), System Functional Review (SFR), and Preliminary Design Review (PDR). Conducted by the Mobility Assistant Project Manager-Engineer (APM-E), this review ensures the preliminary design of the application meets all functional requirements and the initial and allocated baselines for development, test, and deployment have been established. Combining these events allows PMW 240 to shorten the data collection and review timeline to only pertinent information.
- **Test Readiness Review (TRR)**—The Mobility APM-E conducts this review once the application's initial development effort has been completed. This review will assess the application's readiness to begin initial formal testing procedures. These procedures include testing the application on PMW 240-owned mobile devices (including both smartphones and tablets), as well as on mobile platform simulator software. It also includes conducting needed security scans.
- **Production Readiness Review (PRR)**—The Mobility APM-E and Mobility PD conduct the Production Readiness Review (PRR) following the completion of initial testing on PMW 240-owned smartphones and tablets. This review will analyze the application's readiness to begin the migration process to the target mobile application stores. This analysis will include further testing of the application on personally-owned devices to ensure the integrity of its performance.

The PMW 240 Mobility Project Team works with the mobile application developer to ensure the evaluation criteria for entrance and exit of particular technical events are appropriate to the level of effort, cost, schedule, and complexity of the mobile application.

The 240 mobility project team reviews developer-crafted test cases to ensure they prove completion of capabilities they are written to test. The contractor performs a final quality assurance testing phase after the final development iteration. After this final testing iteration, the government enters the final acceptance testing procedures. The PMW 240 Mobility Project Team also integrates security and usability testing and evaluation into the development process to streamline testing cycles and overall impact to cost and schedule. The developer ensures that prior to each iteration release, the developed application has gone through a cycle of developer level testing to ensure functionality intended for demonstration and preview is functioning as expected.

During the government's acceptance testing, the government solicits the necessary testing resources that align with the application's target audience, and the Test Team lead verifies all application functionality works as designed.

Final application approval and permission to release the application is at the discretion of the PMW 240 Mobility Team Decision Authority after the Development Team adjudicates and addresses submitted defects and comments.

Compared to normal weapon system and IT SETR events and timelines, this process tailored for PMW 240 mobile applications is highly innovative and extremely fast in delivering capability to end-users (PMW 240 Sea Warrior Program, 2015b).

MPT&E Mobile Application Toolbox

In an effort to encourage application proliferation for the Navy MPT&E community, PMW 240 developed a "toolbox" that is accessible to civilian, active duty, and reserve members of the Navy. While PMW 240 would still be the clearing house and publishing authority, the toolkit provides tips, style guidance, information on development environments, and tricks for building specific application components for any development audience that wishes to build mobile applications that look, feel, function, and are compatible with those PMW 240 has built for the Navy MPT&E community. The toolbox is designed as a self-sustaining wiki, meaning that developers can use the site to post questions, read topic forums, and even contact the PMW 240 mobility team for specific questions. The website will highlight sample projects and serve as an additional execution arm to the work being completed in PMW 240. The use of a toolkit, shown in Figure 5, allows developers to structure their application to appear and operate as an official U.S. Navy application, yet encourages development by third parties. It is an extremely innovative and collaborative approach that allows any capable entity to develop MPT&E approved mobile applications, instead of restricting that ability to one single vendor or in-house Government development team (PMW 240 Sea Warrior Program, 2016b).

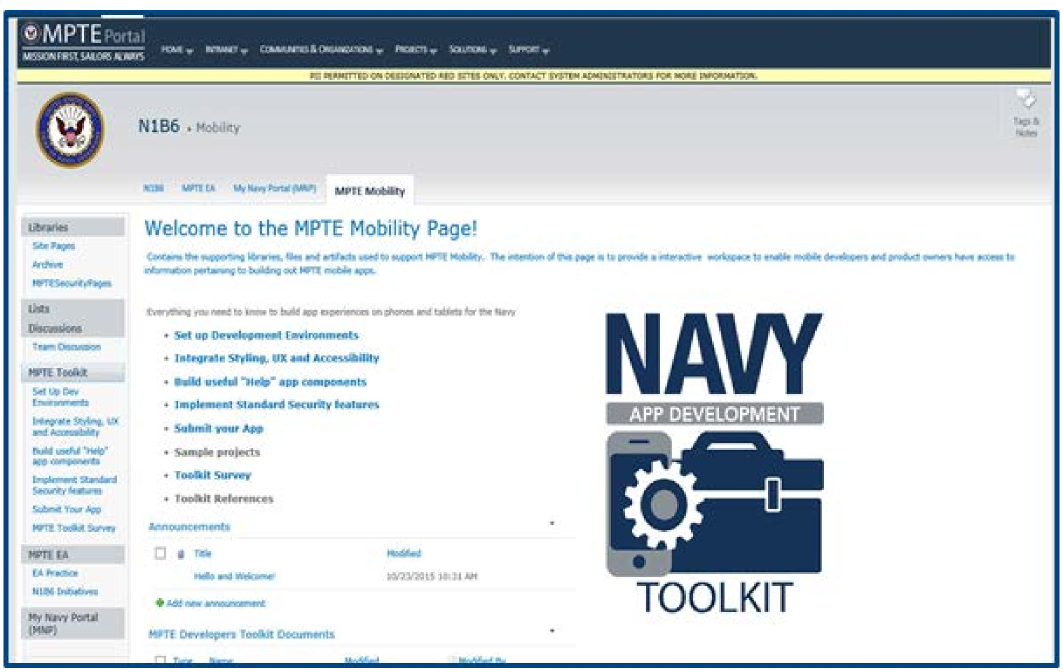

Figure 5. MPT&E Mobility Toolkit

Sustainment Phase Innovations

Although the Idea phase of the lifecycle is relatively short and simple, PMW 240 has applied innovative guidance and tools to both accelerate and simplify this phase.

Customized Sustainment Plans and Reviews

Once an application has been released for use, PMW 240's primary task is to ensure the content and technology is current, functional, and accessible to the user base. As discussed previously, each Product Owner signs a POA before development begins, and the POA is followed throughout sustainment of the application. On a quarterly basis, the application is reviewed to assess the value of the investment. Along with metrics and feedback, discussed below, the internal PMW 240 team reviews the need for any updates (either content-related or technical) to determine whether an application's state is acceptable. On a biannual basis, the Product Owners are invited to the reviews and discuss the feasibility of an upgrade, application usage, alignment with the Product Owner's team, and to decide whether the application's status warrants continued sustainment funding. Monitoring and evaluating the applications every three months prevents stagnant content, unwarranted investment, and insightful trend analysis, and fosters the relationship with the Product Owners—all on an innovatively manageable level and with a minimal time investment.

Metric and Feedback Collection

PMW 240 collects metrics and feedback from each of the applications in order to better assess the status of any particular application and use the results to determine continued investment. Metrics are aggregated from the application stores and a built-in feedback mechanism within the application. From the public stores, PMW 240 can see star ratings, comments, number of downloads per day, and devices that use the application. From the inherent mobile applications feedback mechanism, PMW 240 can view, respond to, and route comments to the development or product owner team for consideration. Comments are often in the form of suggestions for additional content/functionality or reports of bugs. The above-mentioned feedback is collected on a weekly basis, and the compiled version is distributed on a monthly basis for review. The PMW 240 team can actively monitor an application's usage, end user reactions, and any issues and incorporate any resulting changes into future builds of the application. This innovatively thorough yet rapid and easy-to-decipher data collection and monitoring allows for a direct feedback loop and response adjudication to better serve the end user's needs.

Challenges and Next Steps

Mobility within the Navy will continue to grow and reach a broader audience. With this growth, the demand for more mobile capabilities, including transactional applications that interact with current DoD systems, will increase. There are, however, a number of challenges facing the Navy—particularly in the use case of BYOD mobile platforms—to ensure its workforce can fully utilize mobile capabilities for all their mission requirements. Some of these challenges include using Derived Credentials, opening an Official Navy App Store, and implementing a Mobile Application Management (MAM) framework.

Derived Credentials

Supporting secure access to mobile devices through 'Derived Credentials' (a National Institute of Science and Technology coined term to describe cryptographic credentials derived from Personal Identity Verification [PIV] and Common Access Cards [CACs]) is one of the Navy's and U.S. Government's biggest challenges for enabling its mobile workforce to securely access and authenticate mobile devices interacting with

Government data. The current use of physical CACs and card readers limits the use cases of usable mobile devices and is un-scalable, resulting in high costs to implementation. Using software, micro-hardware, or other cryptographic methods of access and authentication will have to be developed, tested, and put into production before the Navy fully realizes the full suite of mobile capabilities currently available to the commercial world.

Navy App Store

Providing Sailors and civilians access to a full suite of official Navy mobile applications, designed to enable their day-to-day work, will ensure they have access to officially authorized Navy information and applications. If and when realized, this “Navy App Store” could serve both GFE and BYOD platforms/devices. Establishing this app store will provide a single location for Sailors and civilians to access Navy applications and content without fear of downloading a fake or malicious Navy application in the open commercial app stores.

MAM Framework

Along with an official Navy application store, utilizing a MAM service to manage the growing number of Navy applications will be vital to sustainment. Keeping applications up to date with their respective operating system and hardware platforms, as well as content updates, will ensure the applications end-users will have fully operational apps with current information. A MAM can also provide robust security for Navy applications when loaded to a Sailor’s personal device which may allow for transactional applications that connect securely with DoD systems while restricting access to any personal data on the device. PMW 240 is currently performing a Material Solutions Analysis (MSA) on various MAM vendors and will assess potential application use cases for future production.

Conclusion

PMW 240 has developed a streamlined and agile process to securely acquire and deliver high quality mobile MPT&E applications to Sailors and civilians. As the appetite for mobile applications and information consumption continues to grow, PMW 240 will continue to be flexible and scalable with its acquisition and associated mobile application fielding processes to meet end user and Department of the Navy future needs while maintaining information security and assurance standards.

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Panel 7. Current Issues in Contracting

Wednesday, May 4, 2016	
1:45 p.m. – 3:15 p.m.	**Chair: Elliott Branch,** Deputy Assistant Secretary of the Navy, Acquisition & Procurement ***Mining for Gold: Developing and Implementing a Strategic Sourcing Prioritization Model for the United States Air Force*** Maj Karen Landale, USAF, Assistant Professor, NPS Roger Westermeyer, Col, USAF (Ret.) Maj John Sharkey Rick Keller Carl Parson MSgt Michael Rankin SSgt Justin Keeney ***An Economic Analysis of the Truth in Negotiations Act (TINA)*** Chong Wang, Associate Professor, NPS Rene Rendon, Associate Professor, NPS 1st Lt Crystal Champion, USAF Capt Meredith Ellen, USAF Capt Jenny Walk, USAF ***Freedom of Market Navigation Versus Duty of Economic Rescue: The U.S. Department of the Navy's Use of Set-Asides Parity, Discretion, and Simplified Acquisitions to Contract With Hubzone Small Businesses*** Max Kidalov, Assistant Professor, NPS

Elliott Branch—is the Deputy Assistant Secretary of the Navy (Acquisition and Procurement) in the Office of the Assistant Secretary of the Navy (Research, Development & Acquisition). He is the senior career civilian responsible for acquisition and contracting policy that governs the operation of the Navy's worldwide, multibillion-dollar acquisition system. Branch is the principal civilian advisor to the Navy Acquisition Executive, serves as the Department of the Navy's Competition Advocate General for procurement matters, and is the community leader of the Navy's contracting workforce. Prior to joining the Navy Acquisition Executive staff, Branch was the first civilian director of contracts at the Naval Sea Systems Command. In that role, he led one of the largest and most complex procurement organizations in the federal government. As the senior civilian for contracting at NAVSEA, Branch was responsible for the contractual oversight of the nation's most complex shipbuilding and weapons systems procurement programs. His duties involved the obligation and expenditure of approximately $25 billion annually. Branch is a member of the Senior Executive Service (SES). Members of the SES serve in the key positions just below the top presidential appointees. They are the major link between these appointees and the rest of the federal work force. SES members operate and oversee nearly every government activity in approximately 75 agencies.

Branch spent time in the private sector, where he specialized in acquisition and project management education, training, and consulting for the federal workforce and its associated contractors. In this role, Branch was responsible for the design, development, delivery, and maintenance for a wide variety of course material ranging from project management to contract law. Branch's clients included the Computer Sciences Corporation, QSS Group, BAE Systems, the Pension Benefit Guaranty Corporation, and the Departments of Defense, Energy, Justice, and State.

Prior to that, he served as the chief procurement officer for the government of the District of Columbia, where he was the agency head responsible for procurement operations, for policy, and for formulating legislative proposals for local and congressional consideration. Branch led a staff of over 200 employees that supported over 40 city agencies, administered a $14 million annual operating budget, and oversaw the placement of $1.5 billion, annually, in city contracts. Before joining the District government, Branch held various positions in the SES with the Department of the Navy (DoN). In 1993, he became a member of the SES as the director, Shipbuilding Contracts Division, at NAVSEA. He next served as executive director, Acquisition and Business Management for the DoN, responsible for policy and oversight of contract operations throughout the entire Navy. While in this position, he also served as project executive officer, Acquisition Related Business Systems. In this role, he was responsible for the formulation and execution of a multi-year effort transforming the Navy's acquisition system from a paper-based system into one that made use of electronic technologies and methods. In this role, Branch was directly responsible for a portfolio of projects worth more than $200 million.

Branch graduated with a Bachelor of Science degree in economics from the University of Pennsylvania and completed the Executive Program at the University of Virginia Darden School. He has received the Navy Distinguished Civilian Service Medal, the David Packard Excellence in Acquisition Award, two Presidential Rank Awards for Meritorious Executive, and the Vice Presidential Hammer Award for Reinventing Government.

Mining for Gold: Developing and Implementing a Strategic Sourcing Prioritization Model for the United States Air Force

Maj Karen Landale, USAF—is an Assistant Professor at the Graduate School of Business and Public Policy, Naval Postgraduate School, Monterey, CA. She teaches strategic sourcing and category management as part of the contracting curriculum. Major Landale received her PhD from the Kenan-Flagler Business School at the University of North Carolina at Chapel Hill. Her research focuses on talent management, services marketing, and contracting in the public domain. She is married to LTC Gordon Landale, USA, and they have one daughter, Amelia, who is 17 months old. [kalandal@nps.edu]

Roger Westermeyer, Col, USAF (Ret.)

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Rick Keller

Carl Parson

MSgt Michael Rankin

SSgt Justin Keeney

Abstract

Strategic sourcing involves aligning the processes and effects of the purchasing and supply management function to the organization's overall business strategy. Strategic sourcing aims to add value to the organization through enhanced supplier relationships, total ownership cost reduction, and demand management. In the Air Force (AF), the agency charged with implementing strategic sourcing for all installation-level spend is the Air Force Installation Contracting Agency (AFICA). AFICA needed a way to determine which supplies and services represent the best strategic sourcing opportunity—a prioritization model that "digs" through the mountain of spend to find veins of "gold."

This research develops a spend analysis prioritization model that mirrors those used by the commercial sector. It marries internal AF spend data to external market data to gain a comprehensive view of each supply and service, and its potential as a strategic sourcing opportunity. Ultimately, 1,706 supplies and services are ranked based on their strategic sourcing opportunity score, thus providing a guidepost for AFICA to assign resources to opportunities with the most potential value. Using this new approach, AFICA can combine supplies and services into related categories to more strategically manage related spend, allowing Category Management teams to thoroughly understand demand, underlying costs, and the market.

Introduction

The Air Force Installation Contracting Agency (AFICA) is tasked with "managing and executing above-Wing-level operational acquisition solutions, across the Air Force enterprise" (AFICA, 2016). In years past, strategic sourcing projects were selected using pivot tables that examined the attributes of each federal supply code (FSC) or product service code (PSC).[1] The process involved examining dollars obligated, number of contracts written, number of suppliers, and other basic attributes that were readily available in the data. Projects were also selected based on customer demand, meaning that if a customer felt their project was worthy of being strategically sourced, AFICA (and its predecessor organizations) would dedicate a team to investigate the potential cost and process savings associated with the project and make a decision to proceed or not based on those potential savings. This process is labor-intensive, and AFICA soon realized it must take a more proactive approach to finding new strategic sourcing opportunities in order to more easily find the veins of "gold" hidden in their "mountain" of spend.

The purpose of this research is to discuss the new proactive approach that was designed as a collaborative effort between AFICA/KA (Strategic Plans and Communication Directorate) and the Naval Postgraduate School (NPS). This new approach mirrors the spend analyses that have been performed in industry for decades. It marries internal Air Force (AF) spend data to external market data to gain a comprehensive view of each FSC/PSC and its potential for strategic sourcing. Ultimately, 1,706 FSCs/PSCs are ranked based on their opportunity score, thus providing a guidepost for AFICA to assign resources to FSCs/PSCs with the most potential value.

Using this new approach, AFICA can combine FSCs/PSCs into related categories in order to more strategically manage AF installation spend.[2] Those categories are managed by Category Management teams, whose primary goal is to thoroughly understand the demand, the underlying costs, and the market related to the category in order to properly manage the category's spend. The value of our research lies in understanding which FSCs/PSCs represent the best strategic sourcing opportunities for the AF in order to properly assign limited resources to exploit potential category savings. We want AF "miners" to "dig" in locations with the highest likelihood of "gold."

The remainder of this paper proceeds as follows: The next section discusses the growing literature related to strategic sourcing and spend analysis, to include a discussion of the government's strategic sourcing goals. The Methodology section details the methods we used to create and implement the algorithm that prioritizes the PSCs. The Results section provides results of the algorithm, and the final section concludes the research and discusses next steps.

Literature Review

Purchasing Transformation—Strategic Sourcing in the Commercial Sector

Transformation in the purchasing function began in the commercial sector in the 1990s. As the business world became more global, organizations began looking for new ways to not only compete on a global scale, but also to gain competitive advantages. They soon discovered that a more strategic approach to managing their costs and supply base

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[1] "Also referred to as federal supply codes, product service codes are used by the United States government to describe the products, services, and research and development purchased by the government" (Outreach Systems, 2016). FSCs describe products, while PSCs describe services. We examine both in our analysis.

[2] While this research examines all AF spend data—installation and weapon system—we are only interested in finding strategic sourcing opportunities in the installation portion of the data.

could reap huge savings, allowing them to produce at lower cost—and often better quality—than their competitors. Purchasing moved from a relatively ignored administrative function, to a more holistic supply management function that aimed to cross organizational boundaries in order to better predict supply needs and deliver better quality goods and services. The tactical function of purchasing was no longer useful in the global marketplace. In its stead came a “more transformational process, performed at higher organizational level … [that] examine[s] the whole supply network, its linkages, and how they impact procurement and purchasing decisions” (Wallace & Xia, 2014). This process is known as strategic sourcing.

Strategic sourcing was developed to better align the mission of the supply management function to the organization’s overall business strategy. In short, strategic sourcing aims to add value to the organization through enhanced supplier relationships, reduced total ownership costs, and demand management. Dwyer and Limberakis (2011) identify organizations that are Best-in-Class strategic sourcing performers using the following criteria: (1) spend under the management of the procurement group, (2) procurement contract compliance, and (3) realized/implemented cost savings (p. 2). In their study of 315 companies across the globe, they found that Best-in-Class performers achieved

- 37% higher spend under management
- 72% higher contract compliance
- 52% higher realized/implemented cost savings

Clearly, implementing strategic sourcing can vastly improve the purchasing and supply management function. So why haven’t all procurement organizations implemented a strategic sourcing process? Most find it difficult to get past the very first step.

Spend Analysis

Laseter’s (1998) Balanced Sourcing Model involves seven steps: (1) spend analysis, (2) industry analysis, (3) cost/performance analysis, (4) supplier role analysis, (5) business process reintegration, (6) savings quantification, and (7) implementation. This research focuses mainly on Step 1, the purpose of which is to understand the organization’s historical spend patterns by examining them from many different angles. We also touch briefly on Step 2, as external market data is critical to developing a sound sourcing strategy. Many regard spend analysis as the most difficult step in the strategic sourcing process (RAND, 2004; Handfield, 2006; Pandit & Marmanis, 2008). It takes the longest amount of time to implement and it requires a team of persistent researchers who are willing to diligently track down the disparate data required to truly understand the organization’s history of spend (or “profile”) in the category. Even after the data are aligned, they are often not readily analyzable, that is, they require a large amount of cleaning to achieve accurate results. Take Handfield’s (2006) bleak assessment:

> Be careful! Doing a spend analysis can in some cases mean diving into a black hole. In about 80 percent of the companies we interviewed, an initial venture into spending analysis proved to be a data nightmare. For example, many companies found that their spend analyses were tracked using Excel spreadsheets. (p. 110)

Despite these difficulties, all agree that the spend analysis is the most critical step, as all subsequent steps rely on the information gathered therein.

> Although such an analysis can be time-consuming and labor-intensive, private enterprises have found that without a spend analysis it is difficult to

> identify prospective targets for applying better [purchasing and supply management] practices, develop supply strategies for specific commodities, select the best suppliers, manage suppliers in a way to maximize rewards and minimize risks, and convince all senior leadership of the need to shift to best [purchasing and supply management] practices and of the need for resources for the shift. (RAND, 2004, p. 7)

Naturally, an organization must first understand its history of spend in a given supply or service in order to make decisions to improve sourcing. “Spend analysis is the starting point of strategic sourcing and creates the foundation for spend visibility, compliance, and control” (Pandit & Marmanis, 2008, p. 5). A spend analysis “can help enterprises improve their purchasing practices in the areas where they are likely to produce the greatest benefits” (RAND, 2004, p. vii). Once an organization understands their spend history, they can develop ways to reduce or aggregate demand, rationalize suppliers to the optimal number, achieve volume discounts by leveraging spend, develop methods to improve supplier performance, and minimize transaction costs. In short, strategic sourcing cannot happen without first conducting a spend analysis.

A spend analysis begins with the collection of data. For most organizations new to spend analysis, this often involves consolidating data across several different databases, as few organizations have their data organized at the corporate level. Data consolidation is often a cumbersome process—data fields do not match perfectly, making them difficult to combine into a rich set of data that contains all the information needed for a spend analysis.[3] Once the data have been collected and consolidated, the next step in the spend analysis is to identify opportunities for strategic sourcing.

Opportunity Assessment

Handfield (2006) defines an opportunity as supplies or services that have “a reasonable possibility of adding more value,” with value coming in the form of time, money, and/or quality (p. 54). Therefore strategic sourcing opportunities are those that can save the organization time and/or money while maintaining or increasing quality.

Spend-level opportunities can be identified by examining as many of the following variables as possible (Pandit & Marmanis, 2008):[4]

- Number of vendors per supply or service (known as vendor fragmentation)
- Number of purchasing offices per supplier
- Number of contracts across purchasing offices
- Number of purchases from preferred/non-preferred suppliers

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[3] The ideal spend analysis application contains components that allow for data definition and loading, data enrichment, spend data analytics, and knowledgebase management (Pandit & Marmanis, 2008).

[4] Notably, not all of these variables are available in AF’s spend data. However, many of these variables were used in the RAND (2004) report that uses spend analysis to identify strategic sourcing opportunities for the AF. Their report focuses on all AF spend, and the results point to achieving more value in weapon systems spend. Our research focuses on where to achieve more value using only *installation* spend data.

- Diversity spend compliance (known as socio-economic factors in the government)
- Amount of spend with suppliers with good performance/bad performance

Each of the variables should be examined for each supply or service. Then, once the information has been unraveled at the lowest possible level, aggregation into appropriate categories can occur. Once aggregated, categories can be scored to show which present the best opportunities for strategic sourcing. Clearly, those with the largest potential for savings with the easiest implementation should be the top priority. Pandit and Marmanis (2008, p. 81) use an "implementation wave" analogy to determine which opportunities to address first, shown in Figure 1.

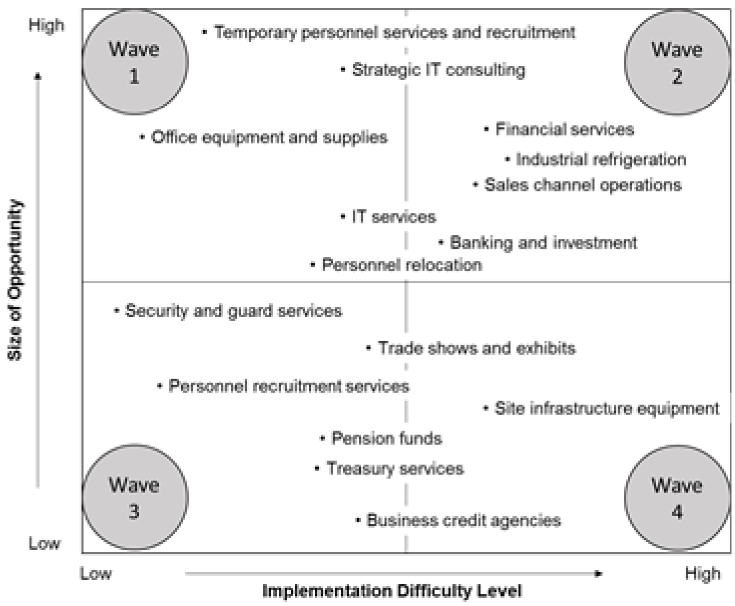

Figure 1. Opportunity Implementation Wave
(Pandit & Marmanis, 2008)

Opportunity assessment does not stop after all the internal spend analysis has been completed. Instead, the internal data are married to external data (Step 2 in Laseter's model) that addresses the market conditions associated with the supply or service. "A spend analysis integrates internal spend data and external supplier and market data and applies analytical techniques to help identify risks and opportunities for performance improvements and savings by applying best practices in purchasing and supply management" (RAND, 2004, p. 8). Using internal and external data, the most viable strategic sourcing opportunities are identified, cross-functional teams are created to further develop the profile of the category (i.e., develop cost/time savings and demand management estimates), and the process continues through the remainder of Laseter's (1998) model.

Purchasing Transformation—Strategic Sourcing in the Federal Government

The Federal government began the purchasing transformation in the early 2000s. In 2003, then-principal deputy under secretary for acquisition, technology, and logistics (USD/AT&L), Michael W. Wynne, challenged the DoD to make improvements to the acquisition process by generating value-added changes (Rendon, 2005). In 2004, then-director of defense procurement and acquisition policy, Deidre Lee, noted that "strategic sourcing and commodity councils [are] procurement processes that are designed so more could be done with less by migrating large contracts to regional centers and consolidating like services" (Rendon, 2005, p. 13). The Office of Management and Budget (OMB) issued a memorandum to all Chief Acquisition Officers, Chief Financial Officers, and Chief Information Officers to "leverage spending to the maximum extent possible through strategic sourcing" (OMB, 2005, p. 1). Agencies were expected to develop strategic sourcing governance, goals and objectives, performance measures, and communication and training strategies to begin implementing strategic sourcing.

In response to these calls to action, the AF began the process of strategic sourcing in 2003 with the advent of the Information Technology Commodity Council. This commodity council was charged with standardizing the computers available to AF units while reducing spend. To do that, they developed three computer configurations that were available for purchase and negotiated a deal with Dell Computers for 12,500 computers. The savings from this deal allowed the AF to purchase 2,500 more computers than planned for in the initial procurement (Rendon, 2005).

With its first success under its belt, the AF created the Enterprise Sourcing Squadron (ESS) in 2010. Along with other responsibilities, the squadron was tasked with finding more opportunities for strategic sourcing. ESS later became the Enterprise Sourcing Group (ESG) and in 2013, the AFICA. During that timeframe, the OMB issued another memorandum that provided more detailed strategic sourcing guidance to the agencies, including the designation of Strategic Sourcing Accountable Officials, an Interagency Strategic Sourcing Leadership Council, and identification of the characteristics that all government-wide strategic sourcing vehicles should have (OMB, 2012). Using this guidance, agencies have been working hard to establish their strategic sourcing programs.

The AFICA currently has six commodity councils under its purview, including: Information Technology, Medical Services, Furnishings, Force Protection, Civil Engineering, and Knowledge Based Services (U.S. Air Force, n.d.). While these councils have been successful at managing demand, reducing costs, and improving quality, the organization must constantly search for the next supply or service to strategically source. The AF is a very large buyer, purchasing an average of $59.8 billion in supplies or services annually.

A 2012 GAO report found that as of fiscal year 2011, the DoD, the Department of Homeland Security, the Department of Energy, and Veterans Affairs—which collectively account for 80% of federal procurement spending—spent only 5% of their funding using strategic sourcing techniques (p. 7).[5] In defense of these organizations, spend analysis is a difficult and time-consuming process, made worse by the fact that the data required to conduct spend analyses exist in many different systems that are not linked for easy consolidation. Further, most federal agencies lack the required employee expertise to lead strategic sourcing efforts.

Despite these limitations, the AF is the leading strategic sourcing organization in the DoD (Defense Procurement & Acquisition Policy, n.d.). Recognizing the need to identify installation-level strategic sourcing opportunities by conducting a thorough spend analysis,

[5] The DoD was just slightly better than the average among the four departments, with 5.8% of spend via strategic sourcing. AF efforts in FY11 account for 3.7% of spend via strategic sourcing, which is higher than any other military service component.

AFICA partnered with NPS to develop a strategic sourcing prioritization model. We detail the methods used to develop and implement the model in the next section.

Methodology

Data

Our analysis uses five years of data (FY2010–FY2014) from the Federal Procurement Data System–Next Generation (FPDS–NG). Data held in this system are input via DD350s–Individual Contract Action Reports (CARs), and consist of 699,522 cases.[6]

Although the data were readily available to us, they did not come without limitations. AF spend data is not particularly "clean"—there are known problems related to user input. The system relies on input from several thousand users—that alone increases the potential for input error. Further, many of those doing the inputting do not know what ultimately happens with the data, therefore they have little incentive to be perfectly correct with their input.

Another limitation of the data is that it is not as comprehensive as we would like it to be, another typical problem with research-related empirical data. FPDS–NG does not currently capture all the fields needed to perform the most rigorous spend analysis possible. See RAND (2004) for a detailed assessment of the issues related to AF spend data.

While we recognize our data are not perfect, using it is far better than continuing to rely on a reactive approach to strategic sourcing. Thus we proceeded with the research, which involved two overarching steps: (1) creating the prioritization algorithm that uses internal spend data to determine which FSCs/PSCs have the most potential for strategic sourcing, and (2) matching the related external market data to those FSCs/PSCs to further assess strategic sourcing viability.

Prioritization Model

The prioritization model was created by (1) culling the data for variables most useful for conducting a spend analysis, and (2) assigning weights to select for the variables we feel are most important. We discuss each of these steps in detail.

Selecting Variables

FPDS–NG contains more than 250 variables. To be parsimonious, we trimmed the number of factors to the seven available in the data that are most similar to those used by the private sectors to perform their spend analyses, and those we believe have the highest reliability.[7] Those seven variables are: (1) number of contracts, (2) number of suppliers, (3) number of purchasing offices, (4) number of offers received, (5) total obligated dollar amount, (6) contracts per time period, and (7) number of AF major commands (MAJCOMs) that purchased the supply or service.

The first variable, number of contracts, assesses how many times in the last five years a contract action has been performed to purchase the supply or service. The larger

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[6] In this case, a case is a contract action.

[7] In this case, reliability refers to the likelihood that the data were input correctly—that the user filled out the DD350 correctly and/or that the system generates the input automatically, thus reducing input error.

the number of contracts, the higher potential that a strategic sourcing opportunity exists to gain volume discounts and reduce transaction costs by consolidating purchases.

The second variable, number of suppliers, assesses how many suppliers the AF uses to purchase the supply or service. The larger the number of suppliers, the higher potential that a strategic sourcing opportunity exists, as strategic sourcing involves rationalizing the supply base to the appropriate number of suppliers to match the value and risk profile for the supply or service.[8]

Number of purchasing offices, the third variable, assesses how many different contracting organizations purchased the supply or service over the last five years—it assesses the commonality of the requirement. The larger the number of purchasing offices, the higher potential that a strategic sourcing opportunity exists, as consolidating purchases for the supply or service allows the AF to leverage their strength as an enterprise (e.g., volume discounts, valuable customer benefits, etc.), rather than appearing as dozens of smaller customers (i.e., individual purchasing offices) to the suppliers.

The fourth variable, number of offers, assesses the level of competition received in the last five years. The larger the number of offers, the higher competition there appears to be in the market. Higher competition indicates the buyer has more power over suppliers, which equates to higher potential that a strategic sourcing opportunity exists.

The fifth variable, total obligated dollar amount, is a simple additive total of the spend for each FSC/PSC over the last five years. Naturally, the more the AF spends on a particular supply or service, the more interested the organization is in getting that spend under management, i.e., the more interested they are in strategically sourcing the supply or service to reap cost and process savings.

The sixth variable, contracts per time period, is an estimate of the trend in purchases for the supply or service. We examine whether the number of contracts is increasing, decreasing, or remaining relatively unchanged over the five-year period. Clearly, an increasing trend indicates that the AF should consider strategically sourcing the supply or service. Unlike the other variables, this variable received binary coding, where an increasing trend received a score of 1, and a decreasing or unchanged trend received a score of 0.

Finally, the seventh variable, number of MAJCOMs that purchased the supply or service, assesses the universality of the supply or service. In other words, are all MAJCOMs purchasing the supply or service, or is it only being purchased by a certain subset of the MAJCOMs? For instance, consider transient alert services. This service is only used for bases with flight lines, which may limit the MAJCOMs who purchase the service to Air Combat Command, Air Mobility Command, and Air Force Education and Training Command. Using this variable, we are attempting to assess if strategically sourcing the

[8] We recognize that an extremely small number of suppliers is also cause to strategically source, as the AF would benefit from developing closer relationships with critical suppliers who have little competition in their markets. In our data, we found that FSCs/PSCs with extremely small numbers of suppliers related mostly to weapon systems spend. Because we are focusing on installation-level spend, we assume that the larger the number of suppliers, the better potential strategic sourcing opportunity.

supply or service should be handled at the enterprise-level (AFICA) or at the MAJCOM-level.

Before weighting, our prioritization algorithm is given in Equation 1.

$$FSC/PSC\ Score = \#Contracts + \#Suppliers + \#PurchOffices + \#Offers + \$Obligated + Trend + \#MAJCOM \quad (1)$$

Weighting Variables

We recognize that each variable does not have equal influence in determining the overall prioritization score for the PSC. Some variables matter more than others. We used a group of subject matter experts to discuss and assign weights to each variable. After weighting, our prioritization algorithm is given in Equation 2.

$$FSC/PSC\ Score = .20(\#Contracts) + .20(\#Suppliers) + .20(\#PurchOffices) + .15(\#Offers) + .12(\$Obligated) + .08(Trend) + .05(\#MAJCOM) \quad (2)$$

When summed, the weights total to 1.00, or, in terms of percentages, 100%. Number of contracts, number of suppliers, and number of purchasing offices are the highest weighted variables, each receiving a weight of .20, or 20%. The subject matter experts weighted these variables heaviest because they are common variables used by industry experts to examine commercial spend for strategic sourcing opportunities. Number of offers received a weight of .15, or 15%. Existence of competition is important as it signals the AF's ability to leverage its large buying power to get a better deal.

Total dollars obligated received a weight of .12, or 12%. Some readers might find it odd that total spend for the supply or service received a relatively smaller weight. This decision was made purposefully, in recognition that high spend does not necessarily mean higher potential for a strategic sourcing. Some high-spend categories may already be operating on thin margins—the savings have already been sifted out. It is important to note that we do not simply ignore high-spend supplies and services. We take special measure to include those FSCs/PSCs in the opportunity assessment, which is discussed later.

The lowest weighted categories took the least precedence for identifying a potential strategic sourcing opportunity in the eyes of our subject matter experts. Trend received a weight of .08, or 8%, and number of MAJCOMs received a weight of .05, or 5%.

Applying the Weights

Each FSC/PSC was given a point score on each variable that could not exceed the weight. In other words, the FSC/PSC with the largest number of contracts received the full weight: .20. The FSC/PSC with the next larger number of contracts received less than the full weight, a decrease equal to the proportional decrease in the number of contracts. For example, FSC 7030, ADP Software, had the highest number of contracts. It received a score of .20 points. The next highest number of contracts belongs to FSC 7110, Office Furniture. It received a score of .1209 points. This scoring method was performed for each variable, with the total points available for each variable equal to the weight for the variable. If a FSC/PSC were to score the max on each of the variables, its overall score would be 1.00; thus the closer to 1.00 in overall score, the higher potential that a strategic sourcing opportunity exists.

Once the weights were applied to each variable, the points were summed for each FSC/PSC, creating a total score for each FSC/PSC. Those FSCs/PSCs with the highest scores are considered the highest potential strategic sourcing opportunities. Finally, external market data were matched with the highest scoring FSCs/PSCs to complete the spend analysis.

Results

We examined the weighted total scores from two different angles: total score and total spend. Using this method, we capture FSCs/PSCs that scored highly using the algorithm as well as FSCs/PSCs that may not have scored highly in the algorithm, but represent a substantial amount of spend. This method simultaneously recognizes that spend may not necessarily be the most important variable (hence the lower weighting in the algorithm), but it is still an important factor in spend analysis.

First, with the FSCs/PSCs ranked by *total score*, we asked the following questions:

- Which FSCs/PSCs have the highest overall scores?
- How much spend is accounted for in the top 100 FSCs/PSCs?
- How many FSCs/PSCs account for 80% of the total spend?

Table 1 shows the top 40 FSCs/PSCs based on overall score. The top 100 FSCs/PSCs account for 64% of total spend. When ranked by algorithm score, it takes 281 FSCs/PSCs to account for 80% of the total spend. Second, with the FSCs/PSCs ranked by *total obligation*, we asked the following questions:

- Which FSCs/PSCs have the highest total obligation (spend)?
- How many FSCs/PSCs account for 80% of the total spend?

Table 2 shows the top 40 FSCs/PSCs based on total obligation. The top 67 FSCs/PSCs account for 80% of the total spend.

Because we wanted to focus on a smaller subset of FSCs/PSCs (not the full 1,706 FSCs/PSCs), we chose to use the 67 FSCs/PSCs that account for 80% of the spend. We selected the top 67 FSCs/PSCs based on total algorithm score and the top 67 FSCs/PSCs based on total spend score. Thirty-two of the FSCs/PSCs were duplicates—there were a total of 102 unique FSCs/PSCs that fell into the top 67 in each category (total algorithm score and total spend).

Next, we performed an analysis to see how many FSCs/PSCs scored in the top 67 across the algorithm variables. We sorted the data by each algorithm variable and selected the top 67 FSCs/PSCs for each variable. Note that we did not include two variables in this analysis: Trend and Number of MAJCOMs. These variables do not discriminate well across FSCs/PSCs, so they were not useful in this analysis. When lined up next to each other, we were able to determine how many times a specific FSC/PSC scored in the top 67. Naturally, the more times an FSC/PSC scored “high” (i.e., in the top 67), the more potential it has as a strategic sourcing opportunity. See Table 3 for the results. Table 3 highlights how many times an FSC/PSC scored in the top 67. The table shows many blue- and green-shaded FSCs/PSCs. That indicates that many FSCs/PSCs scored in the top 67 across four or more variables in the algorithm. That is a positive indication that the model is identifying the FSCs/PSCs with the highest potential for strategic sourcing.

Table 1. Top FSCs/PSCs Based on Total Algorithm Score

Top FSCs/PSCs Based on Total Algorithm Score

	FSC/PSC	PSC Description	# Contracts Score 20%	# Suppliers Score 20%	# Purchasing Offices Score 20%	# Offers Score 15%	$ Obligated 12%	Trend Score 8%	# MAJCOM Score 5%	Total Overall Score 100%	Obligated Amount	% Total Obligation	Cumulative % Total Obligation	Total Algorithm Score Rank	Total Obligation Score Rank
1	7030	ADP SOFTWARE	0.200	0.200	0.163	0.016	0.018	0.080	0.050	0.727	$1,703,974,283	0.96%	0.96%	1	21
2	R499	SUPPORT- PROFESSIONAL: OTHER	0.061	0.160	0.184	0.033	0.116	0.000	0.050	0.604	$10,988,789,841	6.20%	7.16%	2	2
3	R425	SUPPORT- PROFESSIONAL: ENGINEERING/TECHNICAL	0.039	0.083	0.200	0.032	0.115	0.080	0.050	0.598	$10,909,637,068	6.16%	13.32%	3	3
4	5895	MISCELLANEOUS COMMUNICATION EQUIPMENT	0.064	0.125	0.177	0.010	0.033	0.000	0.050	0.460	$3,179,108,198	1.79%	15.11%	4	14
5	1680	MISCELLANEOUS AIRCRAFT ACCESSORIES AND COMPONENTS	0.043	0.072	0.153	0.003	0.064	0.080	0.043	0.458	$6,115,541,065	3.43%	18.56%	5	5
6	7035	ADP SUPPORT EQUIPMENT	0.101	0.113	0.138	0.031	0.007	0.000	0.050	0.440	$640,005,251	0.36%	18.92%	6	53
7	7110	OFFICE FURNITURE	0.121	0.110	0.135	0.012	0.004	0.000	0.050	0.432	$405,617,692	0.23%	19.15%	7	74
8	D399	IT AND TELECOM- OTHER IT AND TELECOMMUNICATIONS	0.075	0.087	0.137	0.019	0.036	0.000	0.050	0.404	$3,402,038,018	1.92%	21.07%	8	13
9	J015	MAINT/REPAIR/REBUILD OF EQUIPMENT- AIRCRAFT AND AIRFRAME STRUCTURAL COMPONENTS	0.020	0.017	0.095	0.013	0.120	0.080	0.039	0.385	$11,393,209,408	6.43%	27.50%	9	1
10	J099	MAINT/REPAIR/REBUILD OF EQUIPMENT- MISCELLANEOUS	0.043	0.124	0.150	0.006	0.013	0.000	0.043	0.377	$1,191,137,058	0.67%	28.17%	10	30
11	R408	SUPPORT- PROFESSIONAL: PROGRAM MANAGEMENT/SUPPORT	0.036	0.065	0.158	0.023	0.032	0.000	0.050	0.365	$3,057,656,613	1.73%	29.90%	11	16
12	7025	ADP INPUT/OUTPUT AND STORAGE DEVICES	0.068	0.078	0.147	0.012	0.005	0.000	0.050	0.359	$463,261,524	0.26%	30.16%	12	68
13	7010	ADPE SYSTEM CONFIGURATION	0.075	0.067	0.131	0.017	0.007	0.000	0.050	0.347	$666,543,000	0.38%	30.54%	13	52
14	7021	ADP CENTRAL PROCESSING UNIT (CPU, COMPUTER), DIGITAL	0.041	0.029	0.123	0.012	0.003	0.080	0.050	0.337	$288,628,522	0.16%	30.70%	14	92
15	R706	SUPPORT- MANAGEMENT: LOGISTICS SUPPORT	0.011	0.022	0.109	0.008	0.059	0.080	0.046	0.335	$5,572,885,855	3.14%	33.84%	15	6
16	J059	MAINT/REPAIR/REBUILD OF EQUIPMENT- ELECTRICAL AND ELECTRONIC EQUIPMENT COMPONENTS	0.018	0.050	0.118	0.002	0.019	0.080	0.043	0.331	$1,779,285,662	1.00%	34.85%	16	20
17	6515	MEDICAL AND SURGICAL INSTRUMENTS, EQUIPMENT, AND SUPPLIES	0.086	0.089	0.099	0.004	0.001	0.000	0.043	0.323	$119,095,117	0.07%	34.92%	17	145
18	Z2JZ	REPAIR OR ALTERATION OF MISCELLANEOUS BUILDINGS	0.033	0.043	0.085	0.024	0.011	0.080	0.043	0.319	$1,043,568,510	0.59%	35.50%	18	33
19	7050	ADP COMPONENTS	0.052	0.069	0.130	0.006	0.004	0.000	0.050	0.310	$360,901,960	0.20%	35.71%	19	81
20	4940	MISCELLANEOUS MAINTENANCE AND REPAIR SHOP SPECIALIZED EQUIPMENT	0.013	0.051	0.117	0.002	0.002	0.080	0.043	0.307	$145,549,322	0.08%	35.79%	20	134
21	8415	CLOTHING, SPECIAL PURPOSE	0.028	0.029	0.112	0.006	0.002	0.080	0.046	0.304	$162,601,634	0.09%	35.88%	21	127
22	Z199	MAINT-REP-ALT/MISC BLDGS	0.050	0.076	0.092	0.031	0.011	0.000	0.043	0.303	$1,034,099,197	0.58%	36.47%	22	34
23	Q201	MEDICAL- GENERAL HEALTH CARE	0.024	0.021	0.083	0.041	0.008	0.080	0.043	0.299	$714,683,080	0.40%	36.87%	23	48
24	5805	TELEPHONE AND TELEGRAPH EQUIPMENT	0.025	0.080	0.108	0.003	0.004	0.080	0.046	0.296	$363,586,150	0.21%	37.07%	24	79
25	5999	MISCELLANEOUS ELECTRICAL AND ELECTRONIC COMPONENTS	0.021	0.073	0.146	0.002	0.006	0.000	0.046	0.294	$581,355,705	0.33%	37.40%	25	57
26	6625	ELECTRICAL AND ELECTRONIC PROPERTIES MEASURING AND TESTING INSTRUMENTS	0.034	0.069	0.138	0.003	0.003	0.000	0.046	0.294	$322,201,830	0.18%	37.58%	26	88
27	Q999	MEDICAL- OTHER	0.021	0.040	0.086	0.018	0.005	0.080	0.043	0.293	$501,524,779	0.28%	37.87%	27	65
28	6910	TRAINING AIDS	0.012	0.088	0.106	0.001	0.007	0.080	0.046	0.290	$679,771,429	0.38%	38.25%	28	50
29	5995	CABLE, CORD, AND WIRE ASSEMBLIES: COMMUNICATION EQUIPMENT	0.010	0.084	0.113	0.001	0.000	0.080	0.043	0.282	$44,339,574	0.03%	38.28%	29	253
30	7490	MISCELLANEOUS OFFICE MACHINES	0.012	0.081	0.105	0.002	0.000	0.080	0.050	0.279	$18,721,944	0.01%	38.29%	30	384
31	R414	SYSTEMS ENGINEERING SERVICES	0.024	0.081	0.116	0.010	0.055	0.000	0.043	0.279	$5,181,082,998	2.92%	41.21%	31	7
32	7290	MISCELLANEOUS HOUSEHOLD AND COMMERCIAL FURNISHINGS AND APPLIANCES	0.013	0.088	0.098	0.002	0.000	0.080	0.046	0.278	$31,732,307	0.02%	41.23%	32	306
33	5820	RADIO AND TELEVISION COMMUNICATION EQUIPMENT, EXCEPT AIRBORNE	0.032	0.056	0.134	0.003	0.003	0.000	0.050	0.277	$288,330,612	0.16%	41.39%	33	93
34	U009	EDUCATION/TRAINING- GENERAL	0.011	0.085	0.094	0.004	0.005	0.080	0.046	0.276	$500,922,553	0.28%	41.67%	34	66
35	D316	IT AND TELECOM- TELECOMMUNICATIONS NETWORK MANAGEMENT	0.013	0.023	0.095	0.010	0.008	0.080	0.046	0.275	$716,577,389	0.40%	42.08%	35	47
36	J058	MAINT/REPAIR/REBUILD OF EQUIPMENT- COMMUNICATION, DETECTION, AND COHERENT RADIATION EQUIPMENT	0.031	0.045	0.138	0.003	0.010	0.000	0.046	0.274	$927,437,498	0.52%	42.60%	36	39
37	3990	MISCELLANEOUS MATERIALS HANDLING EQUIPMENT	0.012	0.081	0.099	0.001	0.001	0.080	0.046	0.271	$62,557,941	0.04%	42.64%	37	205
38	J016	MAINT/REPAIR/REBUILD OF EQUIPMENT- AIRCRAFT COMPONENTS AND ACCESSORIES	0.015	0.032	0.093	0.005	0.086	0.000	0.039	0.270	$8,194,919,625	4.62%	47.26%	38	4
39	5975	ELECTRICAL HARDWARE AND SUPPLIES	0.006	0.024	0.112	0.001	0.000	0.080	0.046	0.269	$24,281,070	0.01%	47.27%	39	350
40	R699	SUPPORT- ADMINISTRATIVE: OTHER	0.017	0.056	0.126	0.010	0.013	0.000	0.046	0.267	$1,230,101,727	0.69%	47.97%	40	29

Table 2. Top FSCs/PSCs Based on Total Obligation Amount

Top FSCs/PSCs Based on Total Obligation Amount

	FSC/PSC	PSC Description	# Contracts Score 20%	# Suppliers Score 20%	# Purchasing Offices Score 20%	# Offers Score 15%	$ Obligated 12%	Trend Score 8%	# MAJCOM Score 5%	Total Overall Score 100%	Obligated Amount	% Total Obligation	Cumulative % Total Obligation	Total Algorithm Score Rank	Total Obligation Score Rank
1	J015	MAINT/REPAIR/REBUILD OF EQUIPMENT- AIRCRAFT AND AIRFRAME STRUCTURAL COMPONENTS	0.020	0.017	0.095	0.013	0.120	0.080	0.039	0.385	$11,393,209,408	6.43%	6.43%	9	1
2	R499	SUPPORT- PROFESSIONAL: OTHER	0.061	0.160	0.184	0.033	0.116	0.000	0.050	0.604	$10,988,789,841	6.20%	12.63%	2	2
3	R425	SUPPORT- PROFESSIONAL: ENGINEERING/TECHNICAL	0.039	0.083	0.200	0.032	0.115	0.080	0.050	0.598	$10,909,637,068	6.16%	18.79%	3	3
4	J016	MAINT/REPAIR/REBUILD OF EQUIPMENT- AIRCRAFT COMPONENTS AND ACCESSORIES	0.015	0.032	0.093	0.005	0.086	0.000	0.039	0.270	$8,194,919,625	4.62%	23.41%	38	4
5	1680	MISCELLANEOUS AIRCRAFT ACCESSORIES AND COMPONENTS	0.043	0.072	0.153	0.003	0.064	0.080	0.043	0.458	$6,115,541,065	3.45%	26.86%	5	5
6	R706	SUPPORT- MANAGEMENT: LOGISTICS SUPPORT	0.011	0.022	0.109	0.008	0.059	0.080	0.046	0.335	$5,572,885,855	3.14%	30.01%	15	6
7	R414	SYSTEMS ENGINEERING SERVICES	0.024	0.031	0.116	0.010	0.055	0.000	0.043	0.279	$5,181,082,998	2.92%	32.93%	31	7
8	2840	GAS TURBINES AND JET ENGINES, AIRCRAFT, PRIME MOVING; AND COMPONENTS	0.008	0.009	0.023	0.001	0.051	0.000	0.014	0.106	$4,838,122,523	2.73%	35.66%	531	8
9	J010	MAINT/REPAIR/REBUILD OF EQUIPMENT- WEAPONS	0.002	0.007	0.044	0.015	0.047	0.080	0.029	0.224	$4,452,307,977	2.51%	38.17%	74	9
10	J028	MAINT/REPAIR/REBUILD OF EQUIPMENT- ENGINES, TURBINES, AND COMPONENTS	0.007	0.013	0.057	0.002	0.046	0.080	0.036	0.240	$4,391,218,269	2.48%	40.65%	57	10
11	5865	ELECTRONIC COUNTERMEASURES, COUNTER-COUNTERMEASURES AND QUICK REACTION CAPABILITY EQUIPMENT	0.008	0.008	0.046	0.001	0.044	0.080	0.036	0.223	$4,138,640,674	2.34%	42.98%	78	11
12	V126	TRANSPORTATION/TRAVEL/RELOCATION- TRANSPORTATION: SPACE TRANSPORTATION/LAUNCH	0.000	0.002	0.004	0.000	0.039	0.080	0.004	0.130	$3,745,176,128	2.11%	45.10%	339	12
13	D399	IT AND TELECOM- OTHER IT AND TELECOMMUNICATIONS	0.075	0.087	0.137	0.019	0.036	0.000	0.050	0.404	$3,402,038,018	1.92%	47.02%	8	13
14	5895	MISCELLANEOUS COMMUNICATION EQUIPMENT	0.064	0.125	0.177	0.010	0.033	0.000	0.050	0.460	$3,179,108,198	1.79%	48.81%	4	14
15	1560	AIRFRAME STRUCTURAL COMPONENTS	0.018	0.027	0.088	0.004	0.033	0.000	0.032	0.203	$3,152,488,542	1.78%	50.59%	105	15
16	R408	SUPPORT- PROFESSIONAL: PROGRAM MANAGEMENT/SUPPORT	0.036	0.065	0.158	0.023	0.032	0.000	0.050	0.365	$3,057,656,613	1.73%	52.32%	11	16
17	S216	HOUSEKEEPING- FACILITIES OPERATIONS SUPPORT	0.019	0.032	0.089	0.013	0.028	0.000	0.046	0.228	$2,688,311,950	1.52%	53.83%	69	17
18	L014	TECHNICAL REPRESENTATIVE- GUIDED MISSILES	0.001	0.001	0.005	0.001	0.024	0.080	0.004	0.116	$2,318,451,192	1.31%	55.14%	427	18
19	5841	RADAR EQUIPMENT, AIRBORNE	0.006	0.008	0.036	0.002	0.019	0.000	0.021	0.092	$1,843,439,191	1.04%	56.18%	721	19
20	J059	MAINT/REPAIR/REBUILD OF EQUIPMENT- ELECTRICAL AND ELECTRONIC EQUIPMENT COMPONENTS	0.018	0.050	0.118	0.002	0.019	0.080	0.043	0.331	$1,779,285,662	1.00%	57.19%	16	20
21	7030	ADP SOFTWARE	0.200	0.200	0.163	0.016	0.018	0.080	0.050	0.727	$1,703,974,283	0.96%	58.15%	1	21
22	AZ16	R&D- OTHER RESEARCH AND DEVELOPMENT (MANAGEMENT/SUPPORT)	0.001	0.003	0.007	0.001	0.017	0.000	0.011	0.040	$1,573,584,727	0.89%	59.03%	1,097	22
23	7510	OFFICE SUPPLIES	0.014	0.027	0.108	0.002	0.015	0.000	0.050	0.216	$1,406,053,340	0.79%	59.83%	87	23
24	R799	SUPPORT- MANAGEMENT: OTHER	0.021	0.045	0.116	0.013	0.015	0.000	0.046	0.256	$1,381,673,587	0.78%	60.61%	45	24
25	F999	OTHER ENVIRONMENTAL SERVICES	0.010	0.017	0.045	0.045	0.014	0.000	0.043	0.173	$1,347,567,820	0.76%	61.37%	167	25
26	B599	SPECIAL STUDIES/ANALYSIS- OTHER	0.008	0.013	0.066	0.002	0.014	0.000	0.043	0.145	$1,303,899,155	0.74%	62.10%	258	26
27	D307	IT AND TELECOM- IT STRATEGY AND ARCHITECTURE	0.014	0.024	0.096	0.004	0.013	0.000	0.046	0.199	$1,245,919,530	0.70%	62.81%	112	27
28	1550	UNMANNED AIRCRAFT	0.001	0.002	0.017	0.000	0.013	0.080	0.021	0.134	$1,238,160,997	0.70%	63.51%	320	28
29	R699	SUPPORT- ADMINISTRATIVE: OTHER	0.017	0.056	0.126	0.010	0.013	0.000	0.046	0.267	$1,230,101,727	0.69%	64.20%	40	29
30	J099	MAINT/REPAIR/REBUILD OF EQUIPMENT- MISCELLANEOUS	0.043	0.124	0.150	0.006	0.013	0.000	0.043	0.377	$1,191,137,058	0.67%	64.87%	10	30
31	J069	MAINT/REPAIR/REBUILD OF EQUIPMENT- TRAINING AIDS AND DEVICES	0.008	0.007	0.036	0.002	0.012	0.000	0.025	0.084	$1,094,909,122	0.62%	65.49%	904	31
32	Z111	MAINT-REP-ALT/OFFICE BLDGS	0.020	0.041	0.084	0.013	0.011	0.000	0.050	0.219	$1,076,718,071	0.61%	66.10%	83	32
33	Z2JZ	REPAIR OR ALTERATION OF MISCELLANEOUS BUILDINGS	0.033	0.043	0.085	0.024	0.011	0.080	0.043	0.319	$1,043,568,510	0.59%	66.69%	18	33
34	Z199	MAINT-REP-ALT/MISC BLDGS	0.050	0.076	0.092	0.031	0.011	0.000	0.043	0.303	$1,034,099,197	0.58%	67.27%	22	34
35	M127	OPER OF GOVT ELCT & COMM SYS FAC	0.000	0.002	0.010	0.002	0.011	0.000	0.018	0.043	$1,019,036,494	0.58%	67.84%	1,077	35
36	M123	OPER OF GOVT RADAR & NAV FACILITY	0.000	0.001	0.006	0.002	0.011	0.000	0.014	0.034	$1,013,244,758	0.57%	68.42%	1,128	36
37	R426	SUPPORT- PROFESSIONAL: COMMUNICATIONS	0.016	0.027	0.095	0.005	0.010	0.000	0.046	0.199	$969,616,073	0.55%	68.96%	111	37
38	M199	OPER OF GOVT MISC BLDGS	0.001	0.002	0.021	0.001	0.010	0.000	0.029	0.063	$968,322,482	0.55%	69.51%	978	38
39	J058	MAINT/REPAIR/REBUILD OF EQUIPMENT- COMMUNICATION, DETECTION, AND COHERENT RADIATION EQUIPMENT	0.031	0.045	0.138	0.003	0.010	0.000	0.046	0.274	$927,437,498	0.52%	70.03%	36	39
40	R707	SUPPORT- MANAGEMENT: CONTRACT/PROCUREMENT/ACQUISITION SUPPORT	0.004	0.010	0.044	0.009	0.009	0.000	0.021	0.098	$888,640,991	0.50%	70.53%	628	40

Table 3. Top 67 FSCs/PSCs for Each Variable

Top 67 FSCs/PSCs for Each Variable						
Rank For Each Variable	# Contracts 20%	# Suppliers 20%	# Purchasing Offices 20%	# Offers 15%	$ Obligated 12%	Total Algorithm Score 100%
1	7030	7030	R425	AJ16	J015	7030
2	7110	R499	R499	F999	R499	R499
3	7035	5895	5895	Q201	R425	R425
4	6515	J099	7030	C211	J016	5895
5	D399	7035	R408	R499	1680	1680
6	7010	7110	1680	R425	R706	7035
7	7025	6515	J099	7035	R414	7110
8	5895	D399	7025	Z199	2840	D399
9	R499	R425	5999	R497	J010	J015
10	7050	7025	7035	Z2JZ	J028	J099
11	Z199	6640	J058	R408	5865	R408
12	J099	Z199	6625	D399	V126	7025
13	1680	5999	D399	Q999	D399	7010
14	7021	1680	7110	S201	5895	7021
15	R425	6625	5820	7010	1560	R706
16	R408	7050	7010	7030	R408	J059
17	6625	7010	7050	J010	S216	6515
18	Z2JZ	R408	6350	C219	L014	Z2JZ
19	Z299	G002	R699	R799	5841	7050
20	5820	U099	7021	S216	J059	4940
21	J058	4920	4920	J015	7030	8415
22	6350	5820	5340	Z111	AZ16	Z199
23	8415	R699	J059	7110	7510	Q201
24	J070	7195	6150	7021	R799	5805
25	7125	7125	U099	7025	F999	5999
26	6640	6350	5810	S208	B599	6625
27	4920	4940	4940	5895	D307	Q999
28	5805	J059	R799	R414	1550	6910
29	R414	J066	R414	R699	R699	5995
30	Q201	J058	7125	D316	J099	7490
31	8465	R799	5995	Z299	J069	R414
32	J066	Z299	5975	R707	Z111	7290
33	Q999	5985	8415	Q401	Z2JZ	5820
34	5999	Z2JZ	S201	R706	Z199	U009
35	R799	4240	4240	AC56	M127	D316
36	J015	5810	5836	Y199	M123	J058
37	S201	Z111	R706	S205	R426	3990
38	Z111	J070	7510	8415	M199	J016
39	U099	Q999	J070	Z119	J058	5975
40	S216	3695	7195	Z2AA	R707	R699
41	J059	S201	5805	R421	Y199	7520
42	G002	6910	6910	J099	S201	V231
43	D304	7290	5998	7050	R421	6350
44	1560	V231	5410	Z222	AC26	4120
45	7195	6150	7490	Z1AA	6930	R799
46	G003	J049	1730	S203	5840	J049
47	6150	6650	5985	J016	D316	S209
48	R699	5836	4310	R426	Q201	U099
49	J061	2590	6515	Y1JZ	5826	5680
50	C211	U009	3990	Z1PZ	6910	4920
51	W023	5995	7290	6515	S203	7125
52	Z1PZ	C211	8465	1560	7010	Z1AA
53	R497	7520	7520	D307	7035	J041
54	R426	7045	3695	U099	5985	Z2AA
55	J016	G099	2330	J066	5810	J063
56	J065	5340	C211	Z2LB	4920	7320
57	7220	S216	D307	U009	5999	J028
58	5810	J016	4120	Z1JZ	D308	4910
59	S208	5680	S205	Y1AA	S112	6640
60	5985	J065	R426	S209	U099	S201
61	4240	D304	J063	Z1AZ	C211	J065
62	4210	3990	D316	5805	1730	5930
63	D307	U005	J015	1680	M119	C211
64	Z1AA	S208	J066	S299	J070	D319
65	7510	R414	U009	4920	Q999	J070
66	S205	7490	8145	J070	U009	7020
67	8010	G003 (tie)	W023	J058	U006	7195
		8465 (tie)				
		3590 (tie)				
# Times FSC/PSC is Listed		One	Two	Three	Four	Five +

Within Table 3, there are 145 individual installation-level FSCs/PSCs.[9] We separate those 145 FSCs/PSCs into two categories: Winners and Weirdos. Winners are those FSCs/PSCs that had a high total score from the algorithm (top 67 on algorithm) and scored in the top 67 across three or more different algorithm variables. Clearly, these FSCs/PSCs present a high likelihood of successful strategic sourcing, thus they are considered Winners. There are 45 installation-level FSCs/PSCs considered Winners.

The FSCs/PSCs in the second category are considered Weirdos—they are not clear Winners, but they are also not clear losers. These FSCs/PSCs require further investigation to determine if they should be elevated to the Winner category, or if they do not have the potential for successful strategic sourcing and should be dropped from analysis. There are two ways a FSC/PSC could be considered a Weirdo: (1) the FSC/PSC scored in the top 67 in total algorithm score, but scored in the top 67 in just two (or fewer) algorithm variables, or (2) the FSC/PSC was in the top 67 of overall spend, but did not score in the top 67 in total algorithm score. There are 71 installation-level FSCs/PSCs considered Weirdos.

After separating the FSCs/PSCs into Winners and Weirdos, we added an assessment of the market for each FSC/PSC by using the IBIS Buyer Power score. IBISWorld publishes business intelligence reports, including detailed reports of industries and procurement reports that provide information about the market, average purchase prices, trends in the market, buyer power in relation to the market, etc. For this research, we are particularly interested in their procurement reports, specifically the buyer power score. IBIS measures buyer power based on a weighted average of Price Trend, Market Structure, and Market Risk. It is an aggregated measure of the softness of the market, where a score of 1 means the supplier has more power and a score of 5 means the buyer has more power. The average score for our FSCs/PSCs was 3.48. The FSCs/PSCs were ranked according to buyer power score, where 1 = highest buyer power.[10] Total algorithm score ranks were then added to buyer power score ranks to compute a Total Rank Score for each FSC/PSC. Thus, each FSC's/PSC's Total Rank Score is equal to their internal AF rank (using the total algorithm score) plus their external market rank (using the buyer power score). Naturally, the lower the Total Rank Score, the more potential opportunity exists to strategically source the FSC/PSC. See Table 4 for a list of FSCs/PSCs ordered by Total Rank Score.

[9] These results show 29 FSCs/PSCs that belong to the Air Force Sustainment Center (AFSC). While not carried forward in this analysis, they represent potential strategic sourcing opportunities for the AFSC.

[10] The median rank was 53, thus a rank of 53 was assigned to all FSCs/PSCs that did not have a corresponding IBIS Report.

Table 4. Installation-Level Winners and Weirdos—Total Rank Score

	PSC/FSC	Description	Total Algorithm Rank	OMB Taxonomy	IBIS Code	IBIS Score	IBIS Rank (Med=88)	Algorithm + IBIS Rank
		Installation-Level Winners & Weirdos - Total Rank Score						
1	5895	5895 (MISCELLANEOUS COMMUNICATION EQUIPMENT)	6	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
2	7010	7010 (ADPE SYSTEM CONFIGURATION)	11	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
3	7025	7025 (ADP INPUT/OUTPUT AND STORAGE DEVICES)	10	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
4	R499	R499 (SUPPORT- PROFESSIONAL: OTHER)	2	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
5	D399	D399 (IT AND TELECOM- OTHER IT AND TELECOMMUNICATIONS)	7	IT Outsourcing	[illegible]	[illegible]	[illegible]	[illegible]
6	7021	7021 (ADP CENTRAL PROCESSING UNIT (CPU, COMPUTER), DIGITAL)	12	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
7	5805	5805 (TELEPHONE AND TELEGRAPH EQUIPMENT)	11	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
8	R408	R408 (SUPPORT- PROFESSIONAL: PROGRAM MANAGEMENT/SUPPORT)	9	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
9	7490	7490 (MISCELLANEOUS OFFICE MACHINES)	23	Office Management Products	[illegible]	[illegible]	[illegible]	[illegible]
10	7030	7030 (ADP SOFTWARE)	1	IT Software	[illegible]	[illegible]	[illegible]	[illegible]
11	R706	R706 (SUPPORT- MANAGEMENT: LOGISTICS SUPPORT)	18	Logistics Support Services	[illegible]	[illegible]	[illegible]	[illegible]
12	5820	5820 (RADIO AND TELEVISION COMMUNICATION EQUIPMENT, EXCEPT AIRBORNE)	27	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
13	7520	7520 (OFFICE DEVICES AND ACCESSORIES)	33	Office Management Products	[illegible]	[illegible]	[illegible]	[illegible]
14	J099	J099 (MAINT/REPAIR/REBUILD OF EQUIPMENT- MISCELLANEOUS)	2	IT Outsourcing	[illegible]	[illegible]	[illegible]	[illegible]
15	7035	7035 (ADP SUPPORT EQUIPMENT)	3	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
16	J058	J058 (MAINT/REPAIR/REBUILD OF EQUIPMENT- COMMUNICATION, DETECTION, AN	30	IT Outsourcing	[illegible]	[illegible]	[illegible]	[illegible]
17	J059	J059 (MAINT/REPAIR/REBUILD OF EQUIPMENT- ELECTRICAL AND ELECTRONIC EQUI	14	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
18	D316	D316 (IT AND TELECOM- TELECOMMUNICATIONS NETWORK MANAGEMENT)	39	IT Outsourcing	[illegible]	[illegible]	[illegible]	[illegible]
19	R699	R699 (SUPPORT- ADMINISTRATIVE: OTHER)	32	Business administration services	[illegible]	[illegible]	[illegible]	[illegible]
20	7050	7050 (ADP COMPONENTS)	17	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
21	R799	R799 (SUPPORT- MANAGEMENT: OTHER)	37	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
22	5810	5810 (COMMUNICATIONS SECURITY EQUIPMENT AND COMPONENTS)	38	IT Security	[illegible]	[illegible]	[illegible]	[illegible]
23	6515	6515 (MEDICAL AND SURGICAL INSTRUMENTS, EQUIPMENT, AND SUPPLIES)	13	Medical Equipment and Accessories and Supplies	[illegible]	[illegible]	[illegible]	[illegible]
24	R425	R425 (SUPPORT- PROFESSIONAL: ENGINEERING/TECHNICAL)	5	Technical and Engineering Services (non IT)	[illegible]	[illegible]	[illegible]	[illegible]
25	7020	7020 (ADP CENTRAL PROCESSING UNIT (CPU, COMPUTER), ANALOG)	30	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
26	J049	J049 (MAINT/REPAIR/REBUILD OF EQUIPMENT- MAINTENANCE AND REPAIR SHOP E	32	Industrial Products Install / Maintenance / Repair	[illegible]	[illegible]	[illegible]	[illegible]
27	V231	V231 (TRANSPORTATION/TRAVEL/RELOCATION- TRAVEL/LODGING/RECRUITMENT	34	Lodging	[illegible]	[illegible]	[illegible]	[illegible]
28	7510	7510 (OFFICE SUPPLIES)	64	Office Management Products	[illegible]	[illegible]	[illegible]	[illegible]
29	U009	U009 (EDUCATION/TRAINING- GENERAL)	32	Specialized Educational services	[illegible]	[illegible]	[illegible]	[illegible]
30	J070	J070 (MAINT/REPAIR/REBUILD OF EQUIPMENT- ADP EQUIPMENT/SOFTWARE/SUPP	33	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
31	R426	R426 (SUPPORT- PROFESSIONAL: COMMUNICATIONS)	68	Public Relations and Professional Communications Services	[illegible]	[illegible]	[illegible]	[illegible]
32	6625	6625 (ELECTRICAL AND ELECTRONIC PROPERTIES MEASURING AND TESTING INSTRU	32	Test & Measurement Supplies	[illegible]	[illegible]	[illegible]	[illegible]
33	AJ10	AJ10 (R&D- GENERAL SCIENCE/TECHNOLOGY: PHYSICAL SCIENCES (MANAGEMENT/	71	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
34	S201	S201 (HOUSEKEEPING- CUSTODIAL JANITORIAL)	31	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
35	7045	7045 (ADP SUPPLIES)	79	IT Hardware	[illegible]	[illegible]	[illegible]	[illegible]
36	R414	R414 (SYSTEMS ENGINEERING SERVICES)	33	Technical and Engineering Services (non IT)	[illegible]	[illegible]	[illegible]	[illegible]
37	7125	7125 (CABINETS, LOCKERS, BINS, AND SHELVING)	68	Office Management Products	[illegible]	[illegible]	[illegible]	[illegible]
38	7290	7290 (MISCELLANEOUS HOUSEHOLD AND COMMERCIAL FURNISHINGS AND APPLIA	30	Office Management Products	[illegible]	[illegible]	[illegible]	[illegible]
39	U099	U099 (EDUCATION/TRAINING- OTHER)	60	Specialized Educational services	[illegible]	[illegible]	[illegible]	[illegible]
40	4120	4120 (AIR CONDITIONING EQUIPMENT)	30	Facility Related Materials	[illegible]	[illegible]	[illegible]	[illegible]
41	S209	S209 (HOUSEKEEPING- LAUNDRY/DRYCLEANING)	39	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
42	6640	6640 (LABORATORY EQUIPMENT AND SUPPLIES)	30	Test & Measurement Supplies	[illegible]	[illegible]	[illegible]	[illegible]
43	Z2JZ	Z2JZ (REPAIR OR ALTERATION OF MISCELLANEOUS BUILDINGS)	10	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
44	7110	7110 (OFFICE FURNITURE)	6	Furniture	[illegible]	[illegible]	[illegible]	[illegible]
45	J066	J066 (MAINT/REPAIR/REBUILD OF EQUIPMENT- INSTRUMENTS AND LABORATORY E	65	Industrial Products Install / Maintenance / Repair	[illegible]	[illegible]	[illegible]	[illegible]
46	S216	S216 (HOUSEKEEPING- FACILITIES OPERATIONS SUPPORT)	39	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
47	Z299	Z299 (MAINT-REP-ALT/MISC BLDGS)	19	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
48	J065	J065 (MAINT/REPAIR/REBUILD OF EQUIPMENT- MEDICAL, DENTAL, AND VETERINAR	33	Medical Equipment and Accessories and Supplies	[illegible]	[illegible]	[illegible]	[illegible]
49	4240	4240 (SAFETY AND RESCUE EQUIPMENT)	60	Fire/Rescue/Safety/Environmental Protection Equipment	[illegible]	[illegible]	[illegible]	[illegible]
50	R497	R497 (SUPPORT- PROFESSIONAL: PERSONAL SERVICES CONTRACTS)	33	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
51	4910	4910 (MOTOR VEHICLE MAINTENANCE AND REPAIR SHOP SPECIALIZED EQUIPMENT	49	Machinery & Components	[illegible]	[illegible]	[illegible]	[illegible]
52	3990	3990 (MISCELLANEOUS MATERIALS HANDLING EQUIPMENT)	31	Transportation Equipment	[illegible]	[illegible]	[illegible]	[illegible]
53	C211	C211 (ARCHITECT AND ENGINEERING- GENERAL: LANDSCAPING, INTERIOR LAYOUT,	38	Construction Related Services	[illegible]	[illegible]	[illegible]	[illegible]
54	D319	D319 (IT AND TELECOM- ANNUAL SOFTWARE MAINTENANCE SERVICE PLANS)	34	IT Software	[illegible]	[illegible]	[illegible]	[illegible]
55	J041	J041 (MAINT/REPAIR/REBUILD OF EQUIPMENT- REFRIGERATION, AIR CONDITIONIN	43	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
56	6650	6650 (OPTICAL INSTRUMENTS, TEST EQUIPMENT, COMPONENTS AND ACCESSORIES	30	Test & Measurement Supplies	[illegible]	[illegible]	[illegible]	[illegible]
57	7195	7195 (MISCELLANEOUS FURNITURE AND FIXTURES)	37	Furniture	[illegible]	[illegible]	[illegible]	[illegible]
58	5340	5340 (HARDWARE, COMMERCIAL)	68	Hardware & Tools	[illegible]	[illegible]	[illegible]	[illegible]
59	Q201	Q201 (MEDICAL- GENERAL HEALTH CARE)	30	Healthcare Services	[illegible]	[illegible]	[illegible]	[illegible]
60	4940	4940 (MISCELLANEOUS MAINTENANCE AND REPAIR SHOP SPECIALIZED EQUIPMENT	32	Machinery & Components	[illegible]	[illegible]	[illegible]	[illegible]
61	Q999	Q999 (MEDICAL- OTHER)	32	Healthcare Services	[illegible]	[illegible]	[illegible]	[illegible]
62	AC[illegible]	AC[illegible] (R&D- DEFENSE SYSTEM: MISSILE/SPACE SYSTEMS (MANAGEMENT/SUPPORT))	107	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
63	J063	J063 (MAINT/REPAIR/REBUILD OF EQUIPMENT- ALARM, SIGNAL, AND SECURITY DET	67	Security Services	[illegible]	[illegible]	[illegible]	[illegible]
64	G002	G002 (SOCIAL- CHAPLAIN)	70	Social Services	[illegible]	[illegible]	[illegible]	[illegible]
65	Z1AA	Z1AA (MAINTENANCE OF OFFICE BUILDINGS)	44	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
66	D308	D308 (IT AND TELECOM- PROGRAMMING)	90	IT Outsourcing	[illegible]	[illegible]	[illegible]	[illegible]
67	3695	3695 (MISCELLANEOUS SPECIAL INDUSTRY MACHINERY)	73	Machinery & Components	[illegible]	[illegible]	[illegible]	[illegible]
68	AC[illegible]	AC[illegible] (R&D- DEFENSE SYSTEM: WEAPONS (MANAGEMENT/SUPPORT))	112	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
69	Z2AA	Z2AA (REPAIR OR ALTERATION OF OFFICE BUILDINGS)	40	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
70	AZ16	AZ16 (R&D- OTHER RESEARCH AND DEVELOPMENT (MANAGEMENT/SUPPORT))	114	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
71	6350	6350 (MISCELLANEOUS ALARM, SIGNAL, AND SECURITY DETECTION SYSTEMS)	32	Security Systems	[illegible]	[illegible]	[illegible]	[illegible]
72	Z2LB	Z2LB (REPAIR OR ALTERATION OF HIGHWAYS/ROADS/STREETS/BRIDGES/RAILWAYS)	61	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
73	D304	D304 (IT AND TELECOM- TELECOMMUNICATIONS AND TRANSMISSION)	84	Telecommunications	[illegible]	[illegible]	[illegible]	[illegible]
74	S299	S299 (HOUSEKEEPING- OTHER)	92	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
75	5410	5410 (PREFABRICATED AND PORTABLE BUILDINGS)	73	Construction Related Materials	[illegible]	[illegible]	[illegible]	[illegible]
76	S208	S208 (HOUSEKEEPING- LANDSCAPING/GROUNDSKEEPING)	72	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
77	4210	4210 (FIRE FIGHTING EQUIPMENT)	87	Fire/Rescue/Safety/Environmental Protection Equipment	[illegible]	[illegible]	[illegible]	[illegible]
78	Z199	Z199 (MAINT, REP/ALTER/ALL OTHER)	60	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
79	7320	7320 (KITCHEN EQUIPMENT AND APPLIANCES)	48	Office Management Products	[illegible]	[illegible]	[illegible]	[illegible]
80	V123	V123 (TRANSPORTATION/TRAVEL/RELOCATION- TRANSPORTATION: SPACE TRANSP	108	Transportation of Things	[illegible]	[illegible]	[illegible]	[illegible]
81	Z211	Z211 (MAINT-REP-ALT/OFFICE BLDGS)	62	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
82	4920	4920 (AIRCRAFT MAINTENANCE AND REPAIR SHOP SPECIALIZED EQUIPMENT)	42	Machinery & Components	[illegible]	[illegible]	[illegible]	[illegible]
83	G004	G004 (SOCIAL- RECREATIONAL)	92	Social Services	[illegible]	[illegible]	[illegible]	[illegible]
84	5680	5680 (MISCELLANEOUS CONSTRUCTION MATERIALS)	41	Construction Related Materials	[illegible]	[illegible]	[illegible]	[illegible]
85	G099	G099 (SOCIAL- OTHER)	94	Social Services	[illegible]	[illegible]	[illegible]	[illegible]
86	Z1JZ	Z1JZ (MAINTENANCE OF MISCELLANEOUS BUILDINGS)	67	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
87	3590	3590 (MISCELLANEOUS SERVICE AND TRADE EQUIPMENT)	97	Machinery & Components	[illegible]	[illegible]	[illegible]	[illegible]
88	7220	7220 (FLOOR COVERINGS)	81	Office Management Products	[illegible]	[illegible]	[illegible]	[illegible]
89	Q401	Q401 (MEDICAL- NURSING)	103	Healthcare Services	[illegible]	[illegible]	[illegible]	[illegible]
90	Y1JZ	Y1JZ (CONSTRUCTION OF MISCELLANEOUS BUILDINGS)	74	Construction Related Services	[illegible]	[illegible]	[illegible]	[illegible]
91	M199	M199 (OPER OF GOVT MISC BLDGS)	111	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
92	R421	R421 (TECHNICAL ASSISTANCE)	82	Technical and Engineering Services (non IT)	[illegible]	[illegible]	[illegible]	[illegible]
93	S203	S203 (HOUSEKEEPING- FOOD)	92	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
94	M127	M127 (OPER OF GOVT ELCT & COMM SYS FAC)	113	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
95	S112	S112 (UTILITIES- ELECTRIC)	104	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
96	M129	M129 (OPER OF GOVT OTHER ADMIN-SVC BLDGS)	113	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
97	M1[illegible]	M1[illegible] (OPER OF GOVT RADAR & NAV FACILITY)	110	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
98	Z1PZ	Z1PZ (MAINTENANCE OF OTHER NON-BUILDING FACILITIES)	70	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
99	U006	U006 (EDUCATION/TRAINING- VOCATIONAL/TECHNICAL)	100	Vocational Training	[illegible]	[illegible]	[illegible]	[illegible]
100	Z1AZ	Z1AZ (MAINTENANCE OF OTHER ADMINISTRATIVE FACILITIES AND SERVICE BUILDIN	77	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
101	4310	4310 (COMPRESSORS AND VACUUM PUMPS)	88	Machinery & Components	[illegible]	[illegible]	[illegible]	[illegible]
102	F999	F999 (OTHER ENVIRONMENTAL SERVICES)	91	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
103	R707	R707 (SUPPORT- MANAGEMENT: CONTRACT/PROCUREMENT/ACQUISITION SUPPO	109	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
104	D307	D307 (IT AND TELECOM- IT STRATEGY AND ARCHITECTURE)	69	IT Outsourcing	[illegible]	[illegible]	[illegible]	[illegible]
105	8145	8145 (SPECIALIZED SHIPPING AND STORAGE CONTAINERS)	82	Package Delivery & Packaging	[illegible]	[illegible]	[illegible]	[illegible]
106	U005	U005 (EDUCATION/TRAINING- TUITION/REGISTRATION/MEMBERSHIP FEES)	110	Specialized Educational services	[illegible]	[illegible]	[illegible]	[illegible]
107	W023	W023 (LEASE OR RENTAL OF EQUIPMENT- GROUND EFFECT VEHICLES, MOTOR VEH	80	Motor Vehicles	[illegible]	[illegible]	[illegible]	[illegible]
108	Z2[illegible]	Z2[illegible] (MAINT-REP-ALT/HWYS-RDS-STS-BRIDGES-RA)	100	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
109	B599	B599 (SPECIAL STUDIES/ANALYSIS- OTHER)	101	Management Advisory Services	[illegible]	[illegible]	[illegible]	[illegible]
110	S205	S205 (HOUSEKEEPING- TRASH/GARBAGE COLLECTION)	72	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
111	Z219	Z219 (MAINT-REP-ALT/OTHER ADMIN BLDGS)	94	Facility Related Services	[illegible]	[illegible]	[illegible]	[illegible]
112	Y1AA	Y1AA (CONSTRUCTION OF OFFICE BUILDINGS)	99	Construction Related Services	[illegible]	[illegible]	[illegible]	[illegible]
113	Y299	Y299 (CONSTRUCT/MISC BLDGS)	103	Construction Related Services	[illegible]	[illegible]	[illegible]	[illegible]
114	C219	C219 (ARCHITECT AND ENGINEERING- GENERAL: OTHER)	90	Construction Related Services	[illegible]	[illegible]	[illegible]	[illegible]
115	2330	2330 (TRAILERS)	39	Transportation Equipment	[illegible]	[illegible]	[illegible]	[illegible]
116	8010	8010 (PAINTS, DOPES, VARNISHES, AND RELATED PRODUCTS)	108	Facility Related Materials	[illegible]	[illegible]	[illegible]	[illegible]

Finally, using the OMB taxonomy of categories (Rung & Sharpe, 2015), the FSCs/PSCs were summed into their respective categories. Categories then received an average rank score (an average rank score of all FSCs/PSCs included in the category), and the categories were ranked according to total average rank score and total spend. Naturally, those categories with the lowest rank score and highest amount of spend represent the best potential category strategic sourcing opportunities. See Table 5 for the results by category.

Table 5. Installation-Level Winners and Weirdos—Total Rank Score by Category

	Installation-Level Winners & Weirdos - Total Rank Score by Category						
	Category	Category Rank Score	# In Category	Average Cat Rank Score	Avg Cat Rank Score Rank	Cat Oblig	Cat Oblig Rank
1	Logistics Support Services Total	39	1	39	1	$5,572,885,855	6
2	IT Hardware Total	446	11	41	2	$5,869,933,636	5
3	Business administration services	48	1	48	3	$1,330,101,727	12
4	IT Security Total	65	1	65	4	$594,464,383	16
5	IT Software Total	135	2	68	5	$1,776,425,182	9
6	IT Outsourcing Total	428	6	71	6	$8,057,772,530	4
7	Lodging Total	74	1	74	7	$56,977,615	30
8	Medical Equipment and Accessories and Supplies Total	167	2	84	8	$176,523,865	23
9	Public Relations and Professional Communications Services Total	84	1	84	9	$969,616,073	14
10	Industrial Products Install / Maintenance / Repair Total	173	2	87	10	$534,060,909	17
11	Office Management Products Total	608	7	87	11	$1,591,701,390	10
12	Test & Measurement Supplies Total	298	3	99	12	$524,692,762	18
13	Management Advisory Services Total	1002	10	100	13	$20,559,852,901	1
14	Technical and Engineering Services (non-IT) Total	309	3	103	14	$16,919,021,645	3
15	Furniture Total	217	2	109	15	$454,106,706	20
16	Specialized educational services Total	337	3	112	16	$1,112,202,148	13
17	Hardware & Tools Total	119	1	119	17	$156,380,747	24
18	Fire/Rescue/Safety/Environmental Protection Equipment Total	243	2	122	18	$120,148,013	25
19	Security Services Total	123	1	123	19	$66,169,544	29
20	Security Systems Total	131	1	131	20	$195,739,063	22
21	Healthcare Services Total	393	3	131	20	$1,369,653,187	11
22	Telecommunications Total	132	1	132	22	$80,850,754	28
23	Machinery & Components Total	810	6	135	23	$851,912,712	15
24	Facility Related Services Total	3679	27	136	24	$18,152,037,809	2
25	Social Services Total	415	3	138	25	$117,744,990	26
26	Construction Related Materials Total	283	2	142	26	$205,760,179	21
27	Transportation of Things Total	143	1	143	27	$3,745,176,138	7
28	Transportation Equipment Total	297	2	149	28	$95,683,009	27
29	Facility Related Materials Total	303	2	152	29	$46,442,575	31
30	Vocational Training Total	159	1	159	30	$474,637,860	19
31	Construction Related Services Total	810	5	162	31	$2,346,979,919	8
32	Package Delivery & Packaging Total	163	1	163	32	$29,719,859	33
33	Motor Vehicles Total	165	1	165	33	$39,191,166	32

Conclusion

Our results suggest that Logistics Support Services, IT Hardware, and Business Administration Services had the best Total Rank Score and would likely make good strategic sourcing candidates. Further, large total obligation categories like Management Advisory Services, Technical and Engineering Services (non-IT), and Facility Related Services account for nearly one-third of all the spend—these categories would also make good strategic sourcing candidates. More research into each category is needed to assess the true viability of the category (i.e., estimated cost and process savings and how demand management might affect the category).

Spend analysis is just the first step in strategic sourcing. While we identify categories that represent a higher likelihood of strategic sourcing success in this research, our results are based solely on the available data—they do not take into account the often-richer data found via qualitative analysis. RAND (2004) warns that the data collected via the DD350 (CAR) can help identify potential strategic sourcing opportunities, "but they should not be used to make final decisions to develop specific supply strategies without additional data validation, cleaning, enhancement, and analyses by substantive experts and manual resolution of anomalies" (p. 15). We agree with this assessment, and, to that end, AFICA has a process in place to assign Category Management teams the task of digging deeper into the details of each category and sub-category of spend to verify if savings exist, where specifically those savings can be garnered, and how to adjust policies and practices to realize those savings and better manage consumption (demand).

AFICA plans to profile each category using Category Intelligence Reports (CIRs). Category teams are tasked with completing four steps to confirm and estimate potential savings. After the spend analysis is complete, they (1) work with the customer to identify and leverage any existing customer data in order to better understand the demand patterns and potential of the category for strategic sourcing, (2) perform a more in-depth market analysis to understand the processes of the commercial sector and how they might apply to the AF, (3) perform a gap analysis that estimates where AF processes are different from commercial processes, and how to minimize the gap to better align the AF's practices to those of the commercial sector (when beneficial), and (4) develop courses of action to present to leadership (i.e., AFICA leadership and customer leadership), who then decide whether to proceed with strategic sourcing, and, if so, which course of action to use.

In summary, the goal of this research was to develop a prioritization list of AF strategic sourcing opportunities using available internal spend and external market data. We aimed to develop an easily repeatable process that quickly enables AFICA "miners" to find the "gold" in their mountain of spend. The algorithm we developed mirrors those used in the commercial sector and can be used by other service components to quickly identify and prioritize their strategic sourcing opportunities.

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An Economic Analysis of the Truth in Negotiations Act (TINA)

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Abstract

The Truth in Negotiations Act (TINA) requires contractors (often sole-source) to submit "cost or pricing data" that is "current, complete, and accurate." The intention of TINA is to protect the government and taxpayers from being ripped off by better informed contractors. We argue that the current TINA practice, despite its good intention, is subject to many unintended negative consequences that arise from contractors' bad incentives. We employ an incentive-centric approach to perform an economic analysis of TINA. Our analysis indicates that the main flaw of TINA is its failure to address the moral hazard problem, that is, contractors lack proper incentives to exert their best efforts to achieve cost efficiency. For example, in fixed-price contracts, where moral hazard is otherwise appropriately addressed, the use of TINA undesirably removes contractors' incentives to exert effort. The policy implication of this report is that a lax use of TINA in the context of firm-fixed-price contracts should be preferred to a strict use. Moreover, in a repeated game situation where a continuous long-term demand for the product from the DoD is expected, a TINA waiver should be considered for the early period contracts so contractors can truthfully reveal their best-effort cost information.

Introduction

The Federal Government obligates approximately $500 billion in contracts every year for supplies and services needed for executing its mission (Federal Procurement Data System–Next Generation, 2015). The majority of procured supplies and services are of a commercial nature, although some are defense-unique projects for research and development as well as major weapon systems acquisition. Regardless of whether the government is procuring commercial-type supplies and services or defense-unique systems, the government aims to negotiate a fair and reasonable price—fair to both parties and reasonable considering the quality and timeliness of contract performance (FAR, 2015). When procuring supplies and services readily available in the commercial marketplace, the government relies on the forces of market competition to obtain fair and reasonable prices. However, when the government procures defense-unique supplies and services in markets where there may be limited competition or only one seller, the government relies on statutory requirements to ensure a level playing field in negotiating fair and reasonable prices with contractors. One such statute is the Truth in Negotiations Act (TINA) promulgated in Public Law 87-653. TINA was enacted to enhance the government's ability to negotiate fair and reasonable prices by ensuring that the government contracting officer has the same factual information that is available to the contractor at the time of price negotiations (Nash et al., 2007). Advocates of TINA argue that the statute effectively levels the playing field between the government and contractor in non-competitive procurements, but opponents argue that TINA is not only administratively burdensome, but also results in negative unintended consequences.

The purpose of this research is to analyze the Truth in Negotiations Act from an economic theory perspective focusing on contractor incentives under different contract types. Our research question asks whether TINA provides the right economic incentive to contractors to induce their best effort under different contract types.

The remainder of the paper is organized as follows: The following section provides a detailed description of the Truth in Negotiations Act. After that is a review of economic literature that is relevant to our research question. Next is a section that performs analysis and makes policy recommendations. In the final section, we conclude.

Truth in Negotiations Act

Federal acquisition policy requires that contracting officers procure supplies and services from responsible sources at fair and reasonable prices (FAR, 2015). Fair and reasonable prices can be assured through the use of competitive proposals providing price competition, commercial or catalog prices, or prices set by law or regulation (FAR, 2015). If these approaches are not available in a procurement, then the government may request the offeror to provide cost or pricing data to be used in negotiating fair and reasonable prices. Additionally, the offeror may be required to certify that the cost or pricing data provided to the government are current, accurate, and complete as of the date of negotiations.

During the procurement planning process, the government will conduct requirements analysis and market research to determine the availability of supplies and services that exist to meet the government's requirements, as well as the capability of the market to provide those supplies and services. The results of procurement planning will determine if there is a competitive market for the required supply or service. Based on the results of the procurement planning process, the government will conduct solicitation planning and develop the solicitation (e.g., a Request for Proposal) and advertise the procurement opportunity by posting the solicitation on the government-wide electronic portal.

During the source selection process, the government will conduct a review of the proposals and determine the existence of adequate price competition, commercial or catalog prices, or prices set by law or regulation. If these are in existence, then the government will be able to conduct a price analysis on the proposals and there will be no need for requiring cost or pricing data. In this case, the TINA requirements will not apply.

If adequate price competition, commercial or catalog prices, or prices set by law or regulation are not in existence—for example, if only one proposal is received—then the government may need to conduct cost analysis as part of the evaluation of the proposals. This cost analysis may require the offeror to provide cost and pricing data to the government. The FAR (2015) defines cost and pricing data as follows:

> Cost or pricing data (10 U.S.C. 2306a(h)(1) and 41 U.S.C. chapter 35) means all facts that, as of the date of price agreement, or, if applicable, an earlier date agreed upon between the parties that is as close as practicable to the date of agreement on price, prudent buyers and sellers would reasonably expect to affect price negotiations significantly. Cost or pricing data are factual, not judgmental; and are verifiable. While they do not indicate the accuracy of the prospective contractor's judgment about estimated future costs or projections, they do include the data forming the basis for that judgment. Cost or pricing data are more than historical accounting data; they are all the facts that can be reasonably expected to contribute to the soundness of estimates of future costs and to the validity of determinations of costs already incurred. They also include, but are not limited to, such factors as—
>
> (1) Vendor quotations;
>
> (2) Nonrecurring costs;
>
> (3) Information on changes in production methods and in production or purchasing volume;
>
> (4) Data supporting projections of business prospects and objectives and related operations costs;
>
> (5) Unit-cost trends such as those associated with labor efficiency;
>
> (6) Make-or-buy decisions;
>
> (7) Estimated resources to attain business goals; and
>
> (8) Information on management decisions that could have a significant bearing on costs.

Additionally, if the value of the procurement exceeds the TINA threshold (currently established at $700,000), the offerors will be required to certify that the cost or pricing data are current, accurate, and complete at the time of negotiations. This is the essence of the TINA requirement. TINA (10 U.S.C. 2306a and 41 U.S.C. ch. 35) requires offerors to submit certified cost or pricing data if a procurement exceeds the TINA threshold and none of the exceptions to certified cost or pricing data requirements applies (see FAR 15.403). Under TINA, the contracting officer obtains accurate, complete, and current data from offerors to establish a fair and reasonable price (see FAR 15.403). TINA also allows for a price adjustment remedy if it is later found that a contractor did not provide accurate, complete, and current data.

The FAR (2015) defines certified cost or pricing data as follows:

> Certified cost or pricing data means "cost or pricing data" that were required to be submitted in accordance with FAR 15.403-4 and 15.403-5 and have been certified, or are required to be certified, in accordance with 15.406-2. This certification states that, to the best of the person's knowledge and belief, the cost or pricing data are accurate, complete, and current as of a date

certain before contract award. Cost or pricing data are required to be certified in certain procurements (10 U.S.C. 2306a and 41 U.S.C. chapter 35).

Thus, during the source selection phase of contract management, in situations where the government does not have adequate price competition, commercial or catalog prices, or prices set by law or regulation, the government relies on the contractor's certified cost or pricing data to negotiate a fair and reasonable price. Once negotiations are complete, the contract is awarded. The contract may be awarded using a fixed-price contract or a cost-reimbursement contract. Fixed-price types of contracts provide for a firm price or, in appropriate cases, an adjustable price. Fixed-price contracts providing for an adjustable price may include a ceiling price, a target price (including target cost), or both. Unless otherwise specified in the contract, the ceiling price or target price is subject to adjustment only by operation of contract clauses providing for equitable adjustment or other revision of the contract price under stated circumstances. Cost-reimbursement types of contracts provide for payment of allowable incurred costs, to the extent prescribed in the contract. These contracts establish an estimate of total cost for the purpose of obligating funds and establishing a ceiling that the contractor may not exceed (except at its own risk) without the approval of the contracting officer (FAR, 2015). If, during contract performance or even after the contract is complete, the government determines that the contractor's cost or pricing data was not current, accurate, or complete, TINA allows for a price adjustment remedy and can recoup any excess costs.

During the contract administration phase of the contract, there may be instances when the government must modify the requirements of the contract. Through the contract changes process, the government may make changes within the general scope of the contract to drawings, designs, or specifications, method of shipment or packing, or place of delivery (FAR, 2015). Additionally, if any such change causes an increase or decrease in the cost of any part of the work under the contract, the government will negotiate an equitable adjustment in the contract price and modify the contract. Since this contract change will occur after the award of the basic contract, the government will not have the benefits of adequate price competition in determining a fair and reasonable price. Thus the government will need to rely on the contractor to submit cost and pricing data to the government, and, if the value of the contract change exceeds the TINA threshold (currently established at $700,000), the contractor will be required to certify that the cost or pricing data are current, accurate, and complete at the time of contract change negotiation.

When the contract period of performance is over and the completed contract is being closed out, the contractor's final actual costs may be audited by the government. If the government has reason to believe that the contractor's certified cost or pricing data was not current, accurate, or complete, TINA allows for a price adjustment remedy and the government can recoup any excess costs.

As can be seen in the previous discussion, the TINA statute is integrated throughout the contract management process and provides the government a level playing field with the contractor in negotiating a fair and reasonable price without the benefit of price of competition. In these situations the government and contractor may be negotiating either a fixed-price contract or a cost-reimbursement contract. The next section will discuss the application of economic theories when the TINA statute is used in each of these contract type categories.

Economic Literature Review

This section reviews academic literature that is relevant to DoD acquisition and sets a foundation for the subsequent analyses. We first start with a general description of the unique characteristics that underlie DoD major weapon system acquisitions, then introduce adverse selection and moral hazard concepts. We further elaborate on why DoD contracting is subject to both adverse selection and moral hazard problems, and consequently, limiting information rents and inducing the best effort naturally become the two objectives for policy makers. We also introduce the concept of "power of incentive schemes" and how this concept applies to various contract types. Finally, the non-commitment and ratchet effect in DoD contracting is discussed, along with a brief introduction to the cost padding behavior of DoD contractors.

Unique Characteristics of Major Weapon System Acquisitions

Major weapon system purchases are very unique and complicated. Wang and San Miguel (2013) argue that "the Major Defense Acquisition Programs (MDAP) contracting environment is unique in the sense that an MDAP contract is typically a sole-buyer-and-sole-seller case, in which market competitive forces rarely exist and significant information asymmetry and potential agency problems prevail" (p. 6). The major contributing factor to the "sole source" or "near sole source" contracting scenario is "the complexity, uncertainty, and long-term commitment in major weapon systems." Other reasons are "the DoD's need for secrecy, expediency, and/or safeguarding human resources" (Wang & San Miguel, 2013).

The "sole-source" scenario puts the DoD at an informational disadvantageous position relative to the contractor in the contracting process. Due to the significant information gap between the contractor and the government, the contractor has the intent and ability to extract information rents from the government. Moreover, since the effort level of the only capable contractor is not observable, contractors' shirking becomes a legitimate concern.

Adverse Selection and Moral Hazard

An adverse selection (i.e., hidden information) problem arises when contractors have superior information relative to the government. Many times, the government is at a loss when it comes to how much a product or a new system should cost. The company that provides the quote is at a high advantage when it negotiates with the less informed government. The government usually has to take the contractor's word on price and quality, especially for a first-time-purchased product or system.

Laffont and Tirole (1993) provide a footnote from Robert Keller, who was the former assistant comptroller general of the United States in regards to adverse selection, stating,

> The government negotiator generally is at a disadvantage in trying to negotiate, since the contractor knows not only all the facts and the assumptions underlying his estimates, the alternatives available to him, and the contingent areas, but he also knows the price at which he will be willing to accept the contract. (p. 2)

Laffont and Tirole (1993) define moral hazard (i.e., hidden effort) as "endogenous variables that are not observed by the regulator. The firm takes discretionary actions that affect its cost or the quality of its products. The generic label for such discretionary actions is effort" (p. 1). Effort is hard to observe and hence cannot be contracted upon. As a whole, society is lazy and hence contractors tend to shirk unless incentives are provided to induce more effort. With moral hazard, the information provided by the contractors on their past performance and quality of work can be manipulated to make it seem as though the company is making their best effort, and some very well might be, but in reality, the contractors are shirking.

In general, DoD contracts are subject to both adverse selection and moral hazard problems, given that significant information asymmetry is the norm, and the effort levels of contractors are generally not observable. Hence, a benevolent government that aims to maximize the whole society's welfare has two policy objectives in mind: limiting undue information rents and inducing cost-saving effort.

Various Contract Types and Power Incentive Schemes

Fixed-Price, Cost-Plus, and Incentive Contracts

There are two major types of contracts: fixed-price and cost-plus contracts. The two polar cases are firm-fixed-price (FFP) and cost-plus-fixed-fee contracts (CPFF).

According to FAR 16.202-1,

> A firm-fixed-price contract provides for a price that is not subject to any adjustment on the basis of the contractor's cost experience in performing the contract. This contract type places upon the contractor maximum risk and full responsibility for all costs and resulting profit or loss. It provides maximum incentive for the contractor to control costs and perform effectively and imposes a minimum administrative burden upon the contracting parties.

FAR 16.306 states,

> A cost-plus-fixed-fee contract is a cost-reimbursement contract that provides for payment to the contractor of a negotiated fee that is fixed at the inception of the contract. The fixed fee does not vary with actual cost, but may be adjusted as a result of changes in the work to be performed under the contract. This contract type permits contracting for efforts that might otherwise present too great a risk to contractors, but it provides the contractor only a minimum incentive to control costs.

An FFP contract without TINA addresses the moral hazard problem but still suffers from adverse selection. In this type of contract, the contractor is motivated to exert the best effort to save on cost and maximize profit. Adverse selection, on the other hand, is still a major problem due to contractors' strong incentive to withhold their proprietary information as well as extract information rents. Even with market research completed by contracting officers, the adverse selection problem remains a significant issue.

A CPFF contract, in contrast, addresses the adverse selection problem better because the reimbursement is based on incurred rather than projected cost. However, moral hazard becomes the main worry since contractors have no incentive to curb costs. The lack of incentive to curb costs is due to the fact that the contractor's profit is fixed and any cost savings will be passed on to the government as opposed to the contractor.

In addition to the FFP and CPFF, there are various incentive contracts that lie between the two extreme cases. They are fixed-price-incentive-fee (FPIF) contracts, cost-plus-incentive-fee (CPIF) contracts, and cost-plus-award-fee (CPAF) contracts. These incentive contracts are intermediate contracting arrangements between the two polar types, and they typically address both adverse selection and moral hazard to some degree, yet neither effectively enough.

Power of Incentive Schemes

Various types of contracts introduced in the first section of this paper possess different power of incentive schemes. Power, in relation to incentive schemes, means the extent to which the scheme can motivate effort. Table 1 is reproduced from Laffont and Tirole (1993).

Table 1. Power of Commonly Used Incentive Schemes
(Laffont & Tirole, 1993, p. 11)

	Transfer Allowed?	
Power	Yes (procurement, most public enterprises)	No (most private regulated firms)
Very High (firm residual claimant)	Fixed price contracts	Price caps
Intermediate (cost or profit sharing)	Incentive contracts	Incentive regulation
Very Low (government or consumers residual claimants)	Cost-plus contracts	Cost-of-service regulation

Note. Highlighted emphasis added by authors.

Laffont and Tirole explain that a cost-plus contract has the government pay the contractor its realized price while the fixed-price contract has a set limit that the government will pay no matter what performance or effort is executed. They also explain that the incentive contracts have the government and the contractors share the realized costs.

With a fixed-price contract, contractors usually put forth the most amount of effort. Although the contractor knows they will receive a fixed fee for their product, the more they save on the cost, the more profit they will receive. Thus, fixed-price contracts are high power incentive schemes.

A cost-plus contract gives few incentives to the contractor to exert effort and hence is labeled as a low power incentive scheme. Incentive contracts, as intermediate arrangements between fixed-price and cost-plus contracts, are intermediate power incentive schemes.

Table 2 in Laffont and Tirole's (1993) *A Theory of Incentives in Procurement and Regulation* shows that if a contract is fixed-price, the effort is induced 100% (p. 40). If the contract is cost-plus, the effort is induced at 0%.

Non-Commitment and the Ratchet Effect

In DoD contracting, contracts are awarded for one basic year with priced options for additional years. This is known as multiple-year contracting. Another approach is multi-year contracting. Multi-year contracting is an annual contract that is awarded each year consecutively. In cost-based requirements, multiple-year contracts may be used to provide long-term incentives to contractors while providing a reliable contract vehicle for recurring needs. Awarding multiple-year contracts ensure that the short-term contract is guaranteed and option years are written in the contract for long-term commitment. The risk of exercising options is still present, but at a lesser extent so as to incentivize the contractor to perform well in order to guarantee an additional year. Multiple-year contracts do not require congressional approval or guarantee of funds stability, and can be used for cost-reimbursement type contracts and fixed-price type contracts. To gain a better understanding, Table 2 shows an example of the difference between multiple-year contracting and multi-year contracting.

Table 2. **Multi-Year vs. Multiple-Year Contracting**
(O'Rourke and Schwartz, 2014)

Multi-year	**Multiple year**
Issue one or more contracts for each year's procurement of four aircraft. After Congress funds the procurement of the first four aircraft in FY2015, DoD would issue one or more contracts for those four aircraft. The next year, after Congress funds the procurement of the next four aircraft in FY2015, DoD would issue one or more contracts for those four aircraft	Issue one contract covering all 20 aircraft to be procured during the five-year period FY2015–FY2019. Contract award in FY2015, at the beginning of the five-year period, following congressional approval to use MYP for the program, and congressional appropriation of the FY2015 funding for the program. Implementation of the contract over the next four years would be completed by obtaining funding for each additional FY.

Laffont and Tirole (1993) state,

> If the firm performs well (produces at a low cost) early in the relationship, the regulator infers that the technological parameter is favorable and tries to extract the firm's rents by being more demanding during the regulatory review. The firm has thus an incentive to keep a low profile by not engaging in much cost-reducing activity. To induce the firm to produce at a low cost when efficient, the regulator must offer it a generous reward for good performance. (p. 45)

Stated equivalently, the lack of the commitment from the government naturally leads to contractors' fear of being "ratcheted up" if they reveal their lowest possible cost. Being efficient one time would eliminate their future rents. Therefore, unless the profit from a one-year contract is sufficiently sizable, contractors would choose not to engage in cost-saving activities as much as they can.

The cure to the problem above is straightforward. Laffont and Tirole (1993) state,

> To put the ratchet effect in perspective, recall that, if the two parties can commit to a long-term contract at the beginning of their relationship, the regulator optimally commits to use each period the optimal static contract. That is, it is optimal for the regulator to commit not to exploit the information acquired from observing the firm's performance. Commitment is crucial for this outcome because the regulator would want to fully extract the firm's rents from the second period on after the firm reveals its efficiency in the first period. (p. 376)

Cost Padding

Cost padding, if not detected and controlled by the government, adds unnecessary cost to the government. Examples of cost padding include but are not limited to, incurring excessive costs to the government such as leisurely meetings, first class travel, and business lunches. Other examples are shifting overhead costs from commercial business to government contracts and engaging in various bookkeeping tricks to manipulate costs. The government counters contractor cost padding by requiring certain contractors to be audited.

The DCMA has a systemic operational cycle that allows monitoring contractor cost driving contractor performance. In the Defense Contract Audit Agency (DCAA; 2014a) *Contract Audit Manual* (CAM), Chapter 9 discusses Audit of Cost Estimates and Cost Proposals. Cost padding is a factor in labor cost data. It states,

> The auditor should examine, on a selective basis and in cooperation with Government technicians … for the new product. When appropriate, contractor personnel should be interviewed to ascertain probable significant changes in engineering production methods and the effect those changes might have on current cost data. When an evaluation indicates that significant technological changes have occurred since the cost data was accumulated, adjustment of experienced costs is necessary before projecting the experience cost pattern. (DCAA, 2014a)

The manual further explains the contractors variances of direct labor cost and illustrates a "guesstimate" is made and then a "padding" is added to protect from any unexplained cost. Through the bookkeeping manipulations, resulting "guesstimates" and subsequent "padding," the contractor audit becomes a significant challenge to accurately appraise the extraneous cost. Cost padding is viewed as being more prevalent in cost-plus contracts, though as will be elaborated later, the incentives for cost padding still exist under a fixed-price contract.

Analysis and Policy Implications

As pointed out in the literature review section, defense procurement is subject to both adverse selection and moral hazard problems; consequently, limiting information rents and promoting contractors' cost-saving efforts become the two main policy objectives for the government.

This section argues that TINA, to some extent, mitigates the adverse selection problem by mandating that contractors provide certified cost and pricing data that are "current, complete, and accurate" and legally holding them accountable. Hence it is fair to say that TINA helps policy makers achieve one of their two policy goals: limiting information rents.

This section, however, emphasizes the ineffectiveness of TINA. In particular, building on an economic-based, incentive-centric approach that investigates contractors' incentives, we argue that the main flaw of TINA is its failure to address the moral hazard problem. In some cases, such as cost-plus contracts, where moral hazard is an inherent concern to begin with, TINA fails to provide remedies. More detrimentally, in other cases such as fixed-price contracts, where moral hazard is otherwise appropriately addressed, the use of TINA undesirably removes contractors' incentives to exert effort. Therefore, TINA, in the context of fixed-price contracts, is the problem rather than the solution.

Based on our arguments, we accordingly make policy recommendations at the end of this section.

Distorted Incentives: Use of Tina With Firm-Fixed-Price (FFP) Contracts

In this subsection, we express our greatest concern over TINA. That is, ill-fated incentives are created if TINA is used with an FFP contract. In the following, we use a step-by-step approach to illustrate the problem.

Background

There is a current policy push toward more use of FFP contracts. Since 2009, support for firm-fixed-price contracts has been steadily increasing in order to limit government risk, reduce cost overruns, and improve contract effectiveness (Wang & Miguel, 2013). As such, there has also been a strong policy push towards regulation in support of fixed-price contracts to be a fix-all to the cost overruns that the DoD faced in prior years. Top leaders, including President Obama; Robert Gates, former Secretary of the DoD; and Ashton Carter, former Under Secretary of Defense for Acquisition, Technology, and Logistics, have all expressed that they favored the use of more FFP contracts in DoD acquisition. The presidential memorandum issued in April 2009 explicitly stated that "there shall be a preference for fixed-price type contracts" (Obama, 2009). Consequently, more and more DoD contracts prescribe FFP.

Given the more frequent use of FFP in the DoD procurement, it has become increasingly more important to understand how contractors' incentives change with respect to the enforcement of TINA within FFP contracts. In particular, we will use a "without and with" approach to demonstrate the unintended negative consequences of bundling TINA with FFP contracts.

FFP Contracts* Without TINA*, Despite Many Weaknesses, Are Free of the Moral Hazard Problem

Wang and San Miguel (2013) challenge the wisdom behind policy-makers' favor toward FFP contracts. In particular, they state, "The notion that fixed price contracts are better than cost-plus contracts for limiting cost overruns is misleading." The article further explains that FFP contracts may in fact have three negative consequences: (1) fixed-price contracts provide few risk-sharing benefits; (2) fixed-price contracts lead to higher government payments; and (3) unjustified favor toward fixed-price contracts promotes inefficient industry structure.

Nevertheless, despite the problems pointed out by Wang and San Miguel (2013), FFP contracts do have one appeal: That is, an FFP contract is a high power incentive scheme that effectively motivates contractors' maximum efforts. Once an FFP contract is awarded, the contractor relentlessly seeks to reduce cost because every dollar saved on cost will directly translate into profit. Stated equivalently, contractors under FFP contracts without TINA voluntarily abstain themselves from shirking, that is, the moral hazard is not a problem at all.

FFP Contracts,* With TINA*, Lose the Last Benefit of Being a High Power Incentive Scheme

Since most DoD weapon procurement FFP contracts exceed the TINA threshold value, unless the TINA waiver is widely applied, FFP contracts without TINA are exceptions rather than norms. Hence, it is important to understand what incentives or disincentives are created or removed if TINA is bundled with an FFP contract.

One astute observation by Rogerson (1994) is that "TINA cannot force defense contractors to reveal the lowest possible cost that they could produce at if they exerted an optimal effort. Rather, it essentially tells them that the price they negotiate must be close to the cost they actually incur."

Therefore, a contractor under an FFP contract that is subject to TINA has the following ill incentive: The fear of being held accountable for any significant unfavorable cost discrepancy (i.e., the actual incurred cost is significantly below the ex-ante cost estimate submitted to the DoD as the basis for contract fixed-price) would strongly motivate the contractor to shirk (i.e., reduce cost-saving effort) or even engage in cost padding (e.g., by opportunistically incurring or allocating more costs to the government contracts), especially when the natural state turns out to be favorable.

In the situation above, shirking becomes a dominant strategy because working hard introduces disutility to the contractor with the additional risk of being penalized by TINA. In the case of a very favorable natural state (i.e., if every exogenous factor turns out to be good), if shirking is not sufficient to bring the cost close enough to the ex-ante cost estimate, the contractor will engage in opportunistic and hard-to-detect cost padding to ensure the reported cost is trouble-free.

To recap, TINA, in the context of FFP contracts, removes the last benefit of FFP contracts and literally turned a high power incentive scheme to a low power one. Here, the moral hazard problem is reintroduced by the misuse of TINA.

A Numerical Example

We use the theoretical framework in Laffont and Tirole (1993) to set up a numerical example to illustrate the point made in prior sections. A contractor's cost function is specified as follows:

$$c = c(\beta,\mathrm{e}) \quad (1)$$

where β is a state parameter (e.g., technology) and e is the effort. One can interpret that β is the adverse selection parameter and represents contractor's private information, and e is the moral hazard parameter.

Without losing generality, assume the state parameter β has three possible outcomes: good, neutral, or bad, with equally likely probability. Moreover, the contractor can choose either work hard (e = 10) or shirk (e = 1).

Imagine the cost function takes the following form:

$$c = \beta + \frac{\beta}{e}$$

Note that the cost increases with β (so β is an inverse indicator of state parameter) and decreases with e (effort reduces cost).

Case (1) Good situation: (β = 10), with probability 1/3.

$$c = 10 + \frac{10}{e} \quad (2)$$

Case (2) Neutral situation: (β = 20), with probability 1/3.

$$c = 20 + \frac{10}{e} \quad (3)$$

Case (3) Bad situation: (β = 30), with probability 1/3.

$$c = 30 + \frac{10}{e} \quad (4)$$

It is reasonable to assume that the contractor knows the probability distribution of the natural state, whereas the government does not know. We also assume that the contractor's negotiation strategy is to ensure breakeven even in the bad situation and he or she can still shirk. So the contractor will submit $40 as the cost estimate by Equation 4, and the less informed government would most likely accept, with TINA strings attached, stating that if the incurred cost is more than 25% lower than $40 (i.e., below $30), then the contractor is subject to a TINA audit.

Let's also assume that this is a one-time static game in which no further contract is possible. The contractor tries to maximize its profit.

The sequence of the actions is as follows: The contractor submits the bidding price, accepted by the government, which attaches TINA to the FFP contract. Then the natural state reveals, the contractor chooses effort, and finally the cost is incurred.

If a bad situation happens, the contractor will choose to work hard (e = 10), so the cost is $31 by Equation 4, a TINA audit is not triggered, and the contractor earned a profit of $9. There is no moral hazard problem.

In the case of a neutral situation, if the contractor works hard (e = 10), his or her cost would be $21 by Equation 3, which is good in the absence of TINA, yet not so when TINA is in place. Because any cost below $30 would trigger a TINA audit. The contractor, knowing this risk, would choose to shirk (e = 1) so the cost would be $30 by Equation 3, which successfully hides the contractor under the radar of TINA. Now a moral hazard problem is created by TINA.

What if the most favorable natural state emerges? In that case, if the contractor works hard, he or she will incur a cost of $11 by Equation 2, which is going to raise a big red flag to the government. Therefore, the contractor is going to shirk; however, because the natural state turns out to be so favorable, even shirking is not enough to mute the alarm of TINA. (Note that shirking in case 1 would yield a cost of $20, which is below the audit threshold value of $30, and hence will trigger the TINA audit.) So what would the contractor do to evade the TINA investigation? The contractor will engage in “cost padding” and artificially increase the reported cost to at least $30, so he or she will not get into trouble. Now, TINA not only created the moral hazard problem, it also generated bad incentives for defense contractors to engage in unethical and opportunistic “cost padding.”

Fixing Incentives: From Static to Dynamic Perspective

One-Shot Static Game

A good starting point is a static situation where no further contract is possible. Using the numerical example, the government already paid $40, because the contractor can avoid a TINA audit in all three possible scenarios, by either “shirking” or “cost padding” or both, government payment becomes fixed. Therefore, any higher profit of the contractor will lead to a higher social welfare. The implication is straightforward: In order to correct the ill incentives created by TINA in the context of FFP, policy makers need to undo the bundling, that is, remove TINA from FFP, so the FFP is back to a high power incentive scheme.

Repeated Game With Non-Commitment

In the one-shot static game, when TINA is removed from an FFP contract, the contractor is fully motivated to exert the best effort to maximize profit. Since no future contract is possible, the contractor is not afraid to reveal private information (i.e., the minimum cost that can be achieved through the best effort) because there is no possibility for the government to exploit the private information revealed against the contractor in the future.

However, in reality, the relationship between a typical contractor and the government is rarely a one-shot game. Rather, it is better characterized as a repeated game with non-commitment from the government. Typically when multiple-year contracts are awarded, the government is agreeing to a single-year term contract with the option of additional years. Nearing the end of the current fiscal year, the government will begin the process of exercising the next option year. This decision is a unilateral process that a contractor may consider as non-commitment and in return may be apprehensive to share true cost or pricing data for fear of being “ratcheted up” in future years.

Stated equivalently, in a repeated game where contracts have one base year and option years which can be exercised by the government, a simple removal of TINA from a one-year FFP contract may not be sufficient to induce the contractor's best effort. The contractor is in a very vulnerable position in the sense that if he or she chooses to reveal private information at the early stage of the game, that information may be used against him or her later so no future information rents are possible. As discussed in the literature review section, contractors' fears of being "ratcheted up" by the government motivates them to withhold their private information so they can still extract information rents from the government in later periods. To recap, a simple removal of TINA from a one-year FFP contract tends to be ineffective in addressing the moral hazard problem

So what is the fix of the lack of incentives? If a one-year FFP contract without TINA is not enough to motivate, the government should consider multiple-year FFP contracts without TINA. This is especially useful if the product is demanded on a continuous basis. The idea is: make the reward of revealing the best-effort cost big enough, so the contractor voluntarily tells the government what is the lowest achievable cost. It is wise to let the contractor win early, win big, but only win once. The government, and hence the taxpayers, win in the long run and win even bigger.

Multiple-Years Contracts: Numerical Example Continued

In this subsection, we extend the static, one-shot numerical example to a repeated game case. Under some reasonable assumptions, we show that government savings can be achieved by fixing contractors' incentives.

Without losing generality, assume the government needs to order this product every year for 15 years. If each year TINA is attached for 15 annual contracts, the contractor will always choose to shirk[1] or "shirk and cost padding" in order to avoid the TINA audit, as well as to keep the information rents for the future. Hence, the government will end up paying $600. Alternatively, if TINA is removed for every annual contract on a yearly basis, the TINA concern is removed for that year; however, the contractor still worries about the consequence of revealing the lowest possible cost under the maximum effort due to the non-commitment nature of government contracts. One-year increased profit due to effort is meagerly too small to entice the contractor to give up their future information rents. Thus the contractor will still withhold effort and choose to shirk.

Without losing generality, assume that a five-year FFP contract is sufficient to induce the contractor to exert his or her best effort. Therefore, the government commits to pay $40 each year for five years with no TINA strings attached. With this commitment, the contractor is fully motivated to work as hard as possible and the lowest possible cost is revealed to the government. The government, which observes that the true expected lowest possible cost is $21 (i.e., $\frac{1}{3} * 11 + \frac{1}{3} * 21 + \frac{1}{3} * 31$), will use that information to price future 10-year contracts. Under the assumption that a 10% profit is allowable, the government will offer $23.1 ($21*1.1) annual FFP contract for the remaining 10 years. So the total government payment now becomes $40*5+$23.1*10 = $431, a savings of $169 relative to the original situation.

[1] Note that in contrast to the one-shot game, the contractor chooses to shirk even in the bad situation, due to the concern of being "ratcheted up" if the lowest possible cost is revealed.

Note that if the time span is longer, say 25 years as opposed to 15 years, then the government savings will be even larger.

TINA Waivers: A Useful Policy Tool

TINA is effective in deterring outright fraud and "defective pricing," especially on the part of the cost that is verifiable. Hence, we should give TINA credit for doing that part right. However, TINA is much less effective at addressing the moral hazard problem, where one key determinant of the cost, namely effort, is unobservable, unverifiable, and not contractible. TINA could even become very destructive when it is applied to an FFP contract setting, as shown earlier.

Fortunately, lawmakers do allow TINA waivers and a shrewd utilization of that tool is essential for making better use of TINA. One of the justifications for a TINA waiver is that "there are demonstrated benefits to granting the waiver." Our analysis in this section detailed the reasoning for the use of TINA waivers. Based on our analyses, we recommend the following policies options:

If an FFP contract is negotiated with a contractor who is unlikely to have a continuous contracting relationship with the government for the same or similar products and services, then a waiver of TINA should be applied. However, it can sometimes be difficult to predict the future of non-continuous relationships until after the first year of performance. Additionally, the Federal Acquisition Regulation allows for certain TINA waivers under HCA approval.[2]

If an FFP contract is negotiated with a contractor who is likely to continue to provide the same or similar product to the government for years to come, then a multiple-year FFP contract, without TINA provisions on defective pricing data, should be offered to motivate the contractor's best effort. Note that in this setting, a multiple-year contract is needed.

TINA and Cost-Plus and Incentive Contracts

TINA is less damaging when it is bundled with cost-plus contracts. In such contracts, the moral hazard is an inherent concern to start with; TINA does not introduce the problem, nor does it solve it. Under a cost-plus contract, the contractor shirks anyway, regardless of the presence of TINA. To the extent that the total realized cost is auditable while the various components of total cost are not (Lafond & Tirole, 1993), "cost padding" would still be possible. That said, TINA does make the verifiable part of the cost more credible, and also provides disincentives for contractors to engage in outright fraud and "defective pricing" behavior.

Incentive contracts are basically intermediate arrangements between fixed-price and cost-plus contracts. Hence, similar to an FFP setting, but to a lesser degree, any cost-saving

[2] Increasing the use of TINA waivers may be a plausible solution if reasonable expectations exist that fair and reasonable pricing is already established. For example, per FAR 14.403-1(c)(4), the HCA may waive the requirement for contractors (and lower-tiered subcontractors) to provide certified cost or pricing data if such data was previously submitted and is updated. Allowing for more waivers is an "easy-fix" to lowering defective pricing cases, but it may not be the most effective in reducing disincentives attached to TINA. Waiving TINA may also subject the government to information rents that were previously mitigated. Simply waiving policy when a need for it still exists is, in and of itself, an ineffective policy solution.

incentives under incentive contracts would be weakened by TINA. The government may change contract vehicles depending on the lifecycle of the acquisition program, and it is important to know how TINA will affect contracts within each milestone of a program. Throughout the lifecycle of the acquisition, a requirement may move along the contract vehicle spectrum to take into account new discoveries and established requirements. Because of this, TINA should also be a living-breathing provision that takes into account the different contract vehicles used in major acquisition rather than an end-all to pricing uncertainty. Because there are certain adverse selection issues and moral hazards that are unique to differing contract types, acquisition personnel will need to be aware of which disincentives may be occurring at each contracting stage. We leave this to our future research.

Conclusion

It has been more than 50 years since TINA was first enacted in 1962. In a nutshell, TINA requires contractors (often sole-source) to submit "cost or pricing data" when they negotiate the price of a contract with the federal government. The contractors must certify that the information they provide is "current, complete, and accurate." Failing to disclose truthful information could lead to a civil or criminal investigation. The intention of TINA is to protect the government and taxpayers from being ripped off by better informed contractors.

We hopefully have convinced our readers that the current TINA practice, despite its good intention, is subject to unintended negative consequences that arise from contractors' bad incentives. Such bad incentives are inherently associated with the current TINA framework. We document both strengths and weaknesses of the current TINA practice, with an emphasis on the latter and in turn generate corrective policy implications.

One major contribution of our study is to introduce an economics-based, incentive-centric approach that focuses on the investigation of agents' (i.e., DoD contractors') various incentives that are generated by TINA. This approach, in our opinion, can be widely applied to many issues in the DoD acquisition environment. The importance of agents' (in our case, DoD contractors') incentive issues can never be overstated in a DoD procurement setting, as testified by Rogerson (1994):

> Defense procurement is unique among regulated industries in the United States in that economists have played virtually no role in helping shape its regulatory practices and institutions. Perhaps this is due to the barrier to entry created by the need to first learn about procurement practices or to a lingering distaste for military matters among academics. Whatever the reason, this lack of economic input is unfortunate, because many of the regulatory and policy issues in defense procurement involve the types of <u>incentive issues</u> [emphasis added] that economists are very good at analyzing. My own hope is that economists are on their way to colonizing this new policy frontier and that some of the ideas discussed in this article will play a role in shaping policy debates over the next decade. (p. 87)

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Freedom of Market Navigation Versus Duty of Economic Rescue: The U.S. Department of the Navy's Use of Set-Asides Parity, Discretion, and Simplified Acquisitions to Contract With Hubzone Small Businesses

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Abstract

Since March 1999, the Department of the Navy (DoN) has had an important shore duty: to exercise its purchasing freedoms and powers in ways that will channel government contracts to small business concerns (SBCs) locating and hiring in Historically Underutilized Business Zones (HUBZones). Under the Small Business Act, the HUBZone Program provides these firms with contracting assistance, notably, competitive and sole sources set-asides. In 2005, this assistance was expanded to FAR Part 13 Simplified Acquisition Procedures. The federal government must also spend at least 3% of its prime contract dollars with HUBZone SBCs. During fiscal years 2006–2015, DoN's HUBZone goal achievements experienced a brief dramatic growth followed by a full-circle decline to the decade-old spending and percentile levels. Academic and legal policy literature offers many possible reasons for this unfortunate U-turn. The HUBZone Program's design was often criticized on the grounds that it impedes creating and finding capable and eligible firms; that it may reward already-successful or overly-costly contractors; that it hurts the government's ability to meet its duties to other socioeconomic programs, such as the 8(a) Program; that it is not strong enough to match the 8(a) Program; and that it introduces undue complexity into federal procurement. Beginning in 2011–2012, the federal HUBZone Program lost about 30% of its participants to decertification. Finally, during the first half of the last decade, the HUBZone Program triggered a constitutional stand-off between legislative, executive, and judicial branches on the Program's discretionary parity or mandatory precedence over the 8(a) SDB, WOSB, and SDVOSB programs. The DoN initially scored a judicial victory over the Small Business Administration (SBA) in favor of precedence, but changed its stance three years later with the rest of the executive branch in favor of discretion and parity. This study examines possible root causes and solutions to DoN's HUBZone contracting woes through the use of the generally accepted Cohen-Eimicke Contract Management Performance Model.

Introduction

Since 1999,[1] the Small Business Act and the Small Business Administration (SBA) imposed on the U.S. Department of the Navy (DoN; the parent agency of the U.S. Navy and the U.S. Marine Corps) a shore duty to render economic development assistance to small business concerns located in so-called Historically Underutilized Business Zones (HUBZones) by means of government contracts. This rescue duty[2] was imposed as a condition on the pre-existing customary legal freedom enjoyed by Navy and Marine buyers to navigate the market and the industrial base looking for the best bargain.[3] Similar to the seafarers' rescue duty, this new economic development duty is based on the rationale that the Navy and the Marines must use their superior power (in this case, buying power) to assist struggling-area firms and not merely wait on some development assistance agencies and experts to come help later (Dilger, 2013). This rescue-on-shore framework contemplates that, as condition of assistance, the DoN will necessarily receive substantial benefits from the HUBZone firms in the form of goods and services to meet the DoN's requirements. Indeed, HUBZone industrial base benefits may well be mission-critical for the DoN.

The Small Business Act and implementing regulations require the DoN to follow certain designated paths to support the federal HUBZone policy. For example, the DoN is required to meet its HUBZone contracting goal, negotiated so as to contribute to the DoD's and government-wide goal of spending not less than 3% of total procurement spending with HUBZone small business concerns.[4] Further, the HUBZone statute and regulations provide several tools, including competitive (currently including reserves) set-asides, sole source set-asides (up to certain dollar thresholds), a price evaluation preference in full and open competitions applicable against other than small business concerns, and a certified HUBZone small firms' database.[5] In addition, as part of rulemaking on veterans contracting, the Federal Acquisition Regulation (FAR) Council on its own made "improving opportunities" for HUBZone firms one of the stated purposes of FAR Part 13, Simplified Acquisition Procedures (Federal Acquisition Regulation [FAR] Council, 2005).

This paper contains the preliminary results of a study conducted at the request of the director, Secretary of the Navy's Office of Small Business Programs, on improving DoN HUBZone contracting.[6] As such, it is necessary to explore DoN's HUBZone goaling

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[1] The HUBZone Program was created by the Small Business Reauthorization Act of 1997, Public Law 105-135, Title VI, codified at 15 U.S.C. §657a (1997); it went into effect in March 1999 once the SBA established certified its first HUBZone firm. See Dilger (2013).

[2] The reference to rescue duty is an attempt at analogy to the seafarers' rescue duty. Historically, when at sea, admiralty and international maritime law gives the U.S. Navy and the U.S. Marine Corps the freedom of navigation but also imposed on them the duty of rescue those in distress (also known as the duty to render assistance). The policy rationale for this duty is the recognition that seafarers must use their powers for good without merely waiting for some other rescue ships to arrive. See generally, Maltzman and Ehrenreich (2015); *Commander's Handbook* (2007), Ch. 3, "Protection of Persons and Property at Sea and Maritime Law Enforcement"; Peltz (2014).

[3] See generally, FAR Parts 5 and 6 (2015).

[4] See 15 U.S.C. § 644 (2007).

[5] See 15 U.S.C. §657a (2015); FAR Subpart 19.13; 13 C.F.R. Part 126 (2015).

[6] This study extensively relies on the analytical framework and conceptual analysis from a prior SECNAV OSBP-sponsored study: Kidalov and Lee (2015)

performance and the HUBZone Program's background to place the study in its proper context. Data in Figure 1, Figure 2, and Table 1 show that the DoN's goaling performance needs a turnaround.

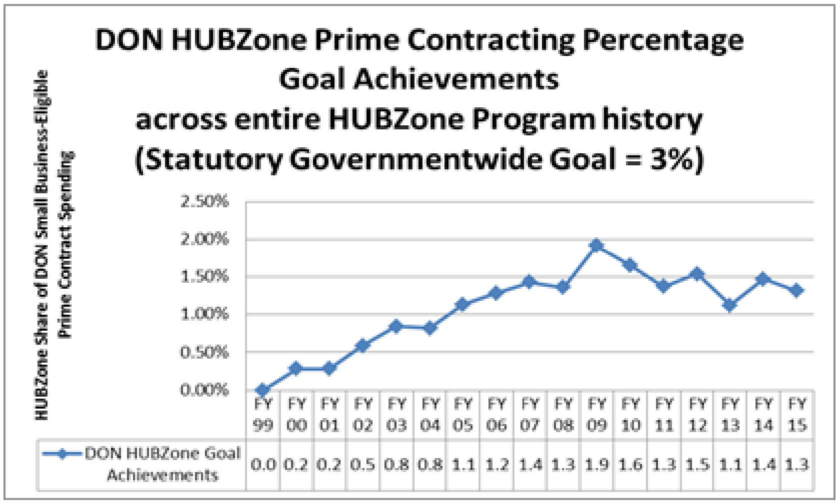

Figure 1. DoN HUBZone Goal Achievements Across HUBZone Program's History

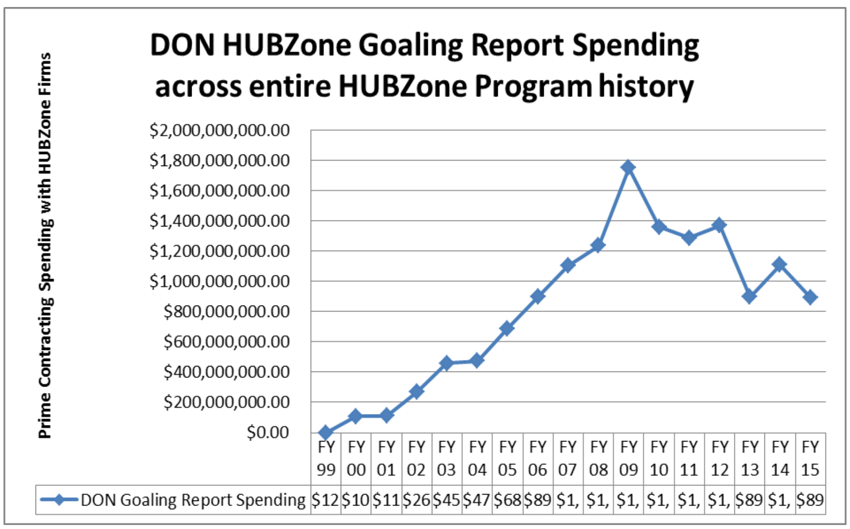

Figure 2. DoN HUBZone Goaling Spending Across HUBZone Program's History

Table 1. DoN HUBZone Historic Goaling Results; Identification of the Period Under Study

DON HUBZone Goaling Results across HUBZone Program history		
Fiscal Year	DON HUBZone Goal Achievements	DON HUBZone Goaling Report Spending
FY 99	0.00%	$124,871.00
FY 00	0.28%	$108,072,889.00
FY 01	0.28%	$111,603,579.00
FY 02	0.59%	$267,233,044.00
FY 03	0.84%	$457,836,297.28
FY 04	0.82%	$472,357,985.95
FY 05	1.13%	$689,181,165.85
FY 06	1.28%	$897,613,942.79
FY 07	1.43%	$1,104,217,860.49
FY 08	1.36%	$1,237,321,102.72
FY 09	1.91%	$1,750,105,357.60
FY 10	1.65%	$1,359,237,241.73
FY 11	1.37%	$1,287,878,332.19
FY 12	1.54%	$1,367,580,177.22
FY 13	1.12%	$898,154,878.94
FY 14	1.47%	$1,109,412,329.02
FY 15	1.31%	$893,143,410.97

At the time of the HUBZone Program's design and since, its design has been the subject of intense criticisms. U.S. Senate Small Business and Entrepreneurship Committee Chairman Senator Kit Bond intended for the HUBZone to replace the 8(a) Business Development Program for Small and Disadvantaged Businesses, while President Clinton and others in Congress did not (e.g., see Dilger, 2013). Others criticized the HUBZone program as interfering with efficiency, or as favoring "close swap" of non-HUBZone firms for HUBZone firms that were close to winning contracts even without HUBZone assistance (e.g., see Dilger, 2013; Reece, 2011).

As noted in the author's prior research (Kidalov & Lee, 2015), Section 8(a) of the Small Business Act authorizes and directs SBA to provide business development assistance to small disadvantaged businesses (SDBs), typically, members of groups victimized by past racial discrimination. Included in this assistance are tailored business development plans, pool of contract requirements "accepted into" the program for not more than seven years for sole source and competitive set-asides, management and technical advice, agency goals, training, and other assistance. In addition, 8(a) sole source contract awards can be made based on such business development plan even if there is another willing, but more successful 8(a). SBA's assistance mix would change as the firms established past performance and progressed towards program graduation. The SBA reports to Congress annually on assistance metrics, including number of firms assisted and agencies' spending goal achievement.[7] Federal and DoD contracting officers make non-competitive 8(a) awards

[7] See generally 15 U.S.C. § 637(a) (2014); 13 CFR Part 124 (2014); SBA Office of Business Development (2008); SBA (2014).

with SBA direction or concurrence, and may not rededicate 8(a) Program contracts for other businesses without SBA approval. This assures the 8(a) Program a “floor” in terms of program spending and breadth of industries. Further, the 8(a) Program increases the outcome of business development of disadvantaged entrepreneurs through a firm-focused process there the SBA assumes much of the responsibility for picking firms in need of contract awards, leaving contracting officers to focus on better requirements definition and contract administration. In contrast, the SBA emphatically stated that no business development assistance will be provided to individual HUBZone firms, but that assistance will be indirect to HUBZone communities at large.[8] In essence, DoN contracting officers bear some moral or public interest responsibility for HUBZone economic development, but well-defined responsibility for performance risk and no specific guidance on how to tailor contracts to HUBZone firms’ needs.

Since the creation of the HUBZone Program, the legal force of this economic assistance duty has been the subject of an intense debate. Between 1999 and 2005, this duty was legally mandatory and took precedence over assistance duties to other types of small businesses. In August 2005, however, the U.S. Small Business Administration decided that the duty to the HUBZone firms must be subject to parity with other so-called socioeconomic small business categories.[9] In the January 11, 2006, case of *Contract Management Industries, Inc. v. Rumsfeld*,[10] which concerned HUBZone set-aside at Naval Base Pearl Harbor, the DoN took a very firm stand against the SBA’s position and in favor of the original mandatory design of the HUBZone Program set-asides and the precedence of HUBZone set-asides over the 8(a) Program. The U.S. Court of Appeals for the 9th Circuit, and at the time, the U.S. Department of Justice sided with the DoN against the SBA. In *International Program Group, Inc*.,[11] a September 19, 2008, case involving pre-deployment training contracts at Marine Corps Camp Pendleton, the DoN doubled down on that victory. The DoN obtained a GAO opinion reinforcing the 9th Circuit and the precedence of HUBZone set-asides over set-asides for service-disabled veteran-owned small businesses (SDVOSBs). However, the debate did not stop. The U.S. Government Accountability Office, the U.S. Court of Federal Claims, the DoJ Office of Legal Counsel, the Executive Office of the President, Congress, and various DoD components all added to the debate (Branch, 2009). On August 4, 2009, the DoN acceded to the view of the SBA, DoD Defense Procurement and Acquisition Policy, and DoJ OLC that HUBZone contracting set-asides must have parity with other Small Business Act socioeconomic categories and be subject to the discretion of the contracting officer (Branch, 2009). The debate, which lasted through 2010–2011, has triggered a constitutional stand-off over congressional, judicial, and executive powers over financial assistance to distressed areas by means of government procurement contracts. The crisis was resolved when Congress acceded to the Executive Branch requests and legislated parity between socio-economic category set-asides in the Small Business Jobs Act of 2010.[12]

[8] See U.S. Small Business Administration, HUBZone Empowerment Contracting Program, Final Rule, 63 Fed. Reg. 31896-31916 (June 11, 1996).
[9] See *International Program Group, Inc.,* B-400278; 4-00308 (GAO) (Sept. 19, 2008).
[10] See *Contract Management Industries, Inc. v. Rumsfeld*, 434 F.3rd 1145 (9th Cir. 2006).
[11] See *International Program Group, Inc.,* B-400278; 4-00308 (GAO Sept. 19, 2008).
[12] Public Law 111-240 (Sept. 24, 2010).

As noted in the author's prior research (Kidalov & Lee, 2015), the SBA and FAR Council amended their respective regulations in 2011 and 2012. The SBA amended its regulations on February 4, 2011 and made market research for purposes of considering HUBZone set-asides mandatory:

> After conducting market research, the contracting officer shall first consider a set-aside or sole source award (if the sole source award is permitted by statute or regulation) under the 8(a) BD, HUBZone, SDVO SBC or WOSB programs before setting aside the requirement as a small business set-aside. There is no order of precedence among the 8(a) BD, HUBZone, SDVO SBC or WOSB programs. The contracting officer must document the contract file with the rationale used to support the specific set-aside, including the type and extent of market research conducted. (13 C.F.R. § 125.19(b)(2)(i), 2011).

The FAR amendments provided for parity and also expressly mandated consideration of the HUBZone Program and other socio-economic programs before proceeding with regular small business set-asides above the Simplified Acquisition Threshold (SAT). The FAR Council (2012) states, "FAR 19.203(d) was added to include language consistent with 13 CFR 125.2(f)(2)(ii) regarding the minimum elements a contracting officer should examine when choosing a socioeconomic program: The results of market research and progress in fulfilling agency small business goals." Moreover, the SBA and FAR regulations provide for discretionary ("may") rather than "shall" mandatory language. Based on the Small Business Jobs Act of 2010, Public Law 111-240 (Sept. 24, 2010), FAR § 19.203 outlines three general rules of precedence for open market procurements. First, "[s]mall business set-asides have priority over acquisitions using full and open competition" (FAR 19.203). Second, "there is no order of precedence" among the four small business socioeconomic programs: the 8(a) Program, the HUBZone Program, the Service–Disabled Veteran–Owned Small Business (SDVOSB) Procurement Program, or the Women–Owned Small Business (WOSB) Program. The choice among the socioeconomic programs is discretionary, in that "the contracting officer should consider, at a minimum—(1) results of market research that was done to determine if there are socioeconomic firms capable of satisfying the agency's requirement; and (2) agency progress in fulfilling its small business goals" (FAR 19.203). The third rule concerns the choice between small business set-asides and small business socio-economic set-asides. However, the parity between those programs is still subject to the 8(a) claw-back priority: "However, if a requirement has been accepted by the SBA under the 8(a) Program, it must remain in the 8(a) Program unless the SBA agrees to its release in accordance with 13 CFR parts 124, 125, and 126" (FAR 19.203). The 8(a) Program also retained the so-called non-advertisement rule in Part 124, which obligates contracting officers not to advertise 8(a) requirements through non-8(a) programs.

Since 2011–2012, the federal HUBZone Program also suffered a decertification crisis due to U.S. Census redesignations of HUBZone areas. As many as 30% of HUBZone firms were decertified (Lee, 2012).

Based on the HUBZone Program's background, this study addresses the following three research questions:

1. Can DoN HUBZone Program's struggles be better explained in terms of the generally accepted Cohen-Eimicke Contract Management Performance Model (inputs, process, outputs, and outcome)?
2. Are measures such as broad and unguided individual-level contracting officer discretion on set-asides, parity with the 8(a) and other socioeconomic

program set-asides, and Simplified Acquisitions effective to support HUBZone participation in Navy and Marine Corps contracting?

3. What should DoN do to turn around its HUBZone Program?

This study's research hypothesis is that the DoN HUBZone Program's design is misaligned from critical performance management criteria that do not include goaling spending. Ironically, this misalignment operates to impede HUBZone goaling achievements over the long run. The study uses the Cohen-Eimicke model to define effective program management of a socioeconomic contracting program, and then examines Federal Procurement Data System data corresponding to the Cohen-Eimicke criteria. Finally, the study makes recommendations for DoN and SBA action.

Theoretical Foundations of Effective Program Design: Applying the Cohen-Eimicke Contract Management Performance Model to Hubzone Socioeconomic Contracting

The description of the Cohen-Eimicke model generally follows the description contained in the author's prior research on the SDVOSB Program based on similar methodology (Kidalov & Lee, 2015). Cohen and Eimicke's 2008 modern classic *The Responsible Contract Manager*, sorts contracting programs' performance measurements according to four types of measures: input(s), process(es), output(s), and outcome(s).[13] Inputs are a measurement of program resources, such as "dollars appropriated and allocated, … length of time committed to the problem," involvement of other organizations, and so forth (Cohen & Eimicke, 2008).

> Input measures are frequently criticized because they tell you only how hard you are trying to do something about a problem or the extent of your commitment to reach a particular goal. … Input measures tell you very little about how well you are doing in reaching the objective—they measure effort much better than they assess results. But input measures should not be ignored. They provide an important barometer of the scope of activity and of the present and future demand on overall resources, serve as surrogates of the organization's priorities, and often reflect the organization's customer preferences as well. (Cohen & Eimicke, 2008, p. 152)

In the HUBZone Program, performance (inputs) is generally measured by means of the statutory 3% prime contracting goal under the Small Business Act (or goals as may be negotiated by the SBAs) which provides the "floor" spending share of agency contracts that should go to HUBZone small businesses (Cohen & Eimicke, 2008, p. 153).

Process is the second performance measurement (i.e., step or steps involved in generating outputs, such as production of items); it is described by Cohen and Eimicke as a function of total quality management (TQM). "Measurement of those activities facilitates organizational learning and improvement. Process measures include the delineation and definition of specific work steps, measures of the amount of time it takes to perform specific

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[13] As noted in the author's prior research, this book's reception is discussed in Girth (2014), Joaquin (2010), and Filipovitch (2010). This book is also used in the Naval Postgraduate School contract management curricula.

tasks, error rates, and similar indicators. Requiring organizational units to report process measures can signal government's concern for the quality and efficiency of an organization's internal operations and can compel attention to these fundamental management issues" (Cohen & Eimicke, 2008, p. 153). In the HUBZone Program, HUBZone set-asides as well as related publicity and market research to meet the set-aside Rule of Two[14] or to find a HUBZone sole source contractor constitutes Program process. On the other hand, non-HUBZone set-asides or unrestricted contracts awarded without the benefit of the price evaluation preference constitutes process outside of the HUBZone Program.

Output is the third performance measurement category, which

> seek[s] to quantify the amount of work accomplished with the inputs or resources provided. Output measures can seek to measure quantity, quality, or both. Typical output measures include customers or clients served, facility condition and cleanliness, miles of road paved, … or number of products sold. … Utilizing a select number of indicators that have a direct impact on performance (particularly for customers and funding agencies) leads to a successful performance measurement system. (Cohen & Eimicke, 2008, p. 153–154)

A typical output measure for the HUBZone Program would be the number of HUBZone small businesses that benefitted from the HUBZone program, or a number of contracts awarded through the HUBZone Program (Cohen & Eimicke, 2008).

Outcome- or impact-based measures are the fourth and final category. They assess whether the desired objective or state is being achieved. As Cohen and Eimicke acknowledged, outcomes are difficult to define and measure. In general, "the function of performance management remains the same: What are we trying to do, and are we succeeding in doing it?" (Cohen & Eimicke, 2008, p. 155). For the HUBZone Program, Section 606 of Public Law "increased employment opportunities and an increased level of investment in HUBZones" and further defines those terms by reference to Section 602 to mean "Federal contracting assistance" provided in accordance with the HUBZone Program. The former part of this convoluted definition could include, for example, factors such as the diversity of industries in which HUBZone firms participate or the diversity of goods or services requirements which they provide. The latter part of the definition appears to duplicate inputs-based measures.

Understanding the Hubzone Program Operations Through the Cohen-Eimicke Contract Management Performance Model

As stated above, this study generally follows the methodology of the Kidalov-Lee (2015) study on SDVOSB contracting. Thus, the methodological explanations and data comparisons in this section follow or closely parallel the Kidalov-Lee study.

[14] The *Rule of Two* refers to a contracting officer's determination, prior to a set-aside, that two or more capable HUBZone firms are willing to submit offers at fair market prices. See 15 U.S.C. § 657a (2015).

HUBZone Program Taxonomy: Inputs—Overall Trends on DoN Spending With HUBZone SBCs

To understand the full investment value of DoN HUBZone contracting, it is necessary to examine the spending data attributable not only to HUBZone goals but also to net spending (through new awards and modifications) as well as through new awards alone. Because the HUBZone Program's legal and management authorities concern New Awards and not contract modifications, this study's primary focus is on New Awards. References in this study to "New Awards" or "Awards" will be interchangeable.

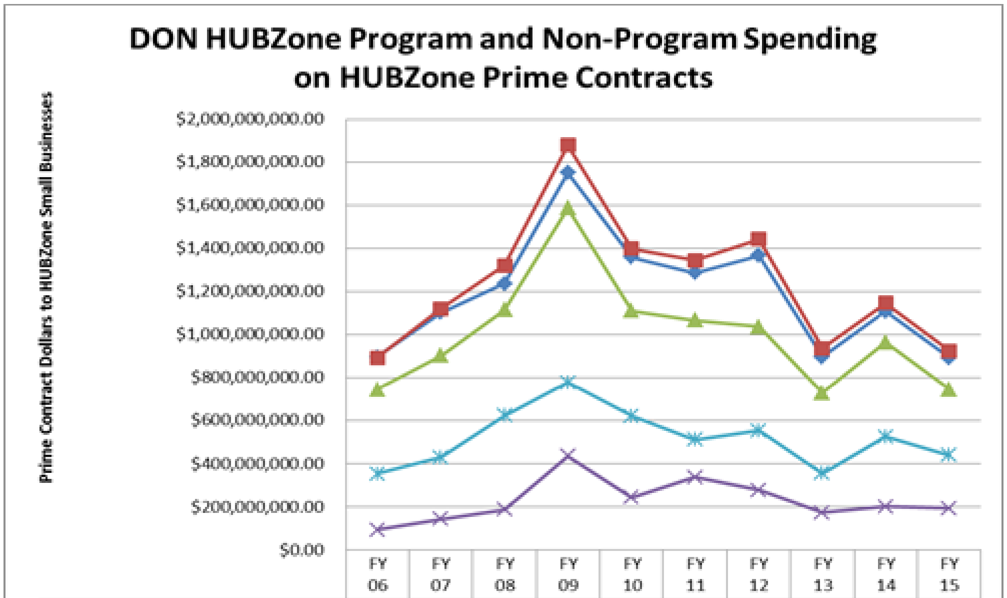
The FPDS Goaling Report spending data typically contain New Awards and various accretive modifications such as options; this data does not cover deductive modifications (such as terminations) and is subject to goaling exclusions (such as overseas contracts) (U.S. General Services Administration [GSA], 2015; SBA, 2003; Kidalov & Snider, 2013). This accounts for varying levels between goaled, net, and New Awards data. The New Awards data show the value of all DoN contracts with HUBZone firms (not to be limited to "HUBZone contracts" through Program mechanisms) identified with "Modification 0." The Net Total Spending data show the net sum of all DoN HUBZone contract spending with all modifications and regardless of goaling exclusions. HUBZone Program contracts are set-aside contracts, which provides for a more direct comparison to other programs that lack tools as the price evaluation preference (PEP). PEPs are not addressed in this study due to data quality concerns.[15] In recognition of the SBA's 2005 position favoring parity of socioeconomic programs, references below to Parity Programs mean the 8(a), Women-Owned Small Business, and Service-Disabled-Veteran Owned Small Business programs as appropriate for the particular year at issue.

DoN HUBZone Spending Trends

Data in Figure 2, Figure 3, and Table 2 below help understand the DoN's overall investment in HUBZone firms over time, as well as the component contributions to that investment from the HUBZone Program, parity programs and other non-program award mechanisms. That relationship between overall and component inputs contributions is important for the Cohen-Eimicke evaluation framework.

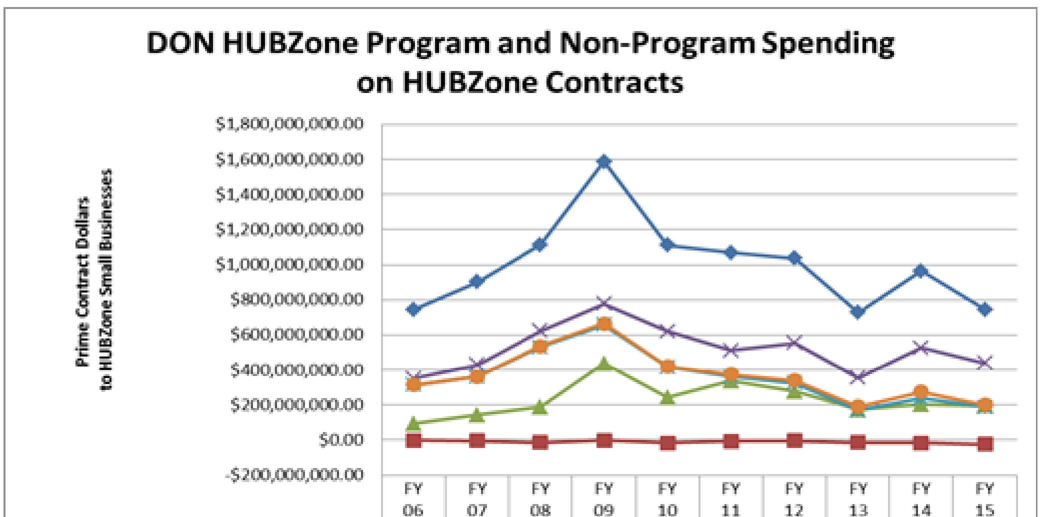
Evaluated spending categories include Goaling, Net, New Awards, HUBZone Program (Set-Asides), Non-HUBZone Set-Asides (covering Parity Programs and regular Small Business Set-Asides), as well as separate data for 8(a) and combined Parity Programs. DoN HUBZone spending across goaled and all other program and non-program categories discussed in the following figure and table below has peaked in FY2009. While the decline of spending was particularly pronounced in FY2013 sequestration year, Net Losses appear to be peaking post-sequestration.

[15] For example, in FY2011 FPDS data, HUBZone price evaluation preferences as high as 60% were recorded. In contrast, 15 U.S.C. 657a statutory price evaluation preference is generally set at no more than 10%.



	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15
DON Goaling Report Spending	$897,61	$1,104,	$1,237,	$1,750,	$1,359,	$1,287,	$1,367,	$898,15	$1,109,	$893,14
HUBZone Net Total Spending	$894,23	$1,121,	$1,321,	$1,879,	$1,399,	$1,344,	$1,443,	$938,46	$1,147,	$924,57
HUBZone New Awards Spending	$745,09	$903,30	$1,114,	$1,586,	$1,111,	$1,067,	$1,036,	$728,64	$965,51	$746,10
HUBZone Set-Aside New Awards	$93,870	$143,83	$187,76	$436,74	$242,99	$337,20	$278,25	$173,55	$202,95	$194,02
Non-HUBzone Set-Aside New Awards	$352,95	$429,56	$623,80	$778,12	$621,56	$511,34	$552,97	$355,20	$526,51	$438,96

Figure 3. DoN Program and Non-Program Spending by Reference to Goaling Report



	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15
HUBZone New Awards Spending	$745,09	$903,30	$1,114,	$1,586,	$1,111,	$1,067,	$1,036,	$728,64	$965,51	$746,10
Net Revenue Losses	-$2,290	-$4,847	-$14,81	-$2,055	-$16,85	-$6,578	-$5,419	-$13,93	-$17,58	-$23,63
HUBZone Set-Aside New Awards	$93,870	$143,83	$187,76	$436,74	$242,99	$337,20	$278,25	$173,55	$202,95	$194,02
Non-HUBzone Set-Aside New Awards	$352,95	$429,56	$623,80	$778,12	$621,56	$511,34	$552,97	$355,20	$526,51	$438,96
8(a) Set-Aside New Awards	$314,76	$360,65	$531,98	$659,31	$417,04	$362,22	$323,30	$166,47	$237,18	$186,90
Parity Programs Set-Aside New Awards	$314,76	$361,05	$536,43	$666,66	$418,27	$375,11	$338,87	$188,93	$275,03	$199,18

Figure 4. DoN HUBZone Spending Through HUBZone Program and Non-Program Contracting

Table 2. DoN HUBZone Spending Through HUBZone Program and Non-Program Contracting

DON HUBZone Spending through HUBZone Program and Non-Program Contracts								
Fiscal Year	DON Goaling Report Spending	HUBZone Net Total Spending	HUBZone New Awards Spending	Net Revenue Losses	HUBZone Set-Aside New Awards	Non-HUBzone Set-Aside New Awards	8(a) Set-Aside New Awards	Parity Programs Set-Aside New Awards
FY 06	$897,613,942.79	$894,237,693.72	$745,099,286.84	-$2,290,366.01	$93,870,834.93	$352,955,351.17	$314,766,915.43	$314,766,915.43
FY 07	$1,104,217,860.49	$1,121,659,908.51	$903,305,189.82	-$4,847,858.24	$143,833,407.38	$429,562,620.08	$360,659,193.46	$361,053,467.85
FY 08	$1,237,321,102.72	$1,321,626,117.21	$1,114,875,420.30	-$14,817,345.81	$187,766,690.03	$623,800,796.80	$531,981,815.52	$536,432,769.52
FY 09	$1,750,105,357.60	$1,879,156,604.79	$1,586,369,272.12	-$2,055,011.95	$436,741,575.96	$778,120,360.33	$659,313,495.91	$666,664,337.37
FY 10	$1,359,237,241.73	$1,399,351,064.32	$1,111,422,998.18	-$16,854,775.20	$242,992,572.04	$621,566,383.14	$417,046,206.09	$418,271,395.75
FY 11	$1,287,878,332.19	$1,344,456,791.81	$1,067,764,655.34	-$6,578,145.87	$337,209,463.35	$511,340,844.81	$362,223,313.69	$375,117,886.76
FY 12	$1,367,580,177.22	$1,443,154,134.37	$1,036,448,725.20	-$5,419,728.18	$278,255,334.11	$552,976,979.76	$323,304,399.27	$338,873,246.68
FY 13	$898,154,878.94	$938,467,793.27	$728,642,269.44	-$13,936,754.28	$173,556,354.24	$355,202,443.64	$166,479,050.57	$188,938,423.46
FY 14	$1,109,412,329.02	$1,147,564,892.62	$965,510,745.11	-$17,586,917.27	$202,952,051.85	$526,513,511.55	$237,188,933.60	$275,037,092.11
FY 15	$893,143,410.97	$924,579,303.17	$746,106,227.18	-$23,630,985.73	$194,024,167.30	$438,968,123.20	$186,907,138.30	$199,187,751.35

Findings: HUBZone Program spending has never been a dominant contributor to DoN HUBZone contracting investment overall. Following the 2009 DoJ- and DoD-mandated reversal of the DoN position on mandatory precedence of HUBZone contracts in favor of contracting officer's discretion, DoN contracting officers chose not to use the tools they previously used to deliver peak spending results. In particular, the declines in HUBZone Program as well as 8(a) and other Parity Programs set-asides appear to correlate with the general decrease in HUBZone spending levels. In their exercise of discretion to meet spending goals, contracting officers appeared to prefer Non-HUBZone set-asides, particularly regular Small Business Set-asides, instead of HUBZone set-asides. The continued increase in Net Losses shows reluctance of contracting officers to keep work with HUBZone firms.

DoN HUBZone Program Spending Trends

In addition to overall HUBZone spending and Program spending, it is important to examine Program spending in more detail by type of set-aside tool. Data in Figure 5 and Table 3 show HUBZone Program spending over the years by competitive, sole source, and SAP. Just as the data above, the data below show that Program spending peaked in FY2009. Trends below suggest that HUBZone Program spending is unstable, going up and down from year to year. This is driven primarily by volatility in competitive set-asides spending. HUBZone sole source set-asides spending is no longer a serious contributor to Program spending. In fact, HUBZone SAP set-aside spending now more than doubles HUBZone sole source set-asides spending.

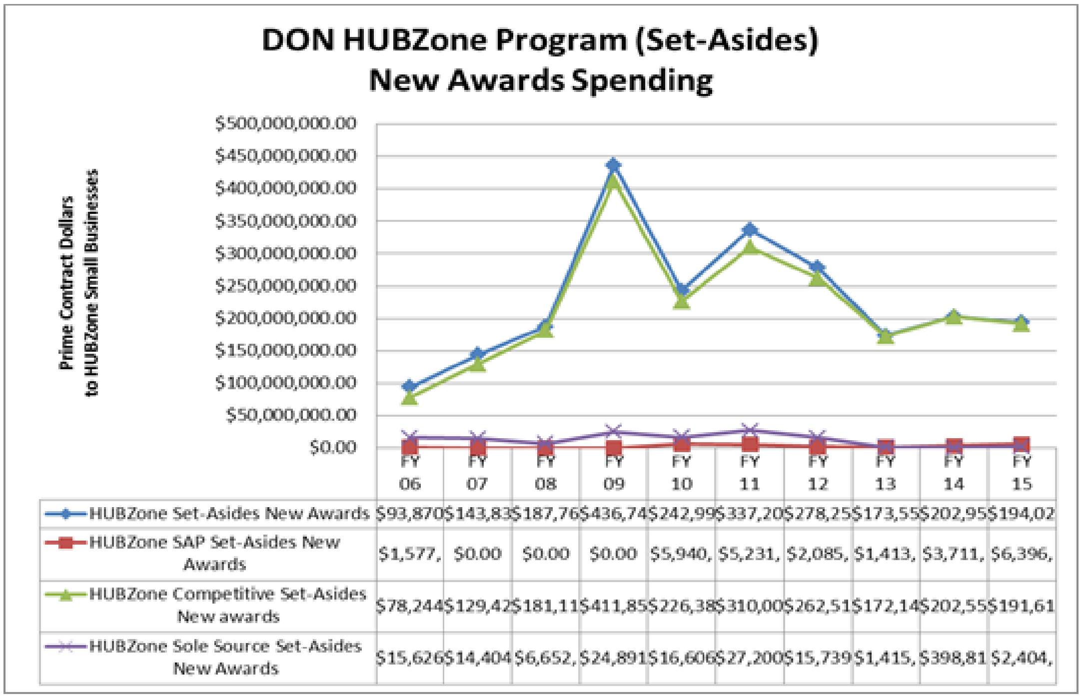


Figure 5. DoN HUBZone Program (Set-Asides) New Awards Spending

Table 3. DoN HUBZone Program (Set-Asides) New Awards Spending

DON HUBZone Program Spending				
Fiscal Year	HUBZone Set-Asides New Awards	HUBZone SAP Set-Asides New Awards	HUBZone Competitive Set-Asides New awards	HUBZone Sole Source Set-Asides New Awards
FY 06	$93,870,834.93	$1,577,755.00	$78,244,003.93	$15,626,831.00
FY 07	$143,833,407.38	$0.00	$129,428,689.71	$14,404,717.67
FY 08	$187,766,690.03	$0.00	$181,113,854.78	$6,652,835.25
FY 09	$436,741,575.96	$0.00	$411,850,286.32	$24,891,289.64
FY 10	$242,992,572.04	$5,940,175.07	$226,386,262.40	$16,606,309.64
FY 11	$337,209,463.35	$5,231,539.77	$310,009,272.52	$27,200,190.83
FY 12	$278,255,334.11	$2,085,736.53	$262,516,058.87	$15,739,275.24
FY 13	$173,556,354.24	$1,413,996.22	$172,140,860.66	$1,415,493.58
FY 14	$202,952,051.85	$3,711,114.10	$202,553,233.69	$398,818.16
FY 15	$194,024,167.30	$6,396,524.48	$191,619,719.08	$2,404,448.22

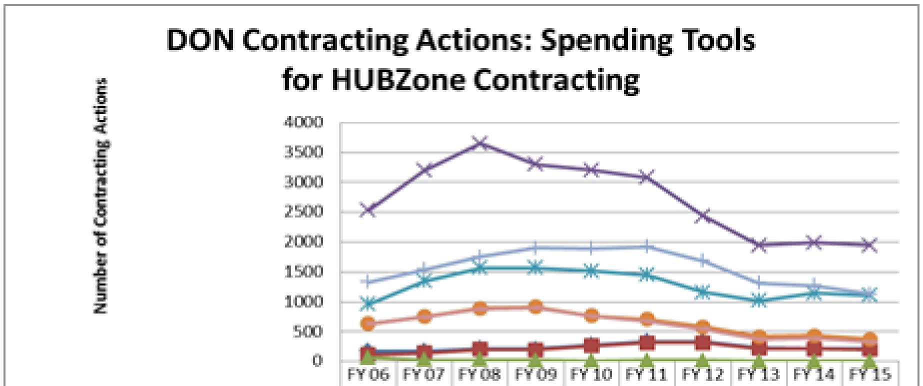
Findings: After a three-year 2007–2009 hiatus, DoN contracting officers rallied to HUBZone SAP set-asides in FY2010 and fully restored the FY2012–2013 slump in FY2015. HUBZone sole source set-asides peaked two years after the DoN parity reversal, but took a substantial drop since. DoN spending on HUBZone competitive set-asides is now barely half it was in FY2009. It appears that DoN buyers may treat HUBZone set-asides as a risky proposition for discretionary spending, except for low-dollar SAPs.

HUBZone Program Taxonomy: Process—Trends on Contracting Officers' Discretion to Use HUBZone Set-Asides and Other Contracting Mechanisms

In the Cohen-Eimicke framework, spending input trends do not necessarily explain the contracting officers' use of the contracting process. To understand process, it is necessary to examine the trends in the HUBZone Program set-aside actions and put them in context of other non–set-aside contract actions.

DoN Contracting Actions With HUBZone SBCs

Data in Figure 6 show that the DoN began a long decline in New Awards to HUBZone firms as early as 2009, after peaking in FY2008. This decline appears to have stabilized over the last three fiscal years. Accretive Modifications (i.e., actions to direct funding to incumbent HUBZone contractors) held relatively steady through FY2011, but then slumped off. Competitive HUBZone set-aside actions peaked in FY2011, while the sole source set-asides have been dropping over the entire decade and reached anecdotal asterisk levels. Non-HUBZone, Parity Programs-only, and 8(a) set-asides peaked in FY2009.



	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15
HUBZone Set-Aside Awards	175	174	224	216	282	342	337	227	222	216
HUBZone Competitive Set-Aside Awards	114	146	203	196	266	320	318	220	217	208
HUBZone Sole Source Awards	62	30	29	20	16	22	19	7	5	8
All New HUBZone Awards	2527	3193	3645	3300	3200	3081	2434	1946	1992	1945
Non-HUBZone Set-Aside New Awards	959	1346	1567	1568	1516	1451	1162	1021	1144	1109
Parity Programs Set-Aside New Awards	638	756	893	920	771	709	582	419	439	377
All HUBZone Accretive Modifications	1329	1540	1750	1899	1897	1920	1683	1314	1272	1132
8(a) Set-Aside New Awards	638	748	881	905	764	673	543	379	391	335

Figure 6. DoN Contracting Actions: Spending Tools for HUBZone Contracting

Findings: When given the freedom to exercise discretion in terms of set-aside program choice, DoN contracting officers prefer meeting HUBZone goals through the use of contracting set-aside tools authorized for small businesses or Parity categories under other Small Business Act programs. This cannot be simply attributed to the loss of HUBZone firms through decertification, since all HUBZone awardees under other set-aside authorities could have received HUBZone sole sources, at the least. Rather, these trends appear to suggest greater comfort with contracting tools under other programs.

DoN HUBZone Sole Source Set-Aside Awards and Their Impact

Data in Table 4 show DoN buyers' use of HUBZone sole source set-asides. FY2006 was peak year for such actions and beneficiaries of such awards. The spending volume of such awards peaked in FY2011, as did their contributions to DoN HUBZone investment metrics. However, in FY2014, the contributions of those awards hit the bottom across actions, beneficiaries, and spending.

Table 4. DoD New HUBZone Sole Source Set-Aside Award Trends; Impact on Market Entry and HUBZone Spending

DON New HUBZone Sole-Source Awards: Impact on Market Entry and Spending								
Fiscal Year	HUBZone Sole Source Awards	Share of All New HUBZone Awards	HUBZone Sole Source Awardees	Share of New HUBZone Awardees under All Methods	HUBZone Sole Source Set-Asides New Awards	Share of All New HUBZone Awards Spending	Share of Net Total HUBZone Spending	Comparative Share of Goaling Report HUBZone Spending
FY 06	62	2.45%	52	5.87%	$15,626,831.00	2.10%	1.75%	1.74%
FY 07	30	0.94%	28	3.41%	$14,404,717.67	1.59%	1.28%	1.30%
FY 08	29	0.80%	25	3.00%	$6,652,835.25	0.60%	0.50%	0.54%
FY 09	20	0.61%	18	2.34%	$24,891,289.64	1.57%	1.32%	1.42%
FY 10	16	0.50%	10	1.35%	$16,606,309.64	1.49%	1.19%	1.22%
FY 11	22	0.71%	12	1.65%	$27,200,190.83	2.55%	2.02%	2.11%
FY 12	19	0.78%	10	1.67%	$15,739,275.24	1.52%	1.09%	1.15%
FY 13	7	0.36%	5	1.04%	$1,415,493.58	0.19%	0.15%	0.16%
FY 14	5	0.25%	5	1.01%	$398,818.16	0.04%	0.03%	0.04%
FY 15	8	0.41%	8	1.68%	$2,404,448.22	0.32%	0.26%	0.27%

<u>Findings</u>: DoN contracting officers clearly disfavor HUBZone sole source awards, even in the face of declining HUBZone goaling spending and declining base of HUBZone certified firms. The contribution of this contracting method to HUBZone investment or market entry is marginal. Businesses or economic development authorities relying on its availability are at risk of disillusionment, while the DoN potentially misses many opportunities for increasing its HUBZone spending numbers.

DoN HUBZone Competitive Set-Aside Awards and Their Impact

Data in Table 5 illustrate the use and role of DoN competitive HUBZone set-asides. By spending volume, these awards peaked in FY2009. By market entry contribution, they peaked in FY2015, but not because of a peak in HUBZone market share growth.

Table 5. DoN New HUBZone Competitive Set-Aside Award Trends; Impact on Market Entry and HUBZone Spending

DON New HUBZone Competitive Set-Aside Awards: Impact on Market Entry and Spending								
Fiscal Year	HUBZone Competitive Set-Aside Awards	Share of All New HUBZone Awards	HUBZone Competitive Set-Aside Awardees	Share of New HUBZone Awardees under All Methods	HUBZone Competitive Set-Asides New awards	Share of All New HUBZone Awards Spending	Share of Net Total HUBZone Spending	Comparative Share of Goaling Report HUBZone Spending
FY 06	114	4.51%	65	7.34%	$78,244,003.93	10.50%	8.75%	8.72%
FY 07	146	4.57%	93	11.34%	$129,428,689.71	14.33%	11.54%	11.72%
FY 08	203	5.57%	77	9.23%	$181,113,854.78	16.25%	13.70%	14.64%
FY 09	196	5.94%	105	13.64%	$411,850,286.32	25.96%	21.92%	23.53%
FY 10	266	8.31%	121	16.33%	$226,386,262.40	20.37%	16.18%	16.66%
FY 11	320	10.39%	132	18.16%	$310,009,272.52	29.03%	23.06%	24.07%
FY 12	318	13.06%	106	17.73%	$262,516,058.87	25.33%	18.19%	19.20%
FY 13	220	11.31%	85	17.63%	$172,140,860.66	23.62%	18.34%	19.17%
FY 14	217	10.89%	92	18.62%	$202,553,233.69	20.98%	17.65%	18.26%
FY 15	208	10.69%	91	19.08%	$191,619,719.08	25.68%	20.73%	21.45%

<u>Findings</u>: DoN contracting officers favor HUBZone competitive set-aside awards much more than they do the sole source set-asides.

DoN Combined HUBZone Set-Aside Awards and Their Impact

Data in Table 6 show the use and impact of combined HUBZone set-asides.

Table 6. DoN New HUBZone Set-Aside Award Trends; Impact on Market Entry and HUBZone Spending

DON New Combined HUBZone Set-Aside Awards: Impact on Market Entry and Spending								
Fiscal Year	HUBZone Set-Aside Awards	Share of All New HUBZone Awards	HUBZone Set-Aside Awardees	Share of New HUBZone Awardees under All Methods	HUBZone Set-Asides New Awards	Share of All New HUBZone Awards Spending	Share of Net Total HUBZone Spending	Comparative Share of Goaling Report HUBZone Spending
FY 06	175	6.93%	108	12.19%	$93,870,834.93	12.60%	10.50%	10.46%
FY 07	174	5.45%	117	14.27%	$143,833,407.38	15.92%	12.82%	13.03%
FY 08	224	6.15%	100	11.99%	$187,766,690.03	16.84%	14.21%	15.18%
FY 09	216	6.55%	121	15.71%	$436,741,575.96	27.53%	23.24%	24.96%
FY 10	282	8.81%	128	17.27%	$242,992,572.04	21.86%	17.36%	17.88%
FY 11	342	11.10%	142	19.53%	$337,209,463.35	31.58%	25.08%	26.18%
FY 12	337	13.85%	115	19.23%	$278,255,334.11	26.85%	19.28%	20.35%
FY 13	227	11.66%	90	18.67%	$173,556,354.24	23.82%	18.49%	19.32%
FY 14	222	11.14%	97	19.64%	$202,952,051.85	21.02%	17.69%	18.29%
FY 15	216	11.11%	99	20.75%	$194,024,167.30	26.00%	20.99%	21.72%

<u>Findings</u>: DoN HUBZone set-asides' utilization, and impact, are fluctuating and limited.

DoN HUBZone Simplified Acquisition (SAP) Awards and Their Impact

Data in Tables 7 and 8 suggest that FAR Part 13 Simplified Acquisitions are having a positive market entry impact. However, SAP HUBZone set-asides appear to have limited impact.

Table 7. DoN SAP HUBZone Awards and Their Impact on HUBZone Market Entry and Contract Spending

DON SAP HUBZone Awards: Impact on Market Entry and Spending								
Fiscal Year	HUBZone SAP Awards	Share of All New HUBZone Awards	HUBZone SAP Awardees	Share of New HUBZone Awardees under All Methods	HUBZone SAP New Awards	Share of All New HUBZone Awards Spending	Share of Net Total HUBZone Spending	Comparative Share of Goaling Report HUBZone Spending
FY 06	1106	43.77%	426	48.08%	$33,601,890.00	4.51%	3.76%	3.74%
FY 07	21	0.66%	9	1.10%	$8,158,943.97	0.90%	0.73%	0.74%
FY 08	16	0.44%	7	0.84%	$26,707,423.71	2.40%	2.02%	2.16%
FY 09	7	0.21%	5	0.65%	$21,028,348.23	1.33%	1.12%	1.20%
FY 10	660	20.63%	202	27.26%	$49,395,163.62	4.44%	3.53%	3.63%
FY 11	1153	37.42%	298	40.99%	$65,100,133.57	6.10%	4.84%	5.05%
FY 12	634	26.05%	225	37.63%	$32,081,480.52	3.10%	2.22%	2.35%
FY 13	544	27.95%	182	37.76%	$21,011,097.89	2.88%	2.24%	2.34%
FY 14	748	37.55%	219	44.33%	$44,259,672.95	4.58%	3.86%	3.99%
FY 15	797	40.98%	231	48.43%	$43,697,377.56	5.86%	4.73%	4.89%

Table 8. DoN SAP HUBZone Set-Aside Awards and Their Impact on HUBZone Market Entry and Contract Spending

DON SAP HUBZone Set-Aside Awards: Impact on Market Entry and Spending								
Fiscal Year	HUBZone SAP Set-Aside Awards	Share of All New HUBZone Awards	HUBZone SAP Set-Aside Awardees	Share of New HUBZone Awardees under All Methods	HUBZone SAP Set-Asides New Awards	Share of All New HUBZone Awards Spending	Share of Net Total HUBZone Spending	Comparative Share of Goaling Report HUBZone Spending
FY 06	33	1.31%	30	3.39%	$1,577,755.00	0.21%	0.18%	0.18%
FY 07	0	0.00%	0	0.00%	$0.00	0.00%	0.00%	0.00%
FY 08	0	0.00%	0	0.00%	$0.00	0.00%	0.00%	0.00%
FY 09	0	0.00%	0	0.00%	$0.00	0.00%	0.00%	0.00%
FY 10	29	0.91%	28	3.78%	$5,940,175.07	0.53%	0.42%	0.44%
FY 11	56	1.82%	46	6.33%	$5,231,539.77	0.49%	0.39%	0.41%
FY 12	31	1.27%	24	4.01%	$2,085,736.53	0.20%	0.14%	0.15%
FY 13	15	0.77%	14	2.90%	$1,413,996.22	0.19%	0.15%	0.16%
FY 14	22	1.10%	21	4.25%	$3,711,114.10	0.38%	0.32%	0.33%
FY 15	34	1.75%	26	5.45%	$6,396,524.48	0.86%	0.69%	0.72%

<u>Findings</u>: DoN is missing the opportunity to convert HUBZone SAP awards into HUBZone set-asides.

DoN 8(a) and Other Non-HUBZone Set-Asides Awards and Their Impact

Table 9 and Table 10 indicate the substantial and dominating impact of non-HUBZone set-asides on DoN HUBZone contracting.

Table 9. DoN 8(a) Set-Aside Awards to HUBZone SBCs and Their Impact on HUBZone SBCs Market Entry and Contract Spending

DON 8(a) HUBZone Set-Aside Awards: Impact on Market Entry and Spending								
Fiscal Year	8(a) Set-Aside New Awards	Share of All New HUBZone Awards	8(a) Set-Aside New HUBZone Awardees	Share of New HUBZone Awardees under All Methods	8(a) Set-Aside New Awards	Share of All New HUBZone Awards Spending	Share of Net Total HUBZone Spending	Comparative Share of Goaling Report HUBZone Spending
FY 06	638	25.25%	218	24.60%	$314,766,915.43	42.24%	35.20%	35.07%
FY 07	748	23.43%	232	28.29%	$360,659,193.46	39.93%	32.15%	32.66%
FY 08	881	24.17%	241	28.90%	$531,981,815.52	47.72%	40.25%	42.99%
FY 09	905	27.42%	216	28.05%	$659,313,495.91	41.56%	35.09%	37.67%
FY 10	764	23.88%	210	28.34%	$417,046,206.09	37.52%	29.80%	30.68%
FY 11	673	21.84%	181	24.90%	$362,223,313.69	33.92%	26.94%	28.13%
FY 12	543	22.31%	157	26.25%	$323,304,399.27	31.19%	22.40%	23.64%
FY 13	379	19.48%	132	27.39%	$166,479,050.57	22.85%	17.74%	18.54%
FY 14	391	19.63%	121	24.49%	$237,188,933.60	24.57%	20.67%	21.38%
FY 15	335	17.22%	119	24.95%	$186,907,138.30	25.05%	20.22%	20.93%

Table 10. DoN Non-HUBZone Set-Aside Awards to HUBZone SBCs and Their Impact on HUBZone SBCs Market Entry and Contract Spending

DON Non-HUBZone Set-Aside Awards: Impact on Market Entry and Spending								
Fiscal Year	Non-HUBZone Set-Aside New Awards	Share of All New HUBZone Awards	Non-HUBZone Set-Aside New HUBZone Awardees	Share of New HUBZone Awardees under All Methods	Non-HUBzone Set-Aside New Awards	Share of All New HUBZone Awards Spending	Share of Net Total HUBZone Spending	Comparative Share of Goaling Report HUBZone Spending
FY 06	959	37.95%	423	47.74%	$352,955,351.17	47.37%	39.47%	39.32%
FY 07	1346	42.15%	473	57.68%	$429,562,620.08	47.55%	38.30%	38.90%
FY 08	1567	42.99%	494	59.23%	$623,800,796.80	55.95%	47.20%	50.42%
FY 09	1568	47.52%	464	60.26%	$778,120,360.33	49.05%	41.41%	44.46%
FY 10	1516	47.38%	441	59.51%	$621,566,383.14	55.93%	44.42%	45.73%
FY 11	1451	47.10%	422	58.05%	$511,340,844.81	47.89%	38.03%	39.70%
FY 12	1162	47.74%	360	60.20%	$552,976,979.76	53.35%	38.32%	40.43%
FY 13	1021	52.47%	316	65.56%	$355,202,443.64	48.75%	37.85%	39.55%
FY 14	1144	57.43%	319	64.57%	$526,513,511.55	54.53%	45.88%	47.46%
FY 15	1109	57.02%	313	65.62%	$438,968,123.20	58.83%	47.48%	49.15%

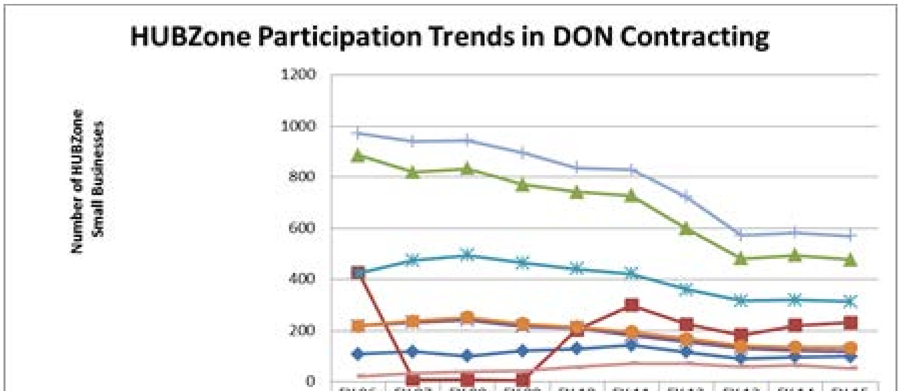
<u>Findings</u>: DoN HUBZone program has a substantial dependency on non-HUBZone set-asides.

HUBZone Program Taxonomy: Outputs—Trends on HUBZone Participation in DoN Contracting

To appreciate the breadth or shallowness of DoN's HUBZone contractors' bench, it is important to examine HUBZone participation in both Program and non-Program DoN contracting.

HUBZone Participation in DoN Contracting Overall

Data in Figure 7 show HUBZone participation in DoN Contracting and across various contracting mechanisms. Data show that more HUBZone firms participate in 8(a) set-asides and non-HUBZone set-asides than in HUBZone set-asides.



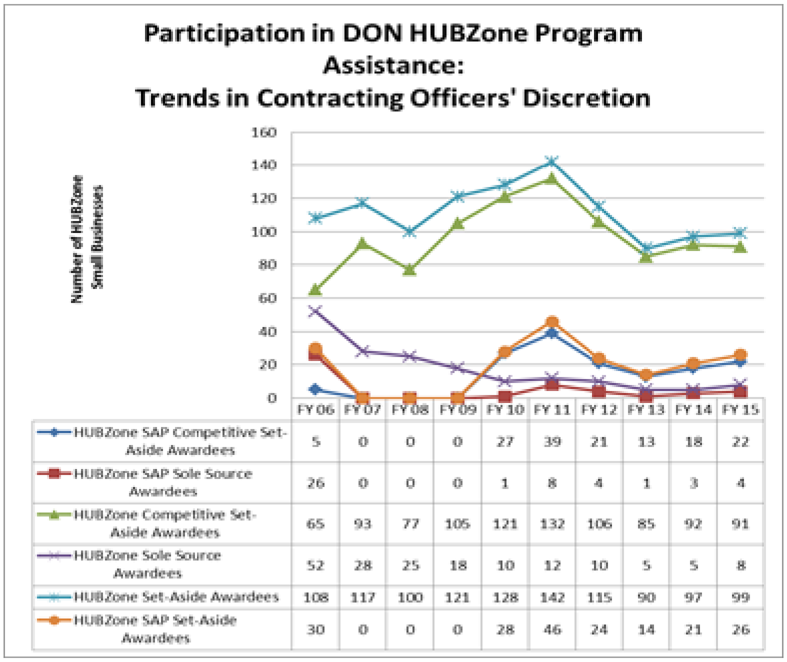
	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15
HUBZone Set-Aside Awardees	108	117	100	121	128	142	115	90	97	99
HUBZone SAP Awardees	426	9	7	5	202	298	225	182	219	231
All New HUBZone Awardees	886	820	834	770	741	727	598	482	494	477
8(a) Set-Aside New HUBZone Awardees	218	232	241	216	210	181	157	132	121	119
Non-HUBZone Set-Aside New HUBZone Awardees	423	473	494	464	441	422	360	316	319	313
Parity Programs Set-Aside New Awardees	218	237	251	226	214	195	168	140	135	133
HUBZone Net Revenue Earner Firms	971	940	945	896	837	830	720	571	582	570
HUBZone Net Revenue Losing Firms	21	32	39	42	57	72	72	59	63	52

Figure 7. HUBZone Participation Trends in DoN Contracting Overall

Findings: The DoN is experiencing a crisis of HUBZone contractor participation in DoN contracting. However, the DoN is not using HUBZone set-asides to reverse this crisis.

HUBZone Program Participation at DoN.

Data in Figure 8 illustrate the HUBZone Program participation trends as a consequence of contracting officer's discretion to set aside or not set aside work for HUBZone SBCs on a competitive or sole source basis. Overall, this data show that DoN contracting officers are not exercising discretion to increase the total count of HUBZone firms in the HUBZone Program.



	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15
HUBZone SAP Competitive Set-Aside Awardees	5	0	0	0	27	39	21	13	18	22
HUBZone SAP Sole Source Awardees	26	0	0	0	1	8	4	1	3	4
HUBZone Competitive Set-Aside Awardees	65	93	77	105	121	132	106	85	92	91
HUBZone Sole Source Awardees	52	28	25	18	10	12	10	5	5	8
HUBZone Set-Aside Awardees	108	117	100	121	128	142	115	90	97	99
HUBZone SAP Set-Aside Awardees	30	0	0	0	28	46	24	14	21	26

Figure 8. DoN HUBZone Program Assistance Participation: Trends in Contracting Officers' Discretion

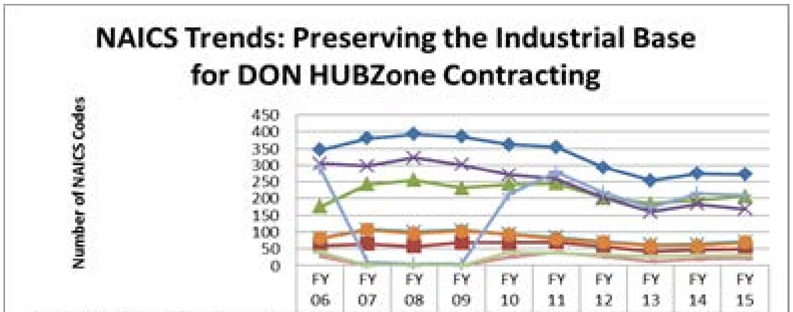
<u>Findings</u>: There is a crisis of participation in DoN HUBZone Program. The HUBZone Program appears to have limited impact as the entryway into the DoN market. The DoN should act to reverse these trends.

HUBZone Program Taxonomy: Outcomes—Trends Related to HUBZone Program's Industrial Base Diversity and DoN Requirements Matching

To evaluate whether HUBZone contracting creates meaningful jobs and a diverse industrial base for the DoN, it is important to evaluate the trends in codes used for identifying industries and requirements. North American Industrial Classification (NAICS) codes are assigned to each contract solicitation for use in market research across industries as well as determinations whether a firm is small by reference to NAICS-based business size standards. Other codes, the Product Service Codes/Federal Supply Codes (PSCs/FSCs), are used to identify what is actually bought (see generally Bunting, 2013).

DoN HUBZone Program's Industrial Base

Figure 9 shows NAICS trends across various contracting mechanisms. The trends show the broadest HUBZone industrial base existed in FY2008.



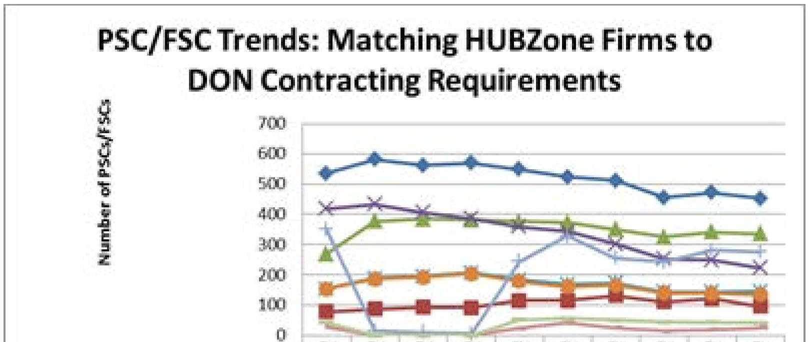
	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15
All HUBZone New Awards	346	380	393	385	362	354	293	253	274	272
HUBZone Set-Aside Awards	59	65	57	68	68	70	56	43	47	50
Non-HUBZone Set-Aside Awards	175	242	255	231	242	245	201	184	195	206
No Set-Asides Used or Identified	305	298	322	301	270	260	201	159	183	168
Parity Programs Set-Aside Awards	82	108	100	105	94	85	71	62	63	71
8(a) Set-Aside New HUBZone Awards	82	107	96	103	93	80	69	58	59	70
HUBZone SAP Awards	288	9	5	4	211	279	217	173	215	209
SAP HUBZone Set-Aside Awards	28	0	0	0	25	40	26	13	19	21
SAP 8(a) Set-Aside Awards	40	0	0	0	40	38	33	28	30	31

Figure 9. DoN HUBZone NAICS Trends: Use of HUBZone Program and SAP for Industrial Targeting and Business Development

Findings: The number of industries used for HUBZone and Non-HUBZone set-asides as well as SAP awards have recently declined, while HUBZone industries overall began falling in FY2008.

HUBZone Contractors' Matching to DoN Requirements

Figure 10 shows trends in matching HUBZone firms to DoN requirements as determined by PSCs/FSCs. The matching trends show a progressive decrease in PSCs/FSCs satisfied through contracts to HUBZone firms, with recent increases in Non-HUBZone set-asides and SAP awards.



	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15
All HUBZone New Awards	535	581	561	569	549	524	512	455	471	452
HUBZone Set-Aside Awards	78	88	94	92	116	116	132	111	121	96
Non-HUBZone Set-Aside Awards	269	377	384	381	376	373	351	326	341	335
No Set-Asides Used or Identified	418	433	407	386	360	343	302	253	249	223
Parity Programs Set-Aside Awards	154	190	195	207	183	169	173	143	144	145
8(a) Set-Aside New HUBZone Awards	154	187	192	204	179	161	166	140	139	135
HUBZone SAP Awards	350	15	10	6	244	328	256	243	281	277
SAP HUBZone Set-Aside Awards	28	0	0	0	24	41	25	15	20	25
SAP 8(a) Set-Aside Awards	43	0	0	0	52	57	50	45	43	42

Figure 10. DoN HUBZone PSC/FSC Trends: Use of HUBZone Program and SAP to Match HUBZone SBCs to DoN Requirements

<u>Findings</u>: DoN contracting officers consistently prefer to fill more PSCs/FSCs through 8(a) set-asides and other non-HUBZone set-asides.

Answers to Research Questions; Recommendations for Hubzone Program Reforms and Further Research

There is no question that the HUBZone Program has suffered from serious adversities, including mass decertification and the parity crisis, as well as the effects of sequestration. Nonetheless, through the Cohen-Eimicke framework, this study succeeds in asking and answering questions about how the DoN can more effectively manage the HUBZone Program back on track towards success. **Concerning the first question, whether the Cohen-Eimicke Contract Management Performance model can explain DoN HUBZone Program's performance trends, the answer is "yes."** The focus predominantly or only on spending goals treats HUBZone Program spending inputs as outputs. DoN contracting officers then default to choosing other program's contracting tools, whether because of SBA's pronouncements about limited assistance to HUBZone firms, because of 8(a) requirements retention and non-advertising mandates, or because non-HUBZone set-asides offer the best possibility to reconcile the complex contracting preferences. Yet confusing this fundamental distinction between performance criteria prevents aligning HUBZone Program process tools, such as set-asides, to true outputs (number of participating HUBZone firms) and outcomes (growth in HUBZone industries and capabilities). When the DoN begins to make a strategic effort to target HUBZone set-asides towards greater number of HUBZone firms, the HUBZone goaling spending will start increasing, too.

As to the second question, whether HUBZone Program's parity coupled with unguided discretion of contracting officers on when to use this parity to target particular HUBZone firms is an effective approach to HUBZone contracting, the answer is "no." Overall, DoN buyers appear to prefer "close swap" transactions where HUBZone firms get the work because they are already established under other Small Business Act programs. Lacking business development skills and SBA business development support, DoN contracting officers are shying away from HUBZone set-asides even to already-successful HUBZone firms that obtain DoN contracts through other tools. Moreover, true regulatory parity appears to be lacking with the 8(a) Program. It is not surprising that 8(a) firms by and large maintained their share of the DoN HUBZone Program, and why 8(a) firms account for virtually all of combined Parity Programs' metrics in HUBZone contracting. **New SAP Awards appear to be playing an increasingly favorable and critical market entry support role for HUBZone firms seeking DoN contracts. This role should be strengthened.**

With this in mind, the answer to the question as to what DoN should do becomes obvious. Rebuilding HUBZone set-aside participants' bench should be the DoN's first step at increasing the HUBZone Program's stability and then turning the HUBZone Program performance around. To do so, the HUBZone Program should be reformed into a business development program similar to the 8(a) Program which would relieve DoN contracting officers of business development burdens. The program will be focused on SAP and set-asides. Absent SBA initiative in that regards, the DoN should craft such a program for itself by using FAR Part 6 and the Small Business Act's 15 U.S.C. § 644(a) industrial base support authorities. Finally, further research on HUBZone contracting topics is recommended, including a more detailed matching of contracting trends to legal and policy authorities.

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Disclaimer

Nothing in this study shall be construed as official views of the Department of the Navy.

Panel 8. Data Policies, Procedures, & Access: Illuminating How Acquisition Information Moves Within the Department to Support Analysis & Decision Making

Wednesday, May 4, 2016	
3:30 p.m. – 5:00 p.m.	**Chair: Mark Krzysko,** Deputy Director, Acquisition Resources and Analysis, OUSD (AT&L) **Discussant: Ralph DiCicco,** Acquisition Chief Information Officer (CIO), United States Air Force ***Issues With Access to Acquisition Data & Information in the Department of Defense: Policy & Practice*** Megan McKernan, Defense Research Analyst, RAND Jessie Riposo, Senior Operations Researcher, RAND ***Issues With Access to Acquisition Data & Information in the Department of Defense: Doing Data Right in Weapon System Acquisition*** Nancy Moore, Senior Management Scientist, RAND Megan McKernan, Defense Research Analyst, RAND

Chair:

Mark Krzysko—is the Deputy Director, Enterprise Information, Office of the Under Secretary of Defense for Acquisition, Technology, & Logistics, Department of Defense (DoD). He directs acquisition data management and analysis, technical transformation, and shared services efforts to make timely, authoritative acquisition information available to support oversight of the DoD's major programs—a portfolio totaling more than $1.6 trillion of investment funds over the life cycle of the programs. Preceding his current position, Krzysko served as Assistant Deputy Under Secretary of Defense (ADUSD) for Business Transformation, providing strategic leadership for reengineering the Department's business improvement decision-making processes and leading strategic sourcing and acquisition process efforts. In the Office of the Secretary of Defense, he also served as Director of the Supply Chain Systems Transformation, championing innovative uses of information technologies to improve and streamline the supply chain process for the Department. Prior to that, Krzysko led the Defense Procurement & Acquisition Policy office as Deputy Director of e-Business, where he provided oversight and led transformation of the acquisition community into a strategic business enterprise. Prior to that, Krzysko led the Electronic Commerce Solutions Directorate for the Naval Air Systems Command and 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.

Discussant:

Ralph DiCicco—is Deputy Acquisition Chief Information Officer (CIO), working for the Deputy Assistant Secretary of the Air Force (Acquisition Integration), SAF/AQX. The Acquisition CIO is responsible for developing architecture, data strategy, systems migration plan, and a portfolio management process for the acquisition domain (defined as one of 14 domains in the Air Force enterprise architecture). DiCicco spent 25 years on active duty in the Air Force and retired as a colonel in April 2006. As an Air Force officer, he served as an acquisition program manager, test manager, and in various staff positions involved in planning, resource allocation, and congressional appropriations liaison. He joined federal service as an Air Force civilian in 2006 and served as Acting Director of the Air Force Acquisition Center of Excellence as well as Program Manager of a Major Automated Information Systems program. DiCicco received his Bachelor of Science degree in mechanical engineering from the University of Massachusetts Lowell in 1980 and a Master of Science degree in electrical engineering from George Washington University in 1988. He is a graduate of the Defense Systems Management College Program Managers Course and Executive Program Management Course. He has attended executive management seminars at University of North Carolina at Chapel Hill and the Center for Creative Leadership.

Issues With Access to Acquisition Data & Information in the Department of Defense: Policy & Practice

Megan McKernan—is a Defense Research Analyst at RAND. McKernan has more than 10 years of experience conducting DoD acquisition analyses. She is currently co-leading research examining acquisition data sharing in the DoD. McKernan has also conducted analyses on other defense acquisition topics: tailoring the acquisition process, program manager tenure, and root causes of Nunn-McCurdy unit cost breaches. She uses a variety of methods in conducting research, including case studies, interviews, and literature reviews. She holds an MA in international trade and investment policy from George Washington University and a BA in economics from William Smith College. [mckernan@rand.org]

Jessie Riposo—is a Senior Operations Researcher at RAND, with over a decade of experience in research and analysis with a specialty in Defense Acquisition and Planning, Programming, and Budgeting. Since 2003, Riposo has led and participated in projects in support of the USD(AT&L), U.S. Navy, UK MoD, and the Australian DoD. Riposo's projects have covered reviews of domestic and foreign acquisition programs, Department acquisition policy and industrial base, personnel, and policy assessments. Riposo has applied a variety of quantitative and qualitative tools, such as statistical analyses, mathematical modeling, surveys, and interviews in her analyses. [riposo@rand.org]

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Abstract

Acquisition data underpin the management and oversight of the U.S. defense acquisition portfolio. However, balancing security and transparency has been an ongoing challenge. Some acquisition professionals are not getting the data they need to perform their assigned duties or are not getting the data and information in an efficient manner. To help guide the Office of the Secretary of Defense (OSD) in addressing these problems, the RAND Corporation identified access problems at the OSD level—including those organizations that require access to data and information to support the OSD, such as analytic support federally funded research and development centers and direct support contractors—and evaluated the role of policy in determining access. The study also involved a limited review of how data are shared between the OSD and military departments. Issues with access to acquisition data and information in the Department of Defense (DoD) finds that the process for gaining access to data is inefficient and may not provide access to the best data to support analysis, and that OSD analytic groups and support contractors face particular challenges in gaining access to data. Given the inherent complexity in securing data and sharing data, any solutions to problems associated with data sharing must be well thought out to avoid the multitude of unintended consequences that could arise.

Introduction

Acquisition data are vast and include such information as the cost of weapon systems (both procurement and operations), technical performance, contracts and contractor performance, and program decision memoranda. These data are critical to the management and oversight of the $1.5 trillion portfolio of major weapon programs by the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (OUSD[AT&L]; GAO, 2014, p. 3). Data collection and analysis enable the Department of Defense (DoD) to track acquisition program and system performance and ensure that progress is being made toward such institutional goals as achieving efficiency in defense acquisition and delivering weapon systems to the field on time and on budget.

Many organizations or groups need access to this information for a variety of purposes (e.g., management, oversight, analysis, and administrative). These organizations include various offices of the DoD, federally funded research and development centers (FFRDCs), university-affiliated research centers (UARCs), and a range of support contractors. For example, an FFRDC may need cost and schedule information to determine whether a weapon system was delivered on time and within budget. Or a support contractor may be responsible for managing a centralized information system for the DoD that contains information about specific procurement programs. Note that that situation does not include classified data, which is not a topic of this report.[1]

However, these organizations may have difficulty getting access to these data. Some examples of the types of issues identified by individuals within DoD offices include the following:

- "It took me three months, multiple e-mails, and phone calls to get a one-hour meeting with five SES [DoD senior executive service–level employees] to view data that might be proprietary."
- "Each access account I create is like five touch points between an email, phone call, their POC, certificate handling, vetting. It's a lot of work."
- "If there are dozens of support contractors and dozens of prime contractors and I have to get an NDA [nondisclosure agreement] for each support contractor and prime contractor combination, it's a lot of work."
- Examples of the types of issues identified by FFRDC, UARC, and direct support contractors include
- "The sponsor has to have access, then request a download of several documents I need, then transfer the data to me."
- "I couldn't get access because I didn't have a .mil e-mail address."

In some cases, the information may be the intellectual property of a commercial firm. Sometimes such information is designated *proprietary*. This information requires the permission of the firm that owns the information to use it. The process of getting permission to use the information can be time-consuming, may never yield permission, or is simply too onerous. An example of the third possibility is a database that has proprietary information from many firms, requiring support contractors to sign NDAs with each firm, which could number many dozens and take a very long time.

The Office of the Secretary of Defense (OSD) asked the RAND National Defense Research Institute to identify the problems and challenges associated with sharing unclassified information and to investigate the role of policies and practices with such sharing in the first phase of two analyses on acquisition data (Riposo et al., 2015). In the second phase, RAND was asked to evaluate how marking and labeling Controlled Unclassified Information (CUI) procedures, practices, and security policy affect access to acquisition oversight data (McKernan et al., 2016). We will present the approaches, findings, and options for improvement for both analyses.

[1] Classified information is any information designated by the U.S. government for restricted dissemination or distribution. Information so designated falls into various categories depending on the degree of harm its unauthorized release may cause. This report does not deal with classified information.

Phase 1 Approach

We pursued a three-pronged approach for the first phase of this research with the objective of defining and evaluating any data-sharing problems. The first part of the approach was a policy review. We began by reviewing DoD directives, instructions, manuals, and guides, along with executive orders, legislation, and regulations concerning information management. The objective of the review was to develop a framework for understanding what governs information sharing in DoD acquisition. As part of this search, we also looked at a limited number of key federal policies that might affect data sharing within the DoD.

We then met with individuals within OSD to discuss information sharing, which is the second part of our approach. We used these discussions to help identify information-sharing practices and issues associated with data access and releasability. The discussions also helped us identify relevant policies and practices. We selected a sample of offices within OUSD(AT&L) to reflect a variety of roles in the acquisition process. We spoke with data owners, maintainers, users, and individuals involved with the governance of information. We categorized the offices represented in the sample by their missions and roles. This step led to three main categories of OSD offices:

- functional and subject-matter experts
- Overarching Integrated Project Team/Defense Acquisition Board (OIPT/DAB) review offices
- analysis offices

Within the OSD, the functional and subject-matter experts mainly work within a specialty (e.g., testing, cost, systems engineering, contracts, earned value). Those in the OIPT offices are primarily responsible for direct interaction with acquisition programs to review portfolio status and program readiness as programs move through the acquisition process. The analysis offices conduct a variety of crosscutting analyses in defense acquisition. The offices that fall into these categories appear in Table 1. We also interviewed service-level acquisition personnel to determine the role that the services play in DoD data sharing.

Our goal for the interviews was to collect the following information regarding interviewees' data sharing and practices:

- role in the acquisition process
- data needed to perform one's job
- how data are handled, obtained, and provided to others
- data access or release problems
- data-sharing recommendations

Table 1. Offices With Roles in the Acquisition Process

Office Category	Offices
Functional and Subject-Matter Experts	• OUSD(AT&L) Performance Assessments and Root Cause Analyses (PARCA) Earned Value Management (EVM) • OSD Cost Assessment and Program Evaluation (CAPE) • OUSD(AT&L) Human Capital Initiative (HCI) • OUSD(AT&L) Defense Procurement and Acquisition Policy (DPAP) • OUSD(AT&L) Developmental Test and Evaluation (DT) • OUSD(AT&L) Systems Engineering (SE)
OIPT/DAB Review Offices	• OUSD(AT&L) Deputy Assistant Secretary of Defense (DASD) Tactical Warfare Systems (TWS) • OUSD(AT&L) DASD Space, Strategic and Intelligence Systems (SSI) • OUSD(AT&L) DASD Command, Control, Communication, Cyber and Business Systems (C3CB)
Analysis Offices	• OUSD(AT&L) Acquisition Resources and Analysis (ARA) • OUSD(AT&L) Defense Acquisition University (DAU) • DPAP • FFRDCs • OUSD(AT&L) PARCA (outside EVM)

The final part of our three-pronged approach for phase 1 involved conducting two case studies to illuminate key issues and challenges associated with data access. Both reflect (or embody) the perception of several key data access issues. The first case study examines the use of proprietary information (PROPIN) in acquisition, with a particular focus on earned value data. The second looks at the various central data repositories that OSD maintains and uses. More specifically, the focus was on the background, benefits, and problems associated with these repositories. During our introductory interviews, we heard about problems with using, managing, and accessing PROPIN due to the need to involve direct support contractors in the collection and analysis of these data. Such relationships require the use of NDAs to help prime contractors and subcontractors protect their information. Both case studies are informed by the interview results and policy analysis.

Phase 2 Approach

During the second phase of this analysis on acquisition data, we evaluated how marking and labeling CUI procedures, practices, and security policy affect access to acquisition oversight data. Our work for this phase of research on managing and handling acquisition data within the DoD included policy analysis, structured discussions with government personnel, and a literature review to further understand and evaluate proprietary information sharing, the origins of commonly used acquisition labels, and how security policy affects the management of two acquisition information management systems within the OUSD(AT&L). We executed our work through three main tasks.

- **Identify and evaluate options to improve nongovernment employee access to proprietary information:** We continued to explore the source of the problems identified in our earlier research with sharing proprietary data among the government, contractor-originators who are providing the acquisition information, and other nongovernment entities such as federally funded research and development centers (FFRDCs), Systems Engineering and Technical Assistance (SETA) support, and information technology (IT) support contractors who are supporting the government. We developed a range of options for improving direct access for nongovernment employees to proprietary data and documented the options that the OUSD(AT&L) is pursuing to improve sharing. We characterized the options and their advantages and disadvantages and assessed implementation strategies for them.

- **Characterize commonly used data markings that support acquisition decision-making and oversight and identify the origins of those markings:** We focused on CUI labels that are commonly used by DoD government and nongovernment employees in the acquisition process. We identified their basis in law and policy and determined whether the policy prescriptions they provide for data labeling and access are clear and consistent and accord with OUSD(AT&L) goals. OUSD(AT&L) decision-making and oversight is intimately connected to acquisition data access, research, and analysis. Whether these data are available for timely, actionable decision-making partially depends on the type of data, the data control system, and the ability of data users to properly identify and label data, and if necessary, challenge improperly marked data.
- **Describe how DoD security policies, processes, and procedures affect OUSD(AT&L)'s ability to provide efficient and secure access to acquisition data:** This task involved multiple steps. First, we collected policies that affect information security and defense acquisition data for two information systems within the OUSD(AT&L)—Acquisition Information Repository (AIR) and the Defense Acquisition Management Information Retrieval (DAMIR) information systems. Second, we described the security policy environment for managing these information systems (e.g., who owns these policies and what topics they discuss). Third, we described and summarized the information security policy and identified how particular policies affect the OUSD(AT&L)'s ability to provide access to acquisition data and manage acquisition data.

Phase 1 Findings and Recommendations

- **The process for gaining access to data is inefficient and may not provide access to the best data to support analysis.** Government personnel and those supporting the government sometimes do not get their first choice of data, and even that data may take a long time to receive. They may be forced to use alternative sources, which often have data of lower quality, which might be dated and thus less accurate, or be subject to a number of caveats. While the consequences of these limitations are undocumented and difficult to assess and quantify, the results of these analyses can be inferior, incomplete, or misleading.
- **Two groups of people face particular challenges in gaining access to data: OSD analytic groups and support contractors.** OSD analytic groups often do not have access to the originators of the data, which precludes them from going to the primary source. They also tend to have poor visibility of all viable data sources, which encourages inefficient data-seeking practices. Direct support contractors have problems similar to OSD analysts, but these problems can be compounded by laws, regulations, and policy that restrict access to certain types of information (especially nontechnical proprietary data that originate and are labeled outside the government), which introduces extreme inefficiencies. Support contractors require special permissions to view nontechnical proprietary data.
- **Difficulty in gaining access occurs for several reasons:**
    - Data access policy is highly decentralized, not well known, and subject to a wide range of interpretation.

- The markings for unclassified information play a significant role in access. The owner or creator of a document determines what protections or markings are required. However, marking criteria are not always clear or consistently applied. In fact, management and handling procedures for many commonly used markings are not clearly described anywhere. Once marked, getting the labels changed can be difficult. When information is not marked, the burden of handling decisions is placed on the receiver of the information.
- Institutional and cultural barriers inhibit sharing. The stove-piped structure of the DoD limits visibility and sharing of data and information. Institutional structure and bureaucratic incentives to restrict data access are exacerbated by policy and guidance to protect information. The result is a strong conservative bias in labeling and a reluctance to share. A lack of trust and established relationships can hinder sharing.

Options for Improving Data Sharing

The variety of identified problems may be addressed in many ways. Each potential option requires further analysis and investigation. We offer initial thoughts to deal with the issue of access to proprietary data, as well as the general confusion regarding policy.

Options to Address Problem of Proprietary Data Access

There are several potential options to resolve the problem of access to proprietary data.

- The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) could seek additional billets and insource any functions that require access to proprietary data. However, this would require Office of Personnel Management and congressional support.
- USD(AT&L) could seek relief through a reallocation of billets to functions that currently require access to proprietary information. This would require cross-organizational prioritization, a difficult process.
- General access could be established for all direct support contractors. This would require legislative or contractual changes. Current legislation, Title 10 U.S. Code, Section 129d, allows litigation support contractors to view proprietary information. Similar legislation might be pursued for all support contractors.
- Alternatively, additional contractual language could be placed on all DoD acquisition contracts granting support contractors restricted access to their data. The direct support contractors who receive the data would have to demonstrate company firewalls, training, personal agreements, and need to know akin to those for classified information.
- The government could seek an alternative ruling on the nondisclosure requirements, whereby blanket nondisclosure agreements could be signed between the government and a direct support organization, or a company and a direct support organization to cover multiple tasks.

Each of these options would require further analysis and coordination with Office of the General Counsel and Defense Procurement and Acquisition Policy (and Congress in the first and third options).

Options to Address Policy Confusion

There are also several options to address the confusion regarding policy.

- OUSD(AT&L) could create and maintain a central, authoritative online resource that references all relevant guidance on information management, handling, access, and release for acquisition data. This would require identifying the relevant policy and posting new policies as they become available.
- However, an online resource may not address the issue of the workforce having a general lack of expertise and insight regarding the existing policy and guidance. To cope with this problem, OUSD(AT&L) could also consider providing additional training for its staff on the identification and protection of data. This could be an annual online training for all OUSD(AT&L) staff and contractors.
- In areas where conflicting interpretations of guidance are particularly problematic, such as with For Official Use Only (FOUO) and proprietary information, additional guidance about how to determine whether information is FOUO or proprietary in the first place would be helpful. The guidance should provide specific examples of information that is considered protected, guidelines for determining whether specific information qualifies, and details regarding handling procedures for this information, to include access privileges.
- Directives and incentives could be established so that markings that appear to be incorrect are challenged and not taken only on a company or individual's claim. If more-detailed determination guidance is available, it could be used to assess the validity of a marking. A process should be in place for challenging markings, and it should be exercised.

There are important reasons for restricting access that require balancing control with granting more access. In information assurance and security policy, there is an understanding that no individual should have unfettered access to all data. Given the inherent complexity in securing data and sharing data, any solutions to problems associated with data sharing must be well thought out to avoid the multitude of unintended consequences that could arise.

Phase 2 Findings and Recommendations

Proprietary Information (PROPIN)

PROPIN is a special class of CUI that relates to information and data developed by a private entity but shared with the government. Substantial confusion exists within the DoD about what information is truly proprietary, who can have access to it, and how to grant access when needed. Despite the fact that some policies attempt to define PROPIN and handling restrictions, no single source describes the processes and procedures for dealing with this type of information. Rather, a patchwork of law, regulation, and policy govern it, some of which is clear, but some of which is less so. This hinders the DoD's use of contractors, restricts information flow, and limits analyses.

DoD personnel are confused about who can access PROPIN. Information so characterized generally can be treated like all other CUI, meaning all government personnel can be granted access (Treanor, 1999). This access is enabled by virtue of the fact that the government has obtained the information under a lawful requirement. Further, federal employees who improperly use PROPIN can be fired and/or prosecuted. In addition, employees with a security clearance sign a blanket nondisclosure agreement (NDA) between the employee and the government. However, many government personnel are not familiar with this longstanding practice and are reluctant to share information with other government personnel because of concerns about violating an unknown law or regulation. In addition, procedures for nongovernment personnel to gain access vary widely. Federal law (10 U.S.C. 2320) specifically addresses support contractor access to technical data provided, but that law does not address nontechnical proprietary information supplied by contractor-originators. Consequently, DoD personnel often grapple with access issues among government and nongovernment personnel because of the lack of clear guidance about who can access what information—and what information constitutes PROPIN.

Ultimately, the company submitting the information to the government is responsible for asserting that certain portions are proprietary, but the government recipient is responsible for determining whether to accept that assertion and maintaining the "proprietary" label.[2] In other words, if the responsible government official determines the information is not proprietary, the government person is under no obligation to go back to the company (originator) to disclose the information within the government to a support contractor. If the government person wants to publicly disclose the information in response to a FOIA request, then the government person would have to notify the company (originator). However, true PROPIN can only be disclosed within the government to support contractors (and now FFRDC employees) when a one-to-one (i.e., between each individual at the support contractor/FFRDC and each company or program originating data) NDA has been executed.

The government distinguishes between contractors, generally, and the special contractual relationship established with federally funded research and development centers (FFRDCs).[3] In the past, the special relationship has meant that FFRDC personnel could be granted access to information directly by government personnel, or by signing a single, blanket NDA between the employee and the government, allowing them access to proprietary information in the course of their government-related work. But federal law does not specifically define what an FFRDC is or how to grant FFRDC personnel access to PROPIN. Nontechnical PROPIN is not specifically defined in statute, and courts have stated that what is truly proprietary is determined on a case-by-case basis under FOIA Exemption 4. Generally, the disclosure of the information must present the potential for a company's

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[2] This statement is based on the researchers' understanding of current practices.

[3] FFRDCs have a unique relationship with the government because they have access beyond that which is common to the normal contractual relationship. They are free from organizational conflicts of interest. Also, it is not the government's intent that an FFRDC use its privileged information or access to installations equipment and real property to compete with the private sector. Finally, FFRDCs are meant to be independent research institutions characterized by objectivity. According to 48 C.F.R. 35.017 (a.k.a. FAR 35.017), "An FFRDC, in order to discharge its responsibilities to the sponsoring agency, has access, beyond that which is common to the normal contractual relationship, to Government and supplier data, including sensitive and proprietary data, and to employees and installations equipment and real property. The FFRDC is required to conduct its business in a manner befitting its special relationship with the Government, to operate in the public interest with objectivity and independence, to be free from organizational conflicts of interest, and to have full disclosure of its affairs to the sponsoring agency. It is not the Government's intent that an FFRDC use its privileged information or access to installations equipment and real property to compete with the private sector."

competitive position to be injured by a competing company (Department of Justice, 2009, p. 305).

Recent DoD interpretations of policy and statute—specifically the Trade Secrets Act (18 U.S.C. 1905)—have changed how FFRDCs are treated with respect to NDAs, resulting in an inefficient and ineffective process of securing them. Specifically, FFRDCs are now required to obtain an NDA between each contractor-originator of data in a system and each FFRDC employee who needs access—referred to in this report as “one-to-one” NDAs. Previously, FFRDC employees could sign a single, blanket NDA with the DoD to enable access to all needed information.

The RAND Corporation operates three FFRDCs: Project AIR FORCE, the Arroyo Research Center, and the National Defense Research Institute. Therefore, we have an interest in FFRDC access to data. We believe that our results are valid independent of that interest, and we have firsthand experience with the struggles of DoD personnel managing data and access.

Commonly Used CUI Data Markings

The current set of CUI labels and guidance states that only information which requires protection by Federal Regulation or government-wide policy can be considered CUI. In other words, a marking that does not originate from a protection established by law or government-wide policy should not be employed. We identified nine data labels commonly used to indicate that the information contained in a document or database requires some type of special handling or restriction. Those nine labels are

- Business Sensitive
- Competition Sensitive
- For Official Use Only
- Pre-Decisional
- Proprietary
- Source Selection Sensitive
- Technical Distribution Statements
- DoD Only
- Government Only

Some of these labels are governed by well-established policies that reflect current understanding of the law and regulatory environment for data protection and data sharing. Others are legacy markings and practices that were not aligned with draft CUI policy at the time this report was written. We were unable to find any single document collecting and describing all these labels; the lack of a single such document contributes to the general confusion surrounding them. It is difficult for government personnel to know how data can be shared. A result of this situation is the likely over-labeling and mislabeling of CUI material. Although we found that many of the most commonly used CUI labels do have a basis in law or policy, labels may not be understood in practice, used properly, or have clear handling procedures.

Consequently, data may not be used to inform, improve, and strengthen the DoD’s acquisition functions. Bottlenecks, risk aversion, and fear of releasing otherwise protected data can restrict legitimate access and data sharing, both within the government and between the government and select partners. While the National CUI program being established by the National Archives will help provide much-needed clarifications, it is unclear when this program will be finalized within the DoD.

Implications of DoD Security Policies for Two OUSD(AT&L) Acquisition Data Information Systems

Information security policies directly affect the access and utility of acquisition databases. The current information security environment does not establish a consistent framework for managing information systems. This makes it difficult for government employees to know how to comply with regulations; find funds and the technical capabilities to implement new policies; develop ways to evaluate costs and benefits of new policies and determine exceptions; and know how to identify, mark, and protect CUI. The impact of these challenges is a potential delay in accessing acquisition data by both government and nongovernment employees, which in turn may result in lower quality analyses or decisions based on incomplete information.

We used the Acquisition Information Repository (AIR) and Defense Acquisition Management Information Retrieval (DAMIR) OUSD(AT&L) acquisition data information systems as case studies to examine the implications of implementing security policies. AIR provides one central location for all Major Defense Acquisition Program (MDAP) and Major Automated Information System (MAIS) acquisition documents to support oversight and decision-making.[4] DAMIR fulfills several key functions, including reporting, storage, quality assurance, analysis, oversight, and tracking cost, schedule, and performance of major acquisition programs.[5] AIR largely represents the unstructured data problem, while DAMIR represents the challenges associated with structured data that both pull from and feed into other information systems.

A multitude of security policies affect management and operation of these systems. We identified about two dozen executive orders, laws, directives, instructions, operating guides, and other policies that affect AIR and DAMIR, some of which cover similar material. The AIR information managers have created a set of business rules based on their interpretation of those policies. For instance, according to DoD (2012) Manual 5200.01, volume 4, “The [government] originator of a document is responsible for determining at origination whether the information may qualify for CUI status, and if so, for applying the appropriate CUI markings” (p. 9). The information managers for AIR have interpreted this policy guidance from USD(I) to mean that the originators of the information being uploaded to AIR (e.g., the services and other OSD offices) are responsible for appropriately marking the information in AIR even though the AIR managers have noticed some inconsistency in the marking of the documents across documents types. The AIR managers attribute this inconsistency to the variety of security classification guides being used to mark documents by the originators. Also, there is no process for ensuring that up-to-date marking conventions are followed for each document uploaded to AIR. Management and use of AIR

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[4] AIR is a document repository that contains specific program documents (reports, certifications) used to inform acquisition decision-making and oversight.

[5] DAMIR has both unclassified and classified versions. It supports the generation, distribution, and archiving of Selected Acquisition Reports (SARs) as well as information supporting the Defense Executive Acquisition System (DAES) process. It also includes higher-level earned value management data. Unlike AIR, DAMIR is structured data that users can combine and analyze in multiple ways serving multiple functions.

are complicated by the need to access it on an IT system approved through Defense Security Service inspection, use a .mil e-mail address associated with a Common Access Card (CAC), and have approval through a government sponsor, who provides the rationale for granting a user access to AIR for a specific purpose. In addition, the permissions process is separate from the sensitivity of documents stored in AIR.

DAMIR is hosted by the Joint Service Provider, which only partially resides within the OUSD (AT&L). External hosting separates operational and security management and creates the possibility of a disconnect between the business case for data use and security policies. In other words, the cost of the security may be high while the perceived benefits may be low. Understanding the business case (or use) for DAMIR is critical to maintaining security without unduly limiting the utility of the system for users. Security policies also inhibit system improvement, which requires code changes and upgrades. A recent determination that real data cannot be used for testing required additional programming work to invent data to test the system. The lack of actual data for testing makes determining whether a new database capability will ultimately work a speculative exercise.

Several years ago a security policy requiring accounts that have not been used in a 30-day period to be disabled significantly affected DAMIR. Many DAMIR users, including congressional staff and FFRDC analysts, log in infrequently (i.e., when new SAR or DAES reports come out) rather than routinely. The policy resulted in the suspension of accounts, which meant the DAMIR team had to re-register about 30% of 4,000 active user accounts initially after the policy was enforced. The DAMIR team continued to have significant problems for several months in re-activating inactive accounts.

Implementing new policies within DAMIR (which has more than 1.5 million lines of code) is also challenging. DAMIR was stood-up under different security-related policies, and adapting its structure, programming, and business rules to accommodate new policies entails substantial effort. Furthermore, there is no up-to-date security architecture document because architecture and security policy governing DAMIR have evolved independently. Similarly, new interpretations of existing policies have consequences. For example, a new interpretation[6] of what potentially constitutes personally identifiable information (PII) caused the DAMIR management team to conduct a formal assessment of how individual privacy is being addressed in DAMIR due to the potential existence of PII in DAMIR.

CUI Marking and the Security Policy Environment

Overall, the current environment in which acquisition data are protected and shared can be characterized by many organizations promulgating policy on overlapping and interrelated topics, policies that are relatively new and change frequently, and an ill-defined CUI policy. Furthermore, security policies tend to be one-size-fits-all, which does not reflect the unique characteristics of each system. Those who originate the policies do not fund their implementation, meaning that a new or changed policy is effectively an unfunded requirement for system managers. This situation creates a number of issues for information system managers. First, it is difficult to know exactly what is required to comply with the

[6] The interpretation was based on the reissue of DoD Directive (DoDD) 5400.11 that updated the established policies and assigned responsibilities of the DoD Privacy Program pursuant to section 552a of Title 5, U.S.C. (also known and referred to in this directive as “The Privacy Act” and Office of Management and Budget [OMB] Circular No. A-130).

numerous applicable policies. Second, managers have to find the funds to comply when policies change. Third, considerable confusion surrounds the identification and marking of CUI. This environment, which is causing a lot of inefficiency and many workarounds to solve problems, creates a managerial problem for the OUSD(AT&L).

The overall effect of these problems almost certainly has a cost, though this cost is difficult to quantify. Government and nongovernment users of both DAMIR and AIR may, for example, simply seek to conduct analyses with other, less insightful data, or without data at all. No system, however, tracks the effects or costs of DAMIR and AIR (or any other information system) compliance with security policy. The cumulative effects of security policy requirements may exceed what is currently documented in the management of these two acquisition information systems. In other words, the effect of compliance actions on other information systems and user behavior can have a cascading effect; the problem is likely much larger than what has been documented here.

What the DoD Can Do to Improve the Situation

Proprietary Data

We suggest[7] that the Federal Acquisition Regulation (FAR) FFRDC provisions could be used as a basis for a DoD decision that FFRDCs are exempt from the relatively new one-to-one NDA requirement created by a change in DoD interpretation of the Trade Secrets Act, or could be covered by a single, blanket NDA with the DoD.[8] Office of Federal Procurement Policy staff suggested in a meeting with the authors of this report that the DoD Office of the General Counsel (OGC) was taking an overly restrictive view of the FAR FFRDC provisions. For non-FFRDC contractors, we also recommend that the DoD consider the following:

- Creating a DFARS provision that would cover nontechnical data,[9] possibly with a blanket NDA requirement
- Proposing a new legislative provision covering all nongovernment personnel similar to 10 U.S.C. 129d, which allows litigation support contractors access to "commercial, financial, or proprietary information" without a nondisclosure agreement
- Proposing a legislative amendment to 10 U.S.C. 2320, which allows access to technical data for providing advice or technical assistance to the government, that would include financial and management data

Regulatory and legislative changes both carry drawbacks. The DoD can propose changes to the DFARS without congressional action and presidential approval, but changing

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[7] Our recommendations are designed to increase access to sensitive data for analysis. As a party that has long analyzed such data, organizations such as RAND (an FFRDC) would, of course, benefit from such actions, and we understand readers may view our recommendations accordingly. Regardless, we trust our research can advance broader discussion of how the DoD can improve oversight of its acquisition programs.

[8] A blanket NDA would be an NDA between an organization and another organization, versus the current requirement of a one-to-one NDA between an individual and a contractor-originator of data.

[9] As noted above, 10 U.S.C. 2320 specifically addresses technical data, so we are only discussing nontechnical data.

the DFARS might not adequately include previous PROPIN designations because a new clause would only affect contractors who presently have active DoD contracts. Changing the law is even more problematic because it requires congressional action and presidential approval, takes approximately two or more years, and may not even result in a change or could result in unwanted changes.

CUI Markings and Labels

A more robust, central program for CUI data labeling, access, and management (including monitoring and challenging document originators) may help facilitate a smoother sharing and protection of CUI within the DoD. The DoD should also train its workforce on the new CUI labeling procedures when they are released and implemented by the DoD. Given that no central reference, institutional structure, or authority exists for defining and establishing proper handling procedures for CUI, we recommend that a function and reference be established within the OUSD(AT&L) for both technical and nontechnical acquisition data.

Security Policy

The problem that needs to be solved with respect to security policy is the clear mismatch of responsibility, authority, and accountability among the organizations that issue security policy and manage or host the information systems. We offer several recommendations oriented at addressing this problem.

First, we suggest using existing information requirements to document how security policies are affecting the management of information systems. While there are many anecdotes about difficulties in implementing security policy for AIR and DAMIR, these are not documented in a central location or updated over time. By documenting difficulties, including resources used to implement various policies, the OUSD(AT&L) would better understand how security policies are affecting their systems and whether a better balance between security and business cases[10] is being achieved.

Second, we suggest that a function be established within the OUSD(AT&L) to review information security policies, de-conflict them, reduce duplication, ensure consistency, and identify gaps for all acquisition data collected and used within the OUSD(AT&L). This function would be responsible for communicating with the OUSD(AT&L) information-system managers in order to have a greater understanding of the inefficiencies in implementing security policy. This function (or working group) should include all relevant stakeholders so as represent both security and mission perspectives.

Third, a single individual should be designated with responsibility for implementing security strategy for a given information system. This individual, the AO, could work with the policy originator to ensure appropriate interpretation and application of policy. For the OUSD(AT&L) information systems, we believe that the AO should be selected based on knowledge of the mission area (i.e., a subject matter expert). The goal is to have someone

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[10] Enterprise Information within OUSD(AT&L)/ARA is responsible for "providing leadership timely access to accurate, authoritative and reliable data supporting acquisition oversight, analysis, and decision-making." EI needs to fulfill its mission with limited resources, so it must balance the business case for adding new capability to its information systems (DAMIR and AIR) with what is being mandated for it to implement for adequate security of its information systems.

who is familiar with the business case for a system to be more involved in the daily operations of that system and to track security policy changes and implementation.

Fourth, the requirement that each information system have and maintain a security strategy should be used as an opportunity to ensure an appropriate balance between security risk, business case, and the use case[11] for each information system. The security strategy should be updated as policies, threats, or system use change, providing a consistent framework over time to evaluate the balance between risk and utility.

Finally, implementation of security policy should be appropriately resourced. The issuing organization should assess required resources as part of policy design, and provide at least some funding to address needed technical changes to the information systems. Similarly, the organizations managing information systems should identify resources to address implementation of security policy as part of the security strategy it maintains.

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[11] Interactions between the users of DAMIR/AIR and system owners that enables the user to achieve the goal of adequate access to acquisition data.

Issues With Access to Acquisition Data and Information in the Department of Defense: Doing Data Right in Weapon System Acquisition

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Abstract

Acquisition data lay the foundational role for decision-making, management, and oversight of the weapon-systems acquisition portfolio for the Department of Defense. How to effectively and efficiently spend these dollars has been a top priority for the Better Buying Power initiatives led by the Office of the Secretary of Defense (OSD) and the Under Secretary of Defense for Acquisition, Technology, and Logistics. The OSD asked RAND to help identify how available data can help assist defense-acquisition decision-making. In particular, we documented factual information on 21 information systems that contain acquisition data. This builds on our earlier work (Riposo et al., 2015, *Issues With Access to Acquisition Data and Information in the Department of Defense: Policy and Practice*, RAND RR-880; and McKernan et al., 2016, *Issues With Access to Acquisition Data and Information in the Department of Defense: A Closer Look at the Origins and Implementation of Controlled Unclassified Information Labels and Security Policy*, RAND RR-1476) by exploring in more detail the data that support decision-making.

Introduction

Acquisition data[1] lay the foundation for decision-making, management, and oversight by the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L])

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[1] Acquisition data are vast and include such information as the cost of weapon systems (both procurement and operations), technical performance, contracts and contractor performance, and program decision memoranda. These data are critical to the management and oversight of the $1.5 trillion portfolio of major weapon programs by the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (OUSD[AT&L]).

of the weapon-system acquisition portfolio for the Department of Defense (DoD). Acquisition data help to inform, monitor, and achieve several DoD objectives, including

- promoting transparency in spending
- understanding and achieving cost control
- visualizing the distribution of defense spending
- achieving small-business goals
- identifying and preventing fraud, waste, and abuse
- conducting analyses for improved decision-making
- compiling and tracking items in various processes
- archiving decisions

It is critical for personnel managing acquisition execution and oversight to know what data resides within DoD as well as what questions can, or cannot, be answered with that data (Table 1).

Table 1. Acquisition Data Can Answer Some Defense Questions, and Not Others
(RAND)

Acquisition Data Can Answer	Acquisition Data Cannot Answer
How much do we spend acquiring weapons and services in DoD?	Where can we access certain technologies?
How long does it take to field a weapon system?	What key suppliers may need help given spending decreases?
What are the key costs of what we buy for DoD?	How well does spending align with requirements?
Who do we buy from?	What value is gained from spending?
Where is our spending geographically located?	How is the health of the defense industrial base?
Why are costs and schedule increasing?	What is the quantity adjusted cost growth for a specific acquisition program?
How competitive is our supply base?	How do the acquisition schedules of a large number of acquisition programs compare over time?
How well does DoD meet small business goals?	What is the workload of various parts of the acquisition workforce (e.g., contracting)?
What can we learn from past acquisition failures/successes?	Which government and non-government personnel are working specific acquisition programs?

How to effectively and efficiently spend taxpayer dollars allocated to the Department of Defense has been a top priority of the Better Buying Power (BBP) initiatives led the Office of the Secretary of Defense (OSD) and the USD(AT&L). In BBP 2.0, the USD(AT&L) specifically acknowledged the need to streamline decision-making by “promptly acquiring relevant data and directing differences of opinion to appropriate decision-makers. Our managers cannot be effective if process consumes all of their most precious resource—time” (Kendall, 2013, p. 2).

Currently, much weapon-system acquisition data is collected based on policy directive, congressional reporting, and the need to meet USD(AT&L)'s statutory authorities. These information requirements largely reside in the Department of Defense Instruction (DoDI) 5000.02 (2015). This data-management strategy fails to address the complete managerial prerogatives of the USD(AT&L) and the Better Buying Power initiatives. Additionally, siloed reporting of acquisition data may not fully support the USD(AT&L) decision-making processes. Data requirements have generally been developed from a particular functional perspective resulting in a data "ecosystem" characterized by individual collections of data that are functionally stovepiped and disjointed, each with different rules for collection, retention, and access.

Approach

In earlier work (Riposo et al., 2015; McKernan et al., 2016), we identified the issues associated with managing and sharing Controlled Unclassified Information (CUI) within the DoD. In this analysis, we examine issues with managing and accessing the sources of that data. Specifically, the OSD asked us to consider

- What data are available to help assist in defense acquisition decision-making?
- Where do acquisition data reside?
- Who can access the information?
- Can we get access to these data for acquisition-related purposes?

To answer these questions, we held targeted discussions with acquisition information system managers, supplemented these discussions with reviews of official policy documentation and other open sources on the information systems and their contents, reviewed literature on master data management to understand practices in commercial data management, and augmented our findings with RAND knowledge of using these data systems. Through these methods, we accomplished four tasks.

What are the major weapon system acquisition data domains? We accomplished this task by reviewing various federal-wide, OSD-wide, and Service-level information systems and their data elements in order to identify where the data that supports current information requirements in DoDI 5000.02 reside. We focused first on a broad look at the enterprise acquisition landscape as a whole, then particularly on sources of acquisition information that support the USD(AT&L) through the Defense Acquisition Executive Summary (DAES) and Defense Acquisition Board (DAB) secretariat, Director, Acquisition Resources and Analysis (D, ARA). Our sponsor, deputy director of Enterprise Information, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, Acquisition Resources and Analysis Directorate, provided the list of information systems to examine for this analysis.

What are the functional communities or major users that weapon system acquisition data domains support within the DoD? We identified, through discussions with the information managers of the 21 information systems, major users of DoD acquisition data within the OSD.

What are the providers of weapon system acquisition data for USD(AT&L) decision-making? We also identified, through discussions with information managers, who is providing acquisition data to OSD information systems in order to inform USD(AT&L) decision-making on defense acquisition.

What are some recommendations for improving the acquisition data environment? In this task, we provide recommendations that would improve the quality of acquisition data, ease of access, efficiency of collection and use, and the ability to link data through common data elements.

Background on Acquisition Data in the Department of Defense

Acquisition data and information take on a wide variety of forms within the Department of Defense and include such information as the cost of weapon systems (both procurement and operations), technical performance, contracts and contractor performance, and program decision memoranda. These data can be characterized as both "structured" and "unstructured."[2] They are critical to the management and oversight of the $1.5 trillion portfolio of major weapon programs by the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics.

This data may be for statutory, regulation, policy, or other reasons. DoDI 5000.02 (2015, Enclosure 1, pp. 47–58) provides a detailed list of "statutory and regulatory requirements at each of the milestones and other decision points during the acquisition process." This does not encompass all of the requirements, but is a centralized source for many of them. Some of the information requirements are to measure cost, schedule, and performance of weapon systems, while others examine testing, cybersecurity, requirements, budgeting, alternatives, and technology readiness.

The information resides throughout the DoD at all levels, from program offices in the Services to various offices within OUSD(AT&L). It can be found in decentralized locations (e.g., individual computers) and centralized locations (e.g., information systems). The DoD also uses data that reside in various federal information systems. There is a plethora of acquisition-related data sources that are now available. The data elements within these information systems vary. Some data elements[3] are unique while others may overlap, depending on different definitions. The timeframes for the various data elements are non-stationary, meaning, for example, that one information system has data from 1960 to current, while another may only have data from 2010 to current. Acquisition data are stored in information systems with differing platforms and hardware: architectures, software, and interfaces; vendors; and databases. There is varying accessibility and security requirements (depending on the data being stored) in the information systems.

Enterprise Information within the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, Acquisition Resources and Analysis Directorate categorizes the data into various business areas including Research and Development

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[2] According to the *PC Magazine Online Encyclopedia*, structured data are "Data that can be immediately identified within an electronic structure such as a relational database." Unstructured data are "Data that are not in fixed locations. The term generally refers to free-form text such as in word processing documents, PDF files, e-mail messages, blogs, Web pages and social sites" ("Structured Data," n.d.-b).

[3] According to the *PC Magazine Online Encyclopedia*, a data element is "The fundamental data structure in a data processing system. Any unit of data defined for processing is a data element; for example, ACCOUNT NUMBER, NAME, ADDRESS and CITY. A data element is defined by size (in characters) and type (alphanumeric, numeric only, true/false, date, etc.). A specific set of values or range of values may also be part of the definition" ("Data Element," n.d.-a).

(R&D), Requirements, Budget, Contracting, Contract Performance, Financial Execution, Program Cost/Schedule/Performance, Human Capital, and Acquisition Oversight/Portfolio Management.

Many factors affect how acquisition data is collected and stored. There are multiple, changing conditions that affect the management of acquisition data. Information owners and managers may need to consider whether a current architecture can support additional statutory requirements, administrative changes, or security policy changes. Technological advancements may also be implemented to improve

- Collection efficiency
- Quality of the data
- Aggregation of the data
- Ease of access/use of the information system and its data
- Analysis of data
- Archiving data for future analysis/education

These same factors can also affect the development of various acquisition systems. Acquisition information systems were created, evolved, or repurposed based upon data needs and legitimate reasons (e.g., statutory needs). They have been developed with varying architectures and interfaces. They also require analysts with cross system-analytic skills. They are also difficult for users to navigate effectively, and can takes years of consistent access and use to fully understand and master. Most systems are built for reporting, not analysis. Compliance and tracking has been a priority. Acquisition information systems and the data they contain may be designed to answer today's current questions, but inflexible to answer tomorrow's questions.

This analysis found that there are also barriers to the use of each system and cross use between the information systems. Access procedures are complicated and generally consist of many steps that may not ultimately guarantee access. There are varying access procedures and permissions between and sometimes within systems. The federal systems have much data available to the public, but DoD systems are mostly restricted. New users can have great difficulty establishing and maintaining access (how to, where, who, what?). Full access to acquisition information systems enables analysts to maximize use of data. The owners and managers of the data have found that balancing security and access needs is difficult.

Background and Findings on Deep Dives of Acquisition Information Systems

As part of this effort to understand acquisition data opportunities,[4] we conducted "deep dives" on a set of information systems. In this section, we summarize the information we gathered through our deep dives. We reviewed 21 federal-wide, OSD-level, and Service-level information systems and their data elements in order to identify where are some of the acquisition data or information that supports current requirements in DoDI 5000.02. We reviewed five federal-level information systems, 12 OSD-level information systems, and

[4] By "data opportunities," we mean identifying data that can potentially be used for analysis of various defense acquisition questions.

three Service-level systems (one Army, one Air Force, and one Navy). Of the 21 systems, at least one study-team member had previous knowledge of 11. For five systems, a study-team member had limited prior or current knowledge; and for the final five systems, no one from the RAND study team had knowledge from use. We worked with our sponsor, ARA/EI, on whether to pursue access to the information systems for this effort, ultimately deciding not to do so.

We did not rely exclusively on access to the information systems in order to conduct the deep dives. We also collected official documentation as available, and requested additional materials from those managing the information systems. We had some level of open-source materials for all but two systems. Finally, we relied heavily on discussions with the information managers, particularly on the information systems for which we had little or no knowledge and open-source materials were not available. We were able to conduct discussions for all but one information system. The results of this study depend on the variety of information we were able to collect.

We verified the deep-dive information with information managers in early 2016 in order to ensure that the deep dives contain the latest available information. Nevertheless, we found that the information in these systems is constantly changing as policy, technology, and other things change. Consequently, it is best to consult the information systems directly for the most up-to-date information.

As stated previously, we gathered additional information for these deep dives through discussions with information managers. The information that we gathered from the discussions covered the following main topic areas:

- Basic details on the acquisition information system
- Types of questions answered with this information system
- Owner, manager, and host of the information system and data in that information system
- Statute or policies that led to the creation of the information system or provide the reason the data in the system is collected
- Characterization of the data in the information system
- Security and access restrictions governing the information system
- Characterization of the users
- Strengths and weaknesses of the information system or data in that information system

Basic Details on the Acquisition Information Systems

For each of the 21 information systems, we gathered basic factual information including the official abbreviation, date that the system entered service, the access point for the information system, whether the system is open to the public or is restricted, the functional business area the system supports, and the purpose. These systems cover a wide variety of functional business areas including

- Research and development (R&D)
- Requirements
- Budgeting
- Contracting
- Contract Performance

- Financial Execution
- Program Cost /Schedule/Performance
- Human Capital
- Acquisition Oversight/Portfolio Management

Some systems cover multiple business areas.

Types of Questions Answered by These Information Systems

Decision-makers and analysts working in defense acquisition need to understand the type of questions that can be answered with the structured and unstructured data in these information systems. They also need to know what questions cannot be answered. We asked information managers to identify some of the questions that can be answered from the data in these information systems.

Owner, Manager, and Host of the Information System

Additional factual information that we collected on these information systems included the owner, manager, and host of these systems. The owner is the office responsible for oversight of the information system. It is sometimes different from the manager of the system who may be responsible for day-to-day operations including approving access and troubleshooting technical issues, but the owner and manager are typically within the same, larger organization. The host of the information system often appears to be an office outside of the owner or manager and is typically a contractor for the federal systems.

Statute/Policies Requiring Each Information System

Most of these systems originated in statute requirements, with the Federal Acquisition Regulation also being a common reason for creating a data system. Some systems originated in policies or memoranda from senior DoD leadership.

Characterization of the Data in the Information System

There is no consensus on whether the data in these systems is authoritative. Some systems contain data that are authoritative, but others pull data from elsewhere. There is also significant variation in the dates of the data in these information systems. A version of one information system goes back as far as 1951 for the DoD. For several other systems, there may be some historical data back to the 1960s. Likewise, there is some variation in whether a formal data dictionary exists and, if one does, whether it is available to users. In some cases, information managers use the data dictionary for planning, but do not provide it to users. In some systems, data elements have been added over time or their definitions have changed.

Characterization of the Users

The number of users for these information systems varied from less than 100 to nearly 400,000 users. Information managers may count their users as “registered,” “active,” “average users per month,” or “number of users in a particular time period.” Composition of users also varies widely. Some of the information managers provided high-level statistics (e.g., public, government, DoD), while others provide specific organization names for users.

Conclusions and Options

Acquisition data and information take on a wide variety of forms within the Department of Defense and include such information as the cost of weapon systems (both procurement and operations), technical performance, contracts and contractor performance, and program decision memoranda. This data is collected for a variety of reasons including statutory requirements, regulation, policy, and other reasons.

The information resides throughout all levels of the DoD and can be found in informal, decentralized locations as well as formal, centralized locations (e.g., information systems). The DoD also uses other federal data residing elsewhere.

Data elements within this plethora of sources may vary. Some data elements are unique, while others may overlap depending on different definitions. The timeframe and source of these data vary as well.

There are multiple, changing conditions that affect the management of acquisition data. Information owners and managers may need to consider whether a current architecture can support additional statutory requirements, administrative changes, or security policy changes. Technological advancements may also be implemented to improve collection efficiency, quality, aggregation, and ease of access or use.

These same conditions can also affect the development of various acquisition systems. Acquisition information systems were created, evolved, or repurposed based upon data needs and legitimate reasons (e.g., statutory needs). Yet they are often difficult for users to navigate effectively and can require years of consistent access and use to fully understand and master. Most systems are built for reporting, not analysis, and compliance and tracking has been a priority. Acquisition information systems and the data they contain might answer current questions but may be inflexible for future ones.

This analysis found that there are also barriers to use of each information system and cross use between the information systems. Access procedures are complicated and generally have many steps that need to be met in order to be permitted access to the information system and its comments. There are also varying access procedures/ permissions between and sometimes within systems. The federal systems have an abundance of data available to the public, but DoD systems are mostly restricted. New users can have great difficulty establishing and maintaining access. Although full access to acquisition information systems enables analysts to maximize use of data, it is not practical given the need to balance security and access.

Deep Dive Conclusions

We compiled information on 21 federal and DoD information systems that contain structured and unstructured acquisition data and information. The level of detail we were able to pull together on each information system and its contents varied considerably based on

- RAND team user experience with individual systems
- Availability and access to official policy documentation and other materials on the information systems
- Interviewee interpretation of discussion questions

There was a wide variety of interpretation of each of the questions in the interview protocol and how these questions pertain to the individual information systems that an information manager is overseeing. The output of these discussions showed that even common terms like “owner,” “user,” or “data element” and “data dictionary” are subject to interpretation, which suggests that a common taxonomy would be difficult to implement, but may be necessary. Basic details were fairly easy to identify and verify. We also pulled together a large variety of potential questions that can be answered by the data in each information system, but the list is not comprehensive nor an assessment of how well the questions could be answered. Nevertheless, both are critical information for decision-makers.

Some factual information can be difficult to assess, given subtle distinctions such as those between owner and manager in some cases. In other cases, it was easy to verify information on owners, managers, and hosts, because all three functions are performed by the same office. Yet some owners, managers, and hosts changed over time, so it was not always clear who held which role.

The list of policies that led to the origins of these systems was not always apparent as some of the systems are older, some systems have “morphed” from one objective to others, and there has been a turnover in personnel who manage the systems. Some information systems provided a list within the information system documenting the policies that led to the system creation/the data in the system. In other cases, we were given the information during our discussions with information managers.

When we asked about security and access and the user base with information managers, the feedback we got was very difficult to compare across systems. Security and access were intertwined in discussions even though there are supposed to be clear origins in statute and policy that require both security and access restrictions. Similarly, the information we received on users varied by number, type, and characteristic.

For each data system we reviewed we also sought to identify strengths and challenges for the information manager and users. We summarized the major cross-cutting strengths and challenges themes associated with the systems reviewed. The following are some of the major strengths:

- The collection and standardization of selected acquisition related information into one place where it can be input, accessed, and analyzed by those needing to use it.
- Data that is input electronically with controls (e.g., through validation checks and business rules) to assure that key data elements are entered, edited, and cross checked against historical and other data, which improves data quality.
- Systems that have been established or improved to answer acquisition questions. These systems are attempting to pull together variables in one place for analysis, so as to improve DoD decision-making, and also to save funding that is typically spent by analysts trying to cobble together information.

Information managers also face several challenges in managing acquisition data, including the following:

- Data quality vary depending on what is input or provided, and often with no means to verify accuracy.
- The need to have the originators input new data when the data have changed.
- Assuring access to those who need-to-know while protecting sensitive data. Access procedures vary greatly by system, burdening those needing to access multiple systems.
- Inconsistency in terms. The same term can have different meanings in different acquisition systems which makes analyses across systems particularly challenging.
- Inconsistency in data formats.

- High variance in hardware and software.
- Need for more data elements, leveraging of authoritative systems, real time editing and verification, and updating to new platforms.
- Desired, backlogged improvements and sometimes critical updates that lack resources for implementation.

Options for Improving the Acquisition Data Environment

Our analysis yields several recommendations for improving the DoD acquisition-data environment.

Formalize a Data Governance and Data Management Function

To answer the DoD's acquisition questions, the USD(AT&L) should consider formalizing a data management and governance function (e.g., data steward) to oversee data opportunities. Any decision on a data steward would need to consider who could be the authority to institutionalize/implement these changes given the diversity of data ownership in the DoD.

Our discussions with information managers and our literature review on Master Data Management found that data governance plays a key role in the success of acquisition data management. In particular, data governance can monitor and enforce the use of acquisition tools. Data governance also determines the process and structure for authority control, planning, monitoring, and enforcement over data assets (American Institute of CPAs, 2013, p. 4). While data quality/validation focuses on managing individual pieces of data, data governance focuses on data definitions, policies, and processes, including those for data quality/validation. Data governance has two primary data-management objectives: planning and supervision/control.

A data steward function would need to further identify where and what data opportunities exist by maintaining a master list of data/information and authoritative sources. As can be seen from this study, authoritative sources are not always integrated into information systems, and it is not apparent that developers have a good understanding of all of the authoritative sources. There appears to be a movement in that direction, but the DoD should continue to re-syndicate data from authoritative sources.

The data steward and information managers should proactively solicit ways to improve value of the data from all categories of users (inputters, overseers, and analysts) in order to improve data quality, capability, access, usability, and functionality. This function could also improve understanding of related systems and identify potential opportunities for consolidation.

Improve Data Quality and Its Analytic Value

The DoD should require that all new systems have user and data entry guides and data dictionaries that describe data elements and their sources (e.g., another system or enterprise/personnel entering). This informs data opportunities and may eliminate duplication. Information managers should try to minimize manual entry whenever possible or provide validation checks. An explicit list of authoritative sources for data elements should be available and new systems should be required to use them, while older systems migrate towards them.

Information managers frequently mentioned that data verification and validation is a top priority and that they have both manual and automated checks built into the systems. Information managers should continue and expand this best practice.

Information managers mentioned one of their challenges is to be able to continue to update their systems to add capability and comply with the latest security requirements. The DoD should require system owners to develop and update plans and budgets for continuous improvement of data quality and analytic value, and document unfunded requirements linked to these improvements.

Make Structured Data the Top Priority

Current practice is to collect DoD Acquisition data in structured and unstructured formats. Both types of formats have an important role in the execution, oversight, and analysis of acquisition programs. However, structured data, which is easier to use for analysis, should be the top priority. The DoD should minimize the use of unstructured data, which takes more resources and different capabilities to make useful for analysis. More specifically, structured data

- allows for topic metatags
- can use strategic algorithms to check quality
- maximizes drop-down menus; minimizes free text

Similarly, a large amount of acquisition information is produced in unstructured formats. Since not all data can be converted to a structured format, the DoD needs to identify ways to make unstructured data more useful. Structured data is easy to use once meaning and access has been determined.

By moving toward structured data, the standardization of formats for acquisition data would promote sharing between systems. The standardization needs to take into account context and meaning when appropriate.

Develop and Train Organic Capability Among the DoD Workforce to Use/Improve Data

RAND has spent decades using acquisition data to solve difficult questions on a variety of defense acquisition topics. Answering sophisticated acquisition questions requires analysts with detailed knowledge, access, and experience with numerous data sets. They also need knowledge of how the information systems and their data have changed over time to do trend and other analyses. When utilizing very large data sets, robust processing and storage capacity and the skills of research programmers are critical.

The DoD needs to ensure that its workforce is educated and trained to fully understand, analyze, and use existing acquisition data opportunities. The acquisition community must have the skills and aptitude to understand, analyze, and use this data to make decisions. Lastly, but importantly, the DoD needs to continue to focus on developing internal, organic capability to use and improve acquisition data to better understand what data is being collected, what data should be collected, and how that information can inform DoD decision-making.

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Panel 9. The Operational and Developmental Dimensions of Cybersecurity

Wednesday, May 4, 2016	
3:30 p.m. – 5:00 p.m.	**Chair: Rear Admiral David H. Lewis, USN,** Commander, Space and Naval Warfare Systems Command ***The Cybersecurity Challenge in Acquisition*** Sonia Kaestner, Adjunct Professor, McDonough School of Business, Georgetown University Craig Arndt, Professor, Defense Acquisition University Robin Dillon-Merrill, Professor, Georgetown University ***Improving Security in Software Acquisition and Runtime Integration With Data Retention Specifications*** Daniel Smullen, Research Assistant, Carnegie Mellon University Travis Breaux, Assistant Professor, Carnegie Mellon University ***Cybersecurity Figure of Merit*** CAPT Brian Erickson, USN, SPAWAR

Rear Admiral David H. Lewis, USN—was born at Misawa Air Force Base, Japan, and commissioned in 1979 through the Navy ROTC Program at the University of Nebraska. As the SPAWAR Commander, he leads a global workforce of 9,700 civilian and military personnel who design, develop, and deploy advanced communications and information capabilities.

At sea, Lewis has served aboard USS *Spruance* (DD 963) as communications officer, where he earned his Surface Warfare qualification; USS *Biddle* (CG 34) as fire control officer and missile battery officer; and USS *Ticonderoga* (CG 47) as combat systems officer. His major command assignment was Aegis Shipbuilding Program manager in Program Executive Office Ships, where he led the delivery of seven DDG 51 class ships and procured another 10 ships.

Lewis's shore assignments include Assistant Chief of Staff for Maintenance and Engineering, Commander, Naval Surface Forces; the Navy Secretariat staff; Naval Sea Systems Command staff; Aegis Shipbuilding Program Office; Supervisor of Shipbuilding, Bath; and Readiness Support Group, San Diego.

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.

Lewis holds a Bachelor of Science degree in computer science from the University of Nebraska and a Master of Science degree in computer science from the Naval Postgraduate School. Lewis's personal awards include the Legion of Merit, Meritorious Service Medal, Navy and Marine Corps Commendation Medal, Navy and Marine Corps Achievement Medal, and various service and unit awards.

The Cybersecurity Challenge in Acquisition

Sonia Kaestner—is an Adjunct Professor at the McDonough School of Business at Georgetown University. She has recently conducted a Strategy and Portfolio Management research study for the Defense Acquisition University and developed the course material, exercises, and instructor support material for a new course offering at DAU on this topic. In addition, she has extensive consulting experience in the benchmarking and risk analysis of capital projects, quantitative and qualitative analysis, and training and development management.

Craig Arndt—is the Department Chair for Engineering and Technology and a Professor of Systems Engineering at the Defense Acquisition University. Dr. Arndt studies the development of new methods for the development of taxonomies of learning environments. This research effort is developing methods that will allow future educational designers to select and develop new learning environments based on the nature of the curriculum and the requirements and demographics of the student population. He holds a PhD in electrical engineering**.**

Robin L. Dillon-Merrill—is a Professor in the McDonough School of Business at Georgetown University. She seeks to understand and explain how and why people make the decisions that they do under conditions of uncertainty and risk. She is currently in year two of a multi-year funded research project with the Department of Homeland Security titled *Beyond Technical Solutions to Cybersecurity Risk Management and Risk Communication: Utilizing Tools and Research from Behavioral, Economic, and Policy Research.*

Abstract

To improve cybersecurity, the acquisition community must understand and manage multiple dimensions of cyber-attacks both as an opportunity and as a risk that can compromise the bottom line of the organizations they work for and with. In particular, the acquisition community must understand and recognize the cyber threats inherent in procuring complex modern systems with significant cyber components. If cybersecurity is not designated as a requirement of a modern system, it is often challenging to add effective security on later, and the severity of the cyber vulnerabilities may only be identified after a breach has already occurred. If appropriate cybersecurity is designed and built-in, these systems will have higher up-front costs but potentially lower life-cycle costs because of the reduced need to fix vulnerabilities in the systems later. Additionally, individuals working in acquisition need to recognize that given the sensitive nature of their work, including intellectual property and financial data, their IT processes, information, and systems will be an attractive target for cyber threats from both criminal sources (e.g., organized crime) and nation state adversaries, and the complexity and integration of the modern supply chain will add vulnerabilities to these linked supplier systems.

Introduction

Cyber Threat Challenges

The accelerated growth in cyber/digital technology development has changed the way we direct our lives, business, and countries. This same technology development has driven the rise in cybersecurity breaches through the increased complexity of IT systems, the increased use of personal and mobile devices, and the explosion of social media. In addition, as users, we have not had the same speed to grow the skills and capabilities required to safely absorb the technologies we now depend on. So far, there are no cybersecurity risk management readiness standards, and organizations' employees (at all levels) lack the cybersecurity training required to prevent and/or promote a cyber-attack. The lack of leadership's understanding of potential vulnerabilities and liabilities leads organizations to address these risks mainly from a technical perspective, and hence, rely mainly on IT professionals to solve the problem. This common approach ignores the vulnerabilities that an untrained workforce represents.

According to the UK Information Commissioner's Office, 93% of cybersecurity incidents are caused by human error (errors even when designing cybersecurity processes and systems); thus this workforce (untrained and sometimes even trained) is the weakest link in the cybersecurity chain. The remaining 7% was due to technical failures.

The consequences of cyber-attacks are diverse and include the suspension of system operations, the loss of current and future revenue, the loss of intellectual property, reputation harm, decreased customer confidence, leaks of sensitive information, and legal liability, among others. These consequences are often exacerbated because attacks are not always detected immediately. Verizon (2013) estimates that 62% of data breaches were not detected for at least several months if not longer.

The Identity Theft Resource Center (ITRC; 2016) found that in 2015, the Health/Medical, Banking/Credit/Financial, Government/Military and the Education sectors were the most affected by cybercrime, but these data may be underestimating the scale of the cybercrime, as often firms (predominantly small- and medium-size business) do not disclose cyber-attacks to attempt to avoid the financial costs, liability, and loss of goodwill that come with disclosure and notification (Supply Chain Quarterly, 2015).

Some progress is being made in increasing the recognition of cybersecurity problems. As of 2015, a survey conducted by PricewaterhouseCoopers (PwC) described that over two-thirds of organizations were more concerned about cyber threats (PwC, 2015) than in previous years' studies. Also, the U.S. Department of Homeland Security (DHS) has included cybersecurity as a top priority for 2016, and $587.5 million have been allocated to fund programs to enhance cybersecurity situational awareness and information sharing (National Cybersecurity Protection System and Continuous Diagnostics and Mitigation; DHS, 2016). Despite all the media coverage, government guidance, and the increasing awareness, cybersecurity risk management continues to not been widely implemented or standardized among all target levels: Individuals, Organizations and Critical Infrastructure. This paper will begin to address some of the training and education needed to improve cybersecurity risk management, particularly in acquisition.

Target Levels: Individuals

As shown in Figure 1, individuals face the risk of losing data and privacy, having their devices hacked for a ransom (denial of service—DoS), or simply damaged. In the first week of March 2016, Mac users were targeted by hackers with "ransomware" in what is believed to be the first complete attack campaign of its kind against users of Apple's operating system. Also, several incidents have been reported where internet-enabled baby monitors have been hacked to disturb infants. This last example depicts the increasing risks associated with the Internet of Things (IoT), the expanding network of billions of everyday objects/devices with network connectivity and data-sharing capabilities that are part of our daily lives. This inappropriate use of these everyday devices was certainly not considered when they were designed. How individuals use pieces of an acquired system and where individual personal devices plug into an acquired system will be a challenge for the acquisition professional to understand and consider.

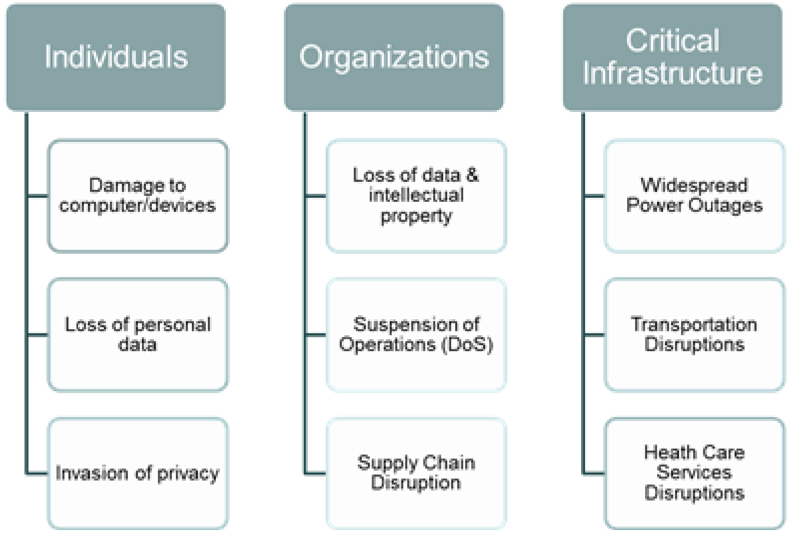

Figure 1. Target Levels for Cyber-Attacks

Target Levels: Organizations

Organizations face the same risks as individuals, but to a larger and more complex extent, as they own customer and proprietary data that represent the core of their business. In addition, they also face legal liability from their customers, reputation damage, and higher exposure to the IoT through their employers, suppliers, and customers. In a recent example (February 2016), the Hollywood Presbyterian Medical Center was victim of a DoS attack that locked employees out of their systems by encrypting files for which only the hackers had the decryption key. The communications between physicians and medical staff were paralyzed, and they suddenly had to rely on paper records to keep operations running. The hospital chose to pay hackers a ransom of $17,000 in bitcoins to regain control of their computer systems after the cyber-attack. The origin of the computer network intrusion remains unknown at this time. The ever increasing sophistication of the cyber-attacks makes the job of the acquisition workforce ever more challenging. Following the Hollywood Presbyterian Medical Center "ransomware" attack, this is now a new concern for those responsible for the acquisition of medical record systems. Since the cyber threats keep changing and evolving, how is a manager trained in acquisition supposed to keep track?

Target Levels: Critical Infrastructure

Critical Infrastructure organizations face all previously mentioned risks, but with bigger consequences, such as the suspension/restriction of normal operations of whole communities. The Ukrainian power grid cyber-attack in 2015, for example, caused a blackout for hundreds of thousands of people in Ukraine. The attack used destructive malware that wrecked computers and wiped out sensitive control systems for parts of the Ukrainian power grid. A team of hackers coordinated attacks at the same time against six power providers. The attack was so severe that it knocked out internal systems intended to help the power companies restore power. Computers were destroyed, and even the call centers used to report outages were knocked out. The source of the attack is still under investigation (but many suspect it originated in Russia). Since the risks associated with critical infrastructure are so great, it is imperative for acquisition specialists in these environments to understand the relevant and evolving threats to their computer systems.

External Attackers Versus Insiders in the Supply Chain

Most frequently, cybersecurity is perceived as a risk from the outside (i.e., hackers/criminals) getting illicit access to the organization's data/assets with ill purposes. However, organizations are not adequately addressing the internal type of cyber risk that includes employees and third-parties which have access to critical assets. Among organizations with cybersecurity risk mitigation plans, 48% have not considered third-party vendors, 43% have not examined the role of contractors, 58% have not examined the role of suppliers, and 92% have not assessed the supply chain risk management as a whole (PwC, 2014, 2015).

External types of cyber-attacks against prominent organizations such as JPMorgan Chase and the U.S. Central Command get plenty of attention. Cyber-attacks involving internal resources (i.e., business partners and direct employees) do not get the same coverage despite the fact that they pose more malicious threats. Internal resources have much easier access to systems and a much greater window of opportunity.

The Target and Home Depot attacks provide good examples where third-party contractors unintentionally facilitated the breach. The Target breach was traced back to stolen network credentials from a third party vendor (a refrigeration, heating and air conditioning subcontractor). Home Depot reported that criminals used a third-party vendor's user name and password to enter the perimeter of their network and then acquired elevated rights that allowed them to navigate portions of Home Depot's network and to deploy unique, custom-built malware on its self-checkout systems in the United States and Canada.

Additionally, at a general level, ill-trained direct employees also pose significant insider cybersecurity risks. Their inability to identify cyber threats leads them to unintentionally click on phishing email links, download malware, access sensitive data from mobile or personal devices, etc. At a more specific level, professionals who are in charge of designing and acquiring products and systems do not have the cybersecurity knowledge to identify potential risks in the programs they are designing, managing, or acquiring. Cyber risks are then left in systems during the requirements, design, and contracting of the systems development, too often only to be discovered later during operations after an attack.

It is widely known that there is a significant shortage of cybersecurity professionals. On average it takes three months to hire a cybersecurity professional, as only 25% of the applicants meet the requirements for the position, but over 70% of these finally hired professionals lack the ability to understand the organization's business (CSX, 2015). There are plenty of efforts made and resources allocated to close the cybersecurity talent gap. However, the focus of these concerns is related to cyber professionals with a technical background to create the protection walls around the organization's assets, and to create the systems to detect and respond to threats. This type of professional is in low supply because organizations (of all sizes) decided in the early 2000s to send "low-level" IT work, such as network and systems administrators, offshore to reduce costs. These same organizations missed the opportunity to grow and groom those professionals that they need now. The solution for this type of shortage is going to require the collaboration of universities (to create cyber-specific careers or add cybersecurity training to complement other fields), marketing campaigns (increase the awareness of a cyber career as an attractive option), private and government incentives (e.g., scholarships), and so forth.

The other, and mostly ignored, cybersecurity talent gap is related to the employees at the different levels of the organization. This is a more specific talent gap that requires a customized type of training that accounts for the roles each employee plays and the type of data he/she has. Certain functions need to have an extensive cybersecurity knowledge comparable to the IT professional to complement their non-IT role. For example, engineers who are designing the next product need to have extensive cybersecurity knowledge to close potential cybersecurity gaps in their designs to prevent a future cyber breach.

The Car Manufacturing Case

As can be seen in most areas of technology, computers have become common components, and this is especially true in the cars we drive. The use of computers embedded into systems does not in itself create cybersecurity vulnerabilities. However, adding computer-based capabilities to existing systems creates the opportunities for a wide range of cyber risks and threats.

The hackers are publicizing their work to reveal vulnerabilities present in a growing number of car computers. All cars and trucks contain anywhere from 20 to 70 computers. They control everything from the brakes to acceleration to the windows and are connected to an internal network. A few hackers have recently managed to find their way into these intricate networks.

In one case, a pair of hackers manipulated two cars by plugging a laptop into a port beneath the dashboard where mechanics connect their computers to search for problems. Scarier yet, another group took control of a car's computers through a cellular telephone and Bluetooth connections and could access systems including, for example, the tire pressure monitoring system.

"The more technology they add to the vehicle, the more opportunities there are for that to be abused for nefarious purposes," says Rich Mogull, CEO of Phoenix-based Securosis, a security research firm. "Anything with a computer chip in it is vulnerable, history keeps showing us."

Two years ago, researchers at the University of Washington and University of California, San Diego did more extensive work, hacking their way into a 2009 midsize car through its cellular, Bluetooth, and other wireless connections. Stefan Savage, a UCSD computer science professor, said he and other researchers could control nearly everything but the car's steering. "We could have turned the brakes off. We could have killed the engine. We could have engaged the brakes," he said. Savage wouldn't identify which manufacturer made the car they hacked into. But two people with knowledge of the work said the car was from General Motors and the researchers compromised the OnStar safety system, best known for using cellular technology to check on customers and call for help in a crash. The people didn't want to be identified because they were not authorized to speak publicly on the matter ("Hackers Find Weaknesses," 2013).

When we look at the underlying causes of the current generation of hacking attacks on the auto industry, we look at the basics of the mechanisms of cybersecurity. First is the threat; given the current state of interest in the hacker community and the ubiquitous nature of cars in the United States there will be a continuing and rapidly evolving level of threat against cars now that there is an understanding that accessing their networks is possible.

Next are the vulnerabilities. There are a number of different vulnerabilities that could be exploited in any of the new car designs as has been noted above. As we look for lessons learned to build better systems we look at where and when the vulnerabilities are introduced. The different vulnerabilities fall into three principle categories: design vulnerabilities, interface vulnerabilities, and supply chain vulnerabilities. In our case, all of their vulnerabilities were introduced by the people in the car companies who designed the car and did not anticipate how cyber threats could work because that was not their job to understand the technical details of cyber intrusion.

Acquisition professionals need to have the technical and cybersecurity skills to identify potential gaps in the products and systems they are acquiring. This type of cybersecurity talent gap needs to be addressed through the implantations of training programs customized to close the specific talent gaps in critical functions of the organization.

Cybersecurity does not always have the strategic priority it should. According to a Ponemon Institute (2015) study, as of 2015, only 34% of companies consider cybersecurity to be a strategic priority, and thus, it is unlikely that enough resources are allocated to support something that is not seen as a priority. Acquisition organizations have to assess their acquisition strategies to include cyber security and need to focus mitigation efforts to include all parties involved in the organization's supply chain.

Acquiring Cyber Secure Systems

Understanding and recognizing the cyber threats inherent in procuring complex modern systems with significant cyber components is a challenge. For example, as was mentioned in the car manufacturing example, in 2011, the vulnerability of telematic systems like GM's OnStar was demonstrated to not require hacking but just identification of each equipped car's OnStar telephone number. That flaw was later fixed, but highlights the challenges of understanding the vulnerabilities of new, complex modern networked systems. As described by Greenberg (2015), from the time the problem was first identified until it was fixed was more than five years. Greenberg (2015) goes on to explain, "Automakers five years ago simply weren't equipped to fix hackable bugs in their vehicles' software … and many of those companies may not be much better prepared today."

Training the acquisition workforce to understand the complex cyber challenges of their systems at the right level of detail is the only viable solution to this problem in the long run.

Securing Supply Chains

Technology development has significantly changed the way organization conduct their business:

> The flexibility, scalability, and efficiency of the technology that enables information sharing among partners, has created additional points of access to an organization's proprietary information, increasing the risks that the corporate knowledge that drives profitability may fall into the wrong hands. (Supply Chain Quarterly, 2015)

Any vendor with company credential access can expose the internal network to an attack.

As shown in Figure 2, the acquisition challenge is based on the complexity of the supply chain that most organizations have, which in many cases includes both upstream (i.e., suppliers) and downstream (i.e., market) components and the global environment. More and more, organizations are required to share information with suppliers, contractors, third-party vendors (and their vendors—fourth-party partners), that do not have the same approach to cybersecurity. Cybersecurity vulnerabilities in their supply chains will in turn introduce new vulnerabilities in the organization and must be managed by those acquisition specialists focused most on the supply chain relationships.

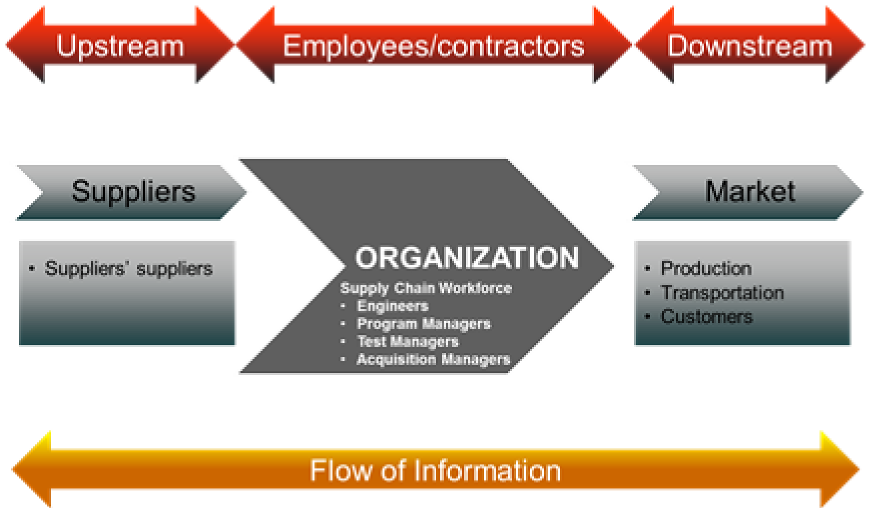

Figure 2. Supply Chain Complexity

In addition, the supply chain not only is the mechanism that develops and delivers products and services from source to customer, but also represents critical parts of the value chain system (inbound logistics, operations, and outbound logistics) in which interdependence is the fundamental tenet behind gaining a competitive advantage (Porter, 1985). Organizations share proprietary data across their value chain (e.g., marketing, dales, pricing, metrics, point-of-sale information, inventory flows, enterprise system activities, etc.), increasing the number of potential cyber breach entry points.

From an organization's strategic point of view, consolidating the supply chain is critical to reduce costs and develop integrated profit centers. The efficiency of the global supply chain is highly dependent on the speed data is transferred among supply change partners. How to do this without introducing more cybersecurity risks is the challenge organizations have now to address.

Vertically integrated organization (upstream and downstream operations) will carry a higher risk profile than a horizontally integrated organization. For example, in the Volkswagen (VW) emissions case, the organization (OEM[1]) was able to install deceiving software to cheat on the emissions testing for its diesel cars. The cars' computers were able to alter how their engines worked to reduce emissions (to meet required levels of pollutants) while they were being tested. Customers became aware of this practice (when the cars have left the supply chain) after six years of "successful" implementations of the software. Although in this case, VW was fully responsible for the implementation of this software. Using the same approach, cyber criminals could use the same strategy to benefit from the potential damage to an organization.

Many breaches seen so far have been because of a lack of standardized credentialing processes and a lack of technology updates and patches. As organizations share their information with their business partners (through the internet, mobile devices,

[1] Original Equipment Manufacturer

cloud computing, etc.), their cybersecurity vulnerability increases, opening new doors for hackers (*Wall Street Journal* [WSJ], 2014).

Third- and fourth-party supplier's technology use also represents a challenge as organizations do not have control over the type of technology and technology upgrades those parties rely on. In 2015, over 40% of large and medium size organizations in the United States and UK were still using Windows XP, which is no longer supported by Microsoft, and, hence, no up-to-date security upgrades are available (Prince, 2015). According to Microsoft, Windows XP users are five times more vulnerable to security risks and viruses than organizations using up-to-date operating systems. Based on these statistics, most likely many suppliers are still using Windows XP.

The most frequent supply chain attacks are related to malware,[2] compromised credentials,[3] distributed denial of services (DDoS),[4] and SQL injections.[5] Supply chain partner relations bring an additional cybersecurity potential entry point (Supply Chain Quarterly, 2015):

- Vendor relationships and global information transmission
- Open access to data rather than "need to know" access
- Frequent changes in suppliers and products
- Lack of standardization of security protocols across vendors and other partners
- Infected devices on a corporate network
- Obsolete security infrastructure or outdated hardware/software

The vulnerabilities of these multiple entry points need to be recognized, monitored, and addressed by the acquisition specialists.

Responsibility and Accountability

Historically, IT managers were responsible and accountable for any issues related to the cyber world which was viewed as a technology-centered issue. Almost half of most organization leadership still views cybersecurity risk as an IT matter, rather than an organization-wide risk. Many organizations (46%; PWC, 2014) do not have a leadership role such as a Chief Information Security Officer (CISO) or a Chief Information Officer (CIO) to centralize all cyber related issues.

Supply chain cyber risk cannot be outsourced and can only be address with a holistic and collaborative risk mitigation plan that includes effective collaboration of a multidisciplinary team that includes not only IT professionals but also supply chain, finance, and HR professionals and, foremost, the support of the senior leadership (PWC, 2015).

[2] Malicious software that is imbedded on computers, devices, or networks, damaging files (e.g., spyware, worms, viruses, and Trojan horses)
[3] Unauthorized use of usernames and passwords to access a company's network
[4] Disruption systems or networks to prevent the normal operations of the organization
[5] Insertion of malicious code into Structured Query Language (SQL) to illegally access proprietary data, bypassing firewalls and other security measures

Creating effective cybersecurity operations requires significant in-house resources, but at the end of the day, it is the only way to protect the organization’s data (CFO, 2015).

The cybersecurity approach is now also expanding the technology-centered view to include people and processes.

IT leadership is required to manage all technical aspects required to address cybersecurity risks (both hardware and software). They also play a key role creating systems and processes to mitigate the risks and communicating cyber threats to the organization’s highest leadership groups.

Supply chain managers need to understand how the cybersecurity risk management process of their suppliers could expose/affect their own organization. They also need to understand the type of threats the organization faces, the assets that are under risk, and how the IT department is handling these risks.

Finance leadership support is required not only to support the cybersecurity program among the organization, but also to identify threats and quantify the financial impact of cyber risk (CFO, 2015).

The Human Resources (HR) managers also play a key role to prevent the hiring and contracting of employees who pose high risk (intentional or not) to the organization. Research has shown that people who are willing to conduct or assist in cyber-attacks suffer from one or more identifiable conditions (Machiavelism, narcissism, and psychopathy) and have a combination of these personality traits: immaturity, low self-esteem, amorality and lack of ethics, superficiality, lack of conscientiousness, manipulativeness, and instability. HR managers can look out for threats when hiring and contracting.

The other role that HR plays in cybersecurity is in the recruiting and retention of highly skilled cybersecurity experts. This is a prevalent challenge for organizations of all sizes. Either because cybersecurity employees choose to create their own security firm or they move to a more attractive job position, the current shortage is affecting the way organizations deal with the cyber risk.

Given that cybersecurity breaches carry a series of financial, operational, reputational, and legal damages, senior leadership involvement becomes more critical to support the development and implementation of a sound cybersecurity risk mitigation program. At the end of the day, the magnitude of the consequences will make them accountable for the approach the organization has taken to address cyber risks.

Cost & Benefits of Cybersecurity

As serious as the cybersecurity risk is, it does not receive the attention and priority it requires among organizations across industries. Most cybersecurity budgets are inadequate to address the organization’s risk until a breach becomes a reality. A sound cybersecurity cost benefit analysis is usually done post mortem (after an attack) and then generally by a third-party, such as the media. The Heartland Payment Systems Inc. attack in 2015 (more than 100 million credit and debit card numbers were stolen) is a good example of this analysis. The company had to pay $150 million in fines and legal costs and suffered damage to its reputation as a payment processor. To address future liabilities, the company quadrupled its security budget, reduced the number of computer systems that process credit and debit card data, and added more encryption and system-monitoring tools.

The WSJ (2014) describes an interesting metric tracked by Gartner Inc. which states that for every $5.62 a business spent after a breach, an organization could spend $1 before an attack on encryption and network protection to prevent intrusions and minimize damages.

As obvious as this might look, not all organizations appear to justify the investment, as they assume the investment cost will be higher than the cost related to the breach. There might be different reasons behind this negligence, and we discuss four: the accounting perspective, the human nature perspective, the financial perspective, and the political perspective.

Accounting Perspective

Since cybersecurity investments do not generate revenue, it is usually treated as an expense of doing business and not part of the net profit of the organization. Hence, the potential impact is not proactively and consistently quantified (much less the assessment of the intangible consequences of a cyber-attack, such as the credibility, reputation, legal expenses, etc.). But even so, a more reasoned approach, as Dew Smith (Supply Chain Quarterly, 2015) suggested, would be to revise the accounting method used to include IT and cybersecurity spending into the cost methodology of supply chain management (absorption costing[6]). This method would consider cybersecurity spending as part of the total direct cost (including overhead cost associated with logistics, sales/marketing, and manufacturing).

Human Nature Perspective

Behavioral and brain science research shows that the human moral judgement system drives the urgent need for actions when it deems the issue at task a moral imperative (the principle originating inside a person's mind that compels that person to act). Reasons that cyber risk is not currently registering as a moral imperative could be (1) that cyber risk is communicated as an abstract and complex potential event (no immediate threat with a specific shape), and hence it does not generate a rapid emotional intuitive reaction; (2) that it is not perceived as an intentional moral transgression on the part of employees, and therefore is judged less severely than if it were an intentional act; and (3) it is deemed to be an uncertain event (may or may not happen) too far away in the future which promotes unrealistic optimisms (it will not happen to us), and this optimism prevents people from identifying themselves as a target. Changing the way in which organizations communicate cybersecurity risk can change the way we perceive its urgency to act.

Financial Perspective

Driven by a financial statement/budget compliance focus, some may argue that for some organizations (especially large ones), the losses involved are so small compared to their revenue that it is easier to take a chance and write off any losses should they occur. For example, Target's data breach had a $252 million cost during 2013 and 2014. After insurance coverage and tax deductions, Target ended up paying $105 million, which is about 0.1% of its 2014 revenue. Similarly, Home Depot paid $28 million, after the $15 million insurance payment, which represents 0.01% of the company's revenue the same year (CBS News, 2015). This approach not only does not assess the full consequences of a data breach (e.g., competitive advantage, brand equity, customer loyalty, reputation, etc.), but also ignores the ethical component. The responsibility to protect customers' data, inform them of the breach, and gain back their trust still lies with the organization, and it is not reflected in the financial statements.

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[6] All of the manufacturing costs are absorbed by the units produced.

Since 2011, the SEC[7] has urged organizations to provide details about the operational and financial risk posed by cyber-attacks in the risk section of their filings and discuss with the investors (in the Management's Discussion and Analysis section) any effects of cyber-attacks on operating results, liquidity, or financial position. So far, investors have not been satisfied with the information provided and feel the disclosures were presented "merely for legal prophylaxis, instead of for informing investors" (Fortune, 2015).

Political Perspective

In 2014, the Obama administration issued new cybersecurity guidelines urging companies in critical infrastructure industries to increase their efforts to protect and monitor their networks and train employees. Some organizations took the guidelines as non-commercial because cybersecurity measures must be cost-effective for an individual company or be supported by some economic incentives. Some suggested that if the government wants to improve cyber-defense, the government should subsidize the cost (e.g., tax breaks). To complicate this matter, many regulators consider this problem more of a corporate responsibility that national security (CFO, 2105).

Organizations perform cost-benefit analysis for expenses. The cybersecurity cost (i.e., budget allocation) then represents a careful balancing act where it is critical to identify the right amount of security given the risks the organization is exposed to.

Trends

Cybersecurity Approach

Cybersecurity risk management has been focused on preventing cybercrime through the use of internal controls, employee training, and firewalls, among others. Acknowledging that it is impossible to protect a network against 100% of the attacks, it is key to include a plan to address the possible breaches to minimize the damage. According to Heather Crofford, CFO of Shared Services at Northrop Grumman, "detections, response and recovery are where the increasing investment needs to be" (CFO, 2015).

Supply Chain Analytics (Souza, 2014), Cyber Risk Modeling (CFO, 2015), & Big Data (PwC, 2016)

Supply chain analytics currently focuses on the use of information and analytical tools to make better decisions regarding the material flows in the supply chain. Some of these same concepts and tools can also be used for cybersecurity purposes (including the supply chain cyber risk). The availability of Big Data and the use of descriptive and predictive analytics could prove useful as tools to fight cybersecurity threats.

Descriptive analytics[8] tools can be quite useful to provide a clear view of the current situation of the suppliers. Supply chain mapping is an example where an organization can map all their suppliers (and their suppliers) and plot them using different criteria such as the importance in the organization's supply chain, level of cybersecurity maturity, etc. Figure 3 illustrates how the French Nuclear Power Supply Chain is mapped using one of the currently available tools (Sourcemap, n.d.).

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[7] Security and Exchange Commission
[8] Uses existing information to evaluate what is happening

Figure 3. Example of Supply Chain Mapping Using Sourcemap.com

Predictive analytics can use past data to forecast future cyber risks, including those coming from the supply chain. Data source and quality are important components to use these tools (e.g., linear and non-linear regression and data mining).

Despite the limited detail data availability (both the causes of the breach and balance sheet impact), some insurance-related organizations are already focusing their efforts on using data analytics in cyber risk modeling to help assess their clients' cyber risk. In theory, the frequency of cyber-attacks is rapidly increasing the amount of data to be analyzed. However, the number of organizations who are cyber-attack victims who are willing to share these types of data is pretty small, and hence current models are based only on publicly available data from various insurance sources.

Furthermore, in 2015, almost 60% of private and government organizations used Big Data analytics to model and monitor cybersecurity threats, respond to incidents and audit and review data to understand how it is used, by whom, and when. As more data become available, this trend is expected to significantly increase in the next few years.

Cloud Enabled Cybersecurity, Advanced Authentication (PwC, 2016)

Cloud service providers have invested significant amounts in advanced technologies for data protection, privacy, network security, and identity and access management. The most frequently used cloud-based cybersecurity services include real-time monitoring and analytics, advanced authentication, identity and access management, threat intelligence, and end-point protection.

Simple password use is no longer an adequate way to access data. All industries are quickly migrating to the use of advanced authentication to help manage access and improve trust among customers and business partners. Combinations of one-time passwords and hardware tokens, biometrics, security keys, and special applications are the most common advanced authentication methods used.

Cybersecurity Risk Management Practices

Risk-Based Cybersecurity Frameworks

Most private and government organizations use a standard framework, or a combination of multiple frameworks, currently available to develop an effective cybersecurity program. The most frequently used are the National Institute of Standards and Technology (NIST) framework and ISO 27001 (Information security management). In addition, there are other, more acquisition specific frameworks, such as the Centre for the Protection of National Infrastructure (CPNI) Framework (methodology) which helps develop supply chain specific security risk mitigation implementation plans, ISO 2800-2700 (Specification for security management systems for the supply chain), and the Supplier Assurance Framework (UK Cabinet Office, 2015).

The **NIST** Framework was developed after President Obama's executive order on "Improving Critical Infrastructure Cybersecurity" and is quickly becoming a standard among industries in the United States. The Framework consolidates existing global standards and practices to help organizations understand, communicate, and manage their cyber risks (White House, 2014). The Framework offers a road map to develop a cybersecurity program for organizations with no security experience. For organizations with a more mature cybersecurity, the Framework helps them improve the communication with the organization's leadership and suppliers about cyber risk management. The Framework has three components: Core, Tiers, and Profile.

The Framework core is a set of cybersecurity activities, desired outcomes, and applicable references that are common across critical infrastructure sectors. The Framework has four implementation Tiers (Partial, Risked Informed, Repeatable, and Adaptive) to reflect how the organization views cybersecurity risk and assess the processes in place to manage that risk. The Framework profile represents the outcomes based on business needs that an organization has selected from the Framework categories and subcategories.

ISO 27001 was developed to "provide a model for establishing, implementing, operating, monitoring, reviewing, maintaining and improving an information security management system." It uses a top-down, risk-based approach and is technology-neutral. Also, it provides requirements to develop an information security management system to managing sensitive company information so that it remains secure. It includes people, processes, and IT systems by applying a risk management process. It can help small, medium, and large businesses in any sector keep information assets secure.

The whole ISO 27000 family aims to help organizations keep information assets (e.g., financial information, intellectual property, employee details or information entrusted to you by third parties) secured.

The **CPNI** proposes that supply chain security risk be an extension of existing risk management processes. The extensions should include:

- Comprehensive maps of all tiers of the upstream and downstream supply chains to the level of individual contracts
- Risk scoring each contractor to link in to the organization's existing security risk assessment
- Due diligence/accreditation/assurance of suppliers (and potential suppliers) and the adoption, through contracts, of proportionate and appropriate measures to mitigate risk
- Audit arrangements and compliance monitoring
- Contract exit arrangement

ISO 2800-2007 (Specification for security management systems for the supply chain) offers a framework for providing effective physical security management through a system that identifies security threats, assesses risk, establishes objectives for implementing controls, and continuously improves the physical security of the organization. It identifies requirements for implementing and operating a security management system, including organizational (security) structure, authorized personnel responsible for security management, assessing and maintaining competence of personnel, and training for personnel responsible for security.

The **Supplier Assurance Framework** (UK Cabinet Office, 2015) applies to official contracts and enables the early identification of high risk projects; it provides a framework for the risk management of contracts that is consistent, effective, and understood by government, stakeholders, and suppliers and enables information sharing and accountability. It is flexible enough to allow its customization to meet specific business needs. It is particularly relevant where information is shared through contracts or agreements.

To different extents, all these frameworks address training needs. Note, however, that none of them do so specifically for the acquisition community and much less to the detail it is required.

High-Reliability Organizations (HROs)—An Alternative Approach to Cybersecurity

As previously discussed, cyber-attacks are mostly driven by network administrators and users' errors rather than by inadequate security technology. Organizations can implement key concepts of HROs (Weick & Sutcliffe, 2015) to address the human error component of cybersecurity risks as the U.S. military has successfully done. The basic principle is to treat the unknown as knowable by following some key principles:

- Mindful organizing (organizing is about coordination)
- Preoccupation with failure
- Reluctance to simplify
- Sensitive to operations
- Commitment to resilience
- Deference to expertise

The U.S. Navy's nuclear-propulsion program is arguably the HRO with the longest track record. There are six principles that helped the Navy contain the impact of human error: (1) integrity, (2) depth of knowledge, (3) procedural compliance, (4) forceful backups, (5) a question of attitude, and (6) formality in communication.

Building an HRO requires the personal attention of senior leadership as well as a substantial financial investment in training and oversight. This is approach has proven to be effective at the whole organization level and can certainly be extended to include the acquisition group of the organization.

Recommendations

Considering that each organization has a different cybersecurity maturity level, the following recommendations are directed to the risks on the acquisition process, and hence, assume there is already a risk analysis based cybersecurity risk management program in place.

Purely technical solutions will not address the magnitude of the risk. Even the best technology will not work well with poorly trained operators. Processes and people need to be part of the solution in order to deliver a comprehensive cybersecurity approach customized to address the cyber risks associated to the supply chain.

To improve cybersecurity, the acquisition community must understand

- and manage the multiple dimensions of cyber-attacks (opportunities and risks) that can compromise the bottom-line of the organizations they work for and with.
- and recognize the cyber threats inherent in procuring complex, modern systems with significant cyber components and the challenges of understanding the vulnerabilities of new, complex modern networked systems.
- that purchasing products and services that have the appropriate cybersecurity designed and built-in may have higher up-front costs but lower life-cycle costs because of the reduced need to fix vulnerabilities in the systems later.
- that given the sensitive nature of their work, including intellectual property and financial data, their IT processes, information, and systems will be an attractive target for cyber threats from both criminal sources and nation state adversaries.

Risk Assessment

Risk management experts agree that the first step to take is to assess the financial risk of a security breach. This requires a detailed inventory of the organization's assets at risk that will be used to assess the financial risk. However, the training of the professionals who will be assessing the cyber risks should be a step even before this, as the validity of the cyber risk assessment will be as good as the cyber risk skill and knowledge the employees who perform the analysis have.

Subsequently, organizations need a detailed accounting of all firms (partners, affiliates, network participants, etc.) that are part of the supply chain (both upstream and downstream) to identify the weakest link then, assess the degree of reliance of each of those organizations (size and scope).

Finally, survey and audit all third-party partners' (i.e., fourth-party contractors) cybersecurity process/programs and capabilities to identify the level of risk each of them carry. All this information will allow the organization to create a vendor compliance protocol and strategic outsourcing guidelines to ensure a standard level of cybersecurity across the supply chain.

New vendor compliance can be achieved through the consistent implementation of cybersecurity incentives/requirements. This can include but is not limited to the requirement of cybersecurity protocols, conditions, and capabilities to be aligned with the organization's cybersecurity risk mitigation process as part of the contract approval criteria.

The case is slightly different with existing vendors, as contracts have already been awarded. In this case, a contract amendment (allowed within the law) to include the new cybersecurity requirements is the easiest way. In the event this is not feasible, the procurement and IT groups should create a process to mitigate the risks those existing vendors bring to the organization.

The greater the complexity of the supply chain, the more extensive the risk management efforts should be. Therefore, organizations with a complex supply chain should include multiple layers of security (e.g., redundant backup systems, multiple-stage access thresholds for credentials, ongoing threat monitoring, etc.).

Insurance Use for Commercially Developed Systems

To reduce the financial impact of a breach, organizations are including cyber liability insurances in their organizations' plans. Cyber insurance organizations provide *partial protection* against internet-based risks relating to information technology infrastructure and information assets. Typical first-party coverage includes forensic investigation, legal advice, notification costs of communicating the breach, credit monitoring, PR expenses, loss of profits and extra expenses during the time your network is down. Common third-party coverage includes legal defense, settlements, damages and judgements related to the breach, liability to banks for re-issuing credit cards, cost of responding to regulatory inquires, and regulatory fines and penalties (WS&Co, 2014).

The use of cyber insurance is meaningful for large organizations with auditable cybersecurity programs. However, some small- or medium-size organizations might get a false sense of security from cyber insurance and fail to implement a sound cybersecurity program (Market Watch, 2015).

From an acquisition perspective, suppliers who have cyber insurance might indicate a higher level of cyber maturity as insurance companies perform extensive cyber audits before securing a policy.

Implementation of KPIs to Monitor Progress

Having a cybersecurity program that includes supplier risk is not enough to conclude the threats are under control. The performance of this program needs to be continuously monitored to address the dynamic nature of the risks. The use of Key Performance Indicators (KPIs) has been proven as an effective way to communicate challenges and opportunities. The cyber world includes technological, process/procedural, and people KPIs that can be implemented to assess the effectiveness of the current cybersecurity program (Dowdy, Hubback, & Solyom, 2014). KPIs can also be used to assess the level of risk each supplier brings to the organization.

Technological KPIs focus on the number and type of electronic touchpoints and highlight the quality of management of these connections. An example of such a KPI is the number of days that elapse between Microsoft issuing a critical software update and the entire organization installing it. Process/procedural KPIs can include data-policy and operational policy indicators to assess, for example, if the percent of sensitive data encryption meets the current policies, or if the number of attempted security-policy breaches within a certain period meets industry standards. People KPIs (including business partners' employees) measure the success rate of training, employee conformity to security guidelines, or employee knowledge and use of best-practice e-mail behavior. They may be assessed through spot tests.

It is certainly a good practice to include cybersecurity metrics into the organizations KPIs, balance scorecard and/or executive dashboard. Given the current technology focus of cybersecurity, it will require the effective training of both cybersecurity professionals and employees to identify (and implement) a set of meaningful KPIs that will bridge technology issues with business context to better respond to the needs of the organization.

The Future

As of 2015, only 34% of U.S. organizations (30% UK/Europe and 28% Middle East/North Africa) were prepared to deal with cybersecurity risks resulting from the IoT (Ponemon Institute, 2015). Current predictions assess the number of devices connected to the internet will reach 30 billion by 2020 (IDC, 2015). From 2014 to 2015, the number of incidents related to the IoT has increased by over 150%. Most of the IoT attacks were related to mobile devices, embedded systems, consumer technologies and operational systems (PwC, 2016). The obvious consequence of the IoT is that the cyber risk penetration area will increase in size and complexity. Organizations need to consider a strategy to deal with risks created by the internet of things.

Early in 2015, President Obama signed the "Promoting Private Sector Cybersecurity Information Sharing" executive order to enable private and government organizations to share industry specific information and intelligence related to geographies, issues, events, or specific threats through the creation of new Information Sharing and Analysis Organizations (ISAOs). The goal of these ISAOs is to address cyber threats to public health and safety, national security, and economic security of the United States by sharing information related to cybersecurity risks and incidents from private companies, nonprofit organizations, executive departments and agencies (agencies), and other entities. Organizations need to join ISAOs or similar organizations to share and receive cyber intelligence.

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Improving Security in Software Acquisition and Runtime Integration With Data Retention Specifications

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Travis Breaux—is an Assistant Professor of Computer Science in the Institute for Software Research at Carnegie Mellon University (CMU). His research program searches for new methods and tools for developing correct software specifications and ensuring that software systems conform to those specifications in a transparent, reliable, and trustworthy manner. This includes compliance with privacy and security regulations, standards, and policies. Dr. Breaux is the Director of the CMU Requirements Engineering Lab and co-founder of the Requirements Engineering and Law Workshop, and he has several publications in ACM- and IEEE-sponsored journals and conference proceedings. [breaux@cs.cmu.edu]

Abstract

The Department of Defense (DoD) Risk Management Framework (RMF) for IT systems is aligned with the National Institute for Standards and Technology (NIST) guidance for federal IT architectures, including emergent mobile and cloud-based platforms. This guidance serves as a prescriptive lifecycle for IT engineers to recognize, understand, and mitigate security risks. However, integrators are left with the challenge—during acquisition and during runtime integration with external services—to reason about the actions on data inherent in their system designs that may have confidentiality risks. These risks may lead to data spills, loss of confidentiality for mission data, and/or revelations about private data related to service members and their families. Solutions are needed to assist acquisition professionals to align system data practices with the RMF and NIST guidance, as well as DoD IA directives—particularly with respect to the collection, usage, transfer, and retention of data. To provide support to this end, we extended our initial automation framework to support reasoning over data retention actions using a formal language. We propose an evaluation method for these extensions, carried out through simulations of real-world IT systems using imitation but statistically accurate synthetic data. Our language aims to address dynamically composable, multi-party systems that preserve security properties and address incipient data privacy concerns. Software developers and certification authorities can use these profiles expressed in first-order logic with an inference engine to advance the RMF, express data retention actions that promote confidentiality, and re-evaluate risk mitigation and compliance as IT systems evolve over time.

Cybersecurity Figure of Merit

CAPT Brian Erickson, USN—SPAWAR

Executive Summary

Over time, Navy warfighters have grown accustomed to the promise of reliable information technology, based on the experience of more than 30 years of relative peace in this domain. However, inspections, Red Teams, and actual adversaries have shown that this reliance on interconnected technology is not well-founded. In 2012, the Defense Science Board determined that

> nearly every conceivable component within DoD is networked. These networked systems and components are inextricably linked to the Department's ability to project military force and the associated mission assurance. Yet, DoD's networks are built on inherently insecure architectures that are composed of, and increasingly using, foreign parts. While DoD takes great care to secure the use and operation of the "hardware" of its weapon systems, the same level of resource and attention is not spent on the complex network of information technology (IT) systems that are used to support and operate those weapons or critical IT capabilities embedded within them.

In many cases, the Navy bases its strategic and operational plans on the very capabilities a cyber enemy will deny or exploit in war. In an interview with *CHIPS* (2014) magazine, Matt Swartz, Director, Communications and Networks Division Deputy Chief of Naval Operations for Information Dominance (N2/N6) and Navy Task Force Cyber Awakening (TFCA) Lead said,

> Recent real world events and attacks on our Navy systems make clear the cyber threat is increasing. The risk calculus in the cyber domain has changed. Our reliance on connected capabilities has significantly increased the potential consequences of a cyber-attack.

In short, the Department of Defense (DoD) has awakened to *a "reliance vs. reliability"* gap in its networks that the services struggle to measure.

Within the Navy, quality efforts to achieve and measure cybersecurity across multiple strategic, operational, and tactical level commands, program offices, and systems and type commands are often coordinated primarily through assumed adherence to overarching strategic guidance. No single organization has the broad area visibility, resources, and influence to orchestrate these efforts.

Compounding the problem is the DoD's lack of a consistent, widely accepted methodology to measure and clearly and concisely express the operational readiness and programmatic wholeness of Information Technology–based Programs of Record. Existing acquisition metrics do not respond to current operational imperatives and cannot adequately express future risk to mission. *The Navy is unable to measure and express cyber program of record wholeness, platform cyber readiness, and the impact of programmatic and budgetary decisions on cyber readiness, or to quantify the value of specific cybersecurity standards or controls.* Without an accepted means of holistically scoring risk within a system of systems construct, *the Navy cannot consistently shape cybersecurity investment priorities to optimize value in a resource constrained environment*. As a result, the Navy struggles to effectively manage, prioritize, and influence the allocation of resources among competing systems

commands and program offices to maximize cyber readiness of the Fleet and to defend those decisions in the planning, programming, and budgeting process.

Cybersecurity Figure of Merit

This paper addresses the lack of a consistent, widely accepted means of measuring current and future cyber risk to mission resulting from acquisition or operational weaknesses in cybersecurity within an Information Technology–based Program of Record through the concept of a Cybersecurity Figure of Merit (CFOM). The objective is to develop a transparent mathematical framework of weighted qualitative and quantitative metrics that expresses the relative effectiveness of an Information Technology–based Program of Record in terms of the completeness and sufficiency of its cybersecurity properties throughout its lifecycle. CFOM can be used to address acquisition readiness for the Milestone Decision Authority as well as impacts of budget decisions on the cybersecurity wholeness of a given program.

CFOM is developed in terms of operational risk as a function of threats, vulnerabilities, and consequences (Defense Science Board, 2012). While CFOM is initially and primarily intended as an acquisition readiness tool, it groups acquisition metrics into operational categories to maintain acquisition's focus on providing future operational capability. As an expression of operational risk, *CFOM predicts future operational risk by measuring a program's long-range budget and spend plan, technology refresh plans, architecture, and sustainment plans through various technical reviews and operational reports.*

CFOM is intended to be a practical application of a large body of theoretical and practical research available on metrics and scoring of cybersecurity. As such, while the authors recognize the mathematical tenets of probability and risk theory, choices between practicality and academic rigor are made in favor of practicality. One of the self-imposed study restraints for initial implementation is that the program must not require new inspections or changes to existing documents and reports to gather the metrics that make up CFOM.

In conclusion, the CFOM framework attempts to provide decision support to both acquisition and operations by enabling greater understanding of

- a program's acquisition readiness in terms of future operational risk throughout its lifecycle.
- the effect of today's budget or technology tradeoffs on future operational risk.
- how technical risk decisions in one part of an enterprise network translate to operational risk at the tactical or operational edge elsewhere.
- how to optimize complex cybersecurity investment combinations to provide the maximum value in terms of operational risk reduction in resource-constrained environments.

Additional work is needed to refine the framework based on real-world data and then to materialize the capability in a software prototype.

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Panel 10. Assessing Industrial Base Implications of a Constrained Fiscal Climate

Wednesday, May 4, 2016	
3:30 p.m. – 5:00 p.m.	**Chair: Lorna B. Estep,** Director, Resource Integration and Deputy Chief of Staff for Logistics, Engineering, and Force Protection, Headquarters U.S. Air Force **Discussant: Emily Harman,** Director, Department of the Navy, Office of Small Business Programs ***Federal Research and Development Contract Trends and the Supporting Industrial Base, 2000–2014*** Andrew Hunter, Director and Senior Fellow, CSIS Gregory Sanders, Deputy Director and Fellow, CSIS Jesse Ellman, Research Associate, CSIS Kaitlyn Johnson, Research Intern, CSIS ***Identifying and Mitigating the Impact of the Budget Control Act on High Risk Sectors and Tiers of the Defense Industrial Base: Assessment Approach to Industrial Base Risks*** Lirio Avilés, Engineer, MIBP, OUSD(AT&L) Sally Sleeper, Senior Advisor, MIBP, OUSD(AT&L)

Chair:

Lorna B. Estep—a member of the Senior Executive Service, is the Director of Resource Integration, Deputy Chief of Staff for Logistics, Engineering and Force Protection, Headquarters U.S. Air Force, Washington, DC. She is responsible for the planning, programming and budgeting of weapons systems sustainment, equipment, and logistics and installations resource requirements. As part of the Air Force corporate structure, she monitors performance of operations and maintenance, working capital funds, and investment programs; participates in program and financial review groups; and advocates for financial adjustments to optimize force readiness. She oversees preparation and defense of these Air Force programs to the Office of the Secretary of Defense, Office of Management and Budget, and Congress.

Estep started her career as a Navy logistics management intern. She has directed the Joint Center for Flexible Computer Integrated Manufacturing, was the first program manager for Rapid Acquisition of Manufactured Parts, and has served as Technical Director of Information Technology Initiatives at the Naval Supply Systems Command. In these positions, she has developed logistics programs for the Department of Defense, implemented one of the first integrated and agile data-driven manufacturing systems, and directed the development of complex technical data systems for the Navy.

As the Director of Joint Logistics Systems Center, Estep had the duties of a commanding officer for a major subordinate command. In addition, she acted as the Logistics Community Manager, an emerging organization to coordinate and implement the revised DoD logistics strategy for achieving Joint Vision 2010 through modern information techniques and processes. She has also served as Chief Information Officer for the Naval Sea Systems Command in Arlington, VA; Executive Director of Headquarters Materiel Systems Group at Wright-Patterson AFB; Deputy Director for Logistics

Readiness at the Pentagon; and Executive Director, Air Force Global Logistics Support Center. Prior to her current assignment, she was Deputy Director, Logistics, Air Force Materiel Command.

Discussant:

Emily Harman—is the Director, Office of Small Business Programs (OSBP), for the Department of the Navy (DoN) serving as chief advisor to the Secretary on all small business matters. She is responsible for small business acquisition policy and strategic initiatives.

Harman joined the Secretary of the Navy staff as member of the Senior Executive Service in August 2015 and has over 30 years of federal service. Prior to receiving this appointment, she served as Associate Director of the Naval Aviation Systems Command's (NAVAIR) OSBP from November 2005 to August 2015.

Harman's previous experience includes serving as a Division Director in the Major Weapons System for Air-Antisubmarine Warfare, Assault, Special Mission Programs Contracts Department, and as the Multi-Mission Helicopters Program Office's (PMA-299) Contracting Officer. Harman has NAVAIR experience as a Services Contracting Officer, as well as Contracting Officer for the AV-8B Weapon Systems Program Office (PMA-257).

Prior to joining NAVAIR in 1997, Harman served as a Contracting Officer for the Naval Supply Systems Command's (NAVSUP) Fleet and Industrial Supply Center (FISC), Norfolk Detachment Washington. Harman served as a Supply Corps Officer in the Navy from 1985 to 1992 and retired from the Naval Reserves. She served onboard the USS *Emory S. Land* (AS-39) and earned the Supply Corps Surface Warfare pin. Her other duty stations include Supreme Allied Command Atlantic, Commander in Chief U.S. Atlantic Fleet, United States Naval Academy, and FISC Norfolk Detachment Washington.

Harman is a member of the DoD Acquisition Professional Community and is Level III certified in Contracting. A Certified Professional Contracts Manager through the National Contract Management Association, she holds a Bachelor of Science degree in physical science from the United States Naval Academy and a master's degree in management/acquisition and contract management from the Florida Institute of Technology. Harman is a member of Leadership Southern Maryland's Class of 2010.

Harman is a graduate of NAVSUP's Corporate Management Development Program, NAVAIR's Senior Executive Leadership Development Program, and the Federal Executive Institute. Harman has a number of personal and command decorations, including the DoN's Meritorious Civilian Service Medal, DoN's FY2010 Acquisition Excellence Award, and the 2015 Public Servant Award from the St. Mary's County Chamber of Commerce.

Federal Research and Development Contract Trends and the Supporting Industrial Base, 2000–2014

Andrew Hunter—is a Senior Fellow in the International Security Program and director of the Defense-Industrial Initiatives Group at CSIS. From 2011 to 2014, he served as a Senior Executive in the Department of Defense, serving first as Chief of Staff to Under Secretaries of Defense (AT&L) Ashton B. Carter and Frank Kendall, before directing the Joint Rapid Acquisition Cell. From 2005 to 2011, Hunter served as a professional staff member of the House Armed Services Committee. Hunter holds an MA in applied economics from the Johns Hopkins University and a BA in social studies from Harvard University. [ahunter@csis.org]

Gregory Sanders—is a Fellow with the Defense-Industrial Initiatives Group at CSIS, where he manages a team that analyzes U.S. defense acquisition issues. Utilizing data visualization and other methods, his research focuses on extrapolating trends within government contracting. This requires innovative management of millions of unique data from a variety of databases, most notably the Federal Procurement Database System, and extensive cross-referencing of multiple budget data sources. Sanders holds an MA in international studies from the University of Denver and a BA in government and politics, as well as a BS in computer science, from the University of Maryland. [gsanders@csis.org]

Jesse Ellman—is a Research Associate with the Defense-Industrial Initiatives Group (DIIG) at CSIS. He specializes in U.S. defense acquisition policy, with a particular focus on Department of Defense, Department of Homeland Security, and government-wide services contracting trends; sourcing policy and cost estimation methodologies; and recent U.S. Army modernization efforts. Ellman holds a BA in political science from Stony Brook University and an MA with honors in security studies, with a concentration in military operations, from Georgetown University. [jellman@csis.org]

Kaitlyn Johnson—is a Research Intern with the Defense-Industrial Initiatives Group at CSIS. Her work focuses on supporting the DIIG research staff through diverse projects. Previously she provided research support as an intern for both the Congressional Research Service and the American Enterprise Institute. Johnson holds a BS in international affairs from the Georgia Institute of Technology and is currently finishing her last semester for an MA at American University in U.S. foreign policy and national security studies with a concentration in defense studies. [kjohnson@csis.org]

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Abstract

As the current budget drawdown has progressed, numerous policy makers and informed observers have expressed concerns about the effect on federal research and development (R&D) efforts. Across the federal government, but particularly within the Department of Defense (DoD), there have been fears that the sharp downturn in federal contract obligations would disproportionately impact the R&D contracting portfolios within individual agencies and their major components.

Looking at the period from 2000–2014, this report examines data for the four major R&D contracting agencies: the DoD, NASA, the HHS, and the Department of Energy. It also examines four hypotheses, generated by the study team from a review of the literature and consultation with experts, that test how the budget drawdown has affected the R&D

contracting portfolios, and the industrial base that supports those efforts, within each R&D contracting agency.

The main finding of this initial inquiry is that the conventional wisdom regarding how R&D contracting would be affected by the budget drawdown has not been borne out. Early stage, "seed corn" R&D has been relatively protected, cuts were not done within agencies on a "salami slice" basis, and large prime vendors have seen their shares of the federal R&D contracting market decline precipitously.

Introduction

As the current budget drawdown, resulting from fiscal restraints imposed by the Budget Control Act, as well as sequestration and its aftermath, has progressed, numerous policy makers and informed observers have expressed concerns about the effect on federal research and development (R&D) efforts. Across the federal government, but particularly within the Department of Defense (DoD), there have been fears that the sharp downturn in federal contract obligations would disproportionately impact the R&D contracting portfolios within individual agencies and their major components. Using data from the publicly-available Federal Procurement Data Systems (FPDS), this report examines trends with federal R&D contracting during the current drawdown and analyzes the degree to which actual data conforms to predicted trends.

In order to analyze trends within the R&D contracting portfolios of the four largest federal R&D customers (the DoD, Department of Energy [DoE], National Aeronautics and Space Administration (NASA), and Department of Health & Human Services [HHS]), CSIS has developed a methodology to categorize R&D contracts by stage of R&D using a categorization schema that roughly corresponds to the commonly-used DoD R&D Budget Activity Codes (BACs):[1]

- Basic Research (6.1)
- Applied Research (6.2)
- Advanced Technology Development (ATD) (6.3)
- Advanced Component Development & Prototypes (ACD&P; 6.4)
- System Development & Demonstration (SD&D; 6.5)
- Operational Systems Development (6.7)
- Operation of Government R&D Facilities (GOCO)[2]

The following section (Federal R&D Contracting in Context) looks at the overall trends for federal R&D, both by which federal agency or major component is doing the contracting and by what stage of R&D the work falls under. The next section after that—How Has the Budget Drawdown Affected Federal R&D Contracting?—examines four hypotheses regarding how federal R&D will be affected by the budget drawdown, drawn from the literature and from consultation with experts, and examines how well the data conforms to those predictions.

[1] CSIS does not include contracts for R&D Management Support (6.6) in this analysis.
[2] Though not classified as R&D in the FPDS, CSIS now includes the codes for management/ operation of federal R&D facilities in its R&D category, as a significant amount of R&D activity, particularly in the DoE, is structured in this manner.

Based on the available data, the study concludes that most of the assumptions that the study team, policy makers, and outside experts made about the impact of the budget drawdown on federal R&D contracting were not borne out. While R&D contracting portfolios in some parts of the federal government saw dramatic cuts, others were relatively preserved, and the distribution of those cuts did not conform to expectations.

Federal R&D Contracting in Context

Four federal agencies have accounted for 95% or more of total federal R&D contract obligations in every year since 2000: the DoD, the DoE, NASA, and the HHS. Of these, the DoD accounts for by far the largest share, with over 50% in every year during the 2000–2014 period, reaching as high as 66% in 2007. The DoE accounted for 39% of total federal R&D contract obligations in 2000, but has accounted for between 20% and 25% in most years since 2004. NASA, which accounted for between 4% and 5% of federal R&D contract obligations from 2000–2003, has seen steady growth since then and has accounted for double-digit shares in every year since 2009. Meanwhile, the HHS has accounted for between 3% and 5% of total federal R&D contract obligations in all but one year in the 2000–2014 period (6% in 2013).

Figure 1 shows overall federal R&D contract obligations, broken down by customer, with the federal-wide total for each year at the top of each column.

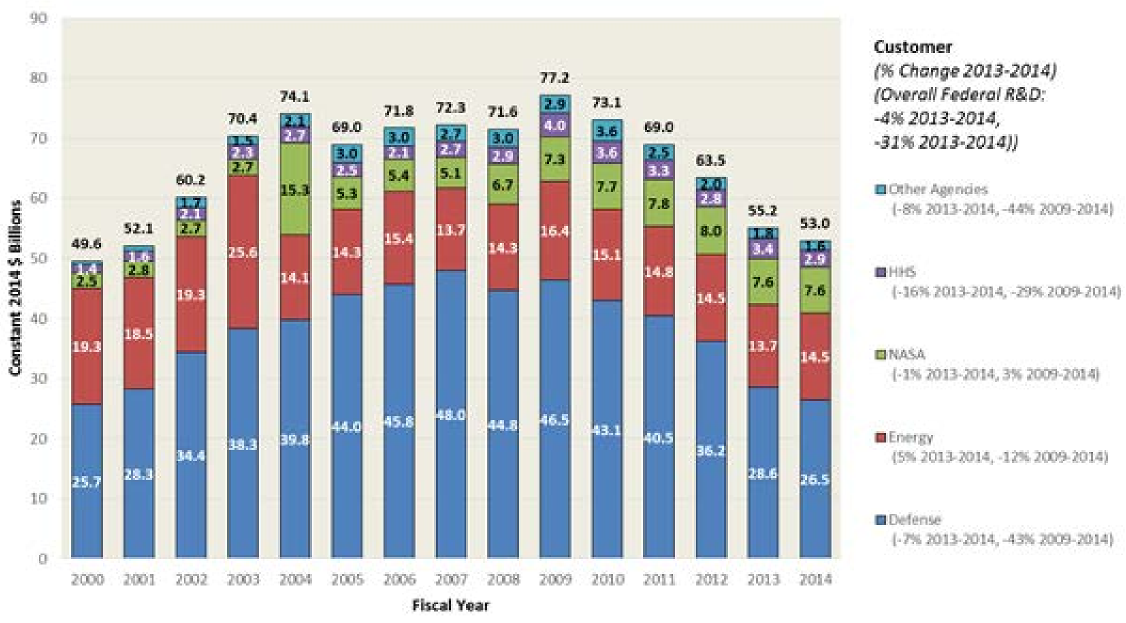

Figure 1. Federal R&D Contract Obligations by Customer, 2000–2014
(Federal Procurement Data Systems [FPDS]; CSIS analysis)

Since their peak in 2009, as overall federal contract obligations declined by 26%, federal R&D contract obligations have declined by 31%. Interestingly, most of this disproportionate decline in federal R&D contracts occurred prior to the impact of sequestration—since 2012, as overall federal contract obligations declined by 16%, federal R&D contract obligations fell roughly in parallel (-17%), with similarly parallel declines in both 2013 and 2014.

To better understand trends within the federal R&D contracting portfolio, CSIS has created a methodology to classify R&D contracts by stage of R&D, using the widely-understood Budget Activity Codes (BACs) as a guide. Figure 2 shows federal R&D contract obligations by stage of R&D.

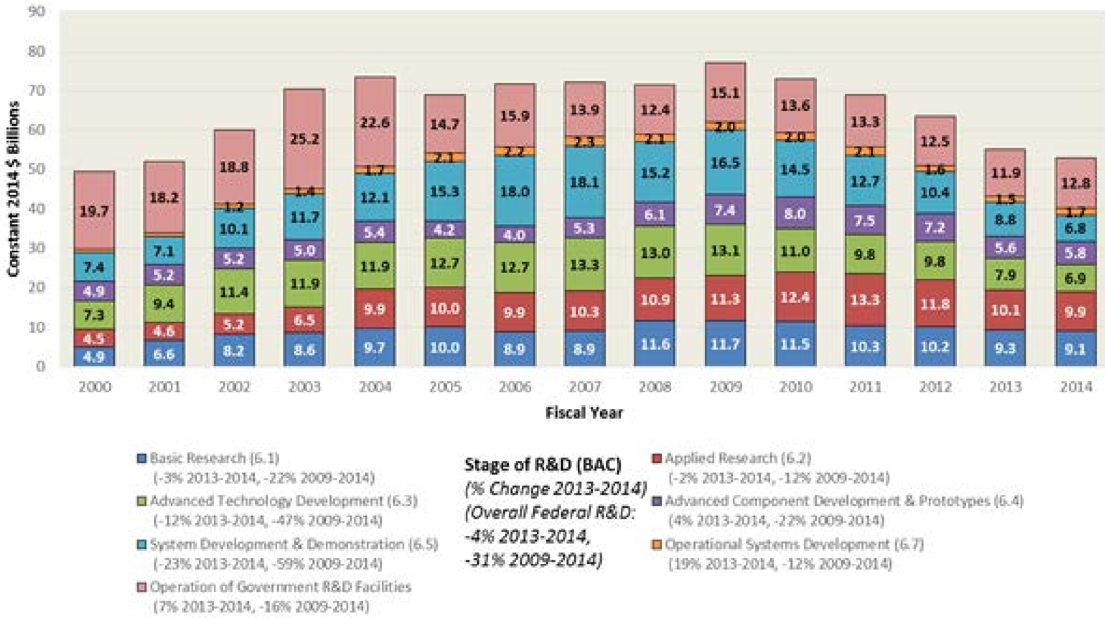

Figure 2. Federal R&D Contract Obligations by Stage of R&D, 2000–2014
(FPDS; CSIS analysis)

As overall federal R&D contract obligations declined by 31% since 2009, Basic Research (-22%), Applied Research (-12%), ACD&P (-22%), Operational Systems Development (-12%), and GOCO (-16%) were all relatively preserved. Meanwhile, ATD (-47%) and SD&D (-59%) both saw dramatic, disproportionate declines. As a share of overall federal R&D contract obligations, Basic Research and Applied Research, combined, rose from 30% in 2009 to 36% in 2014. Meanwhile, ATD fell from 17% to 13%, and SD&D declined from 21% in 2009 to 13% in 2014. Overall, the current drawdown has seen a notable shift within the federal R&D contracting portfolio, with a greater share of obligations going to early stage, “seed corn” R&D. The drivers of this trend will be analyzed in the sections that follow, which will look at the R&D contracting portfolios within the major federal R&D customers.

Department of Defense[3]

Since 2009, DoD R&D contract obligations have declined by 43%, notably faster than the 31% decline in overall DoD contract obligations over this same period. As a share of overall DoD contract obligations, R&D declined from 11% in 2009 to 9% in 2014, the lowest share seen in the 2000–2014 period.

[3] Portions of this section are adapted from CSIS’ January 2016 report on overall Defense Acquisition Trends, which drew in part upon research and analysis done in preparation for this research effort.

Throughout the budget drawdown, numerous policy makers have expressed concern that the DoD would end up sacrificing investment in “seed corn” R&D in order to preserve funding for later stage, more established development programs. But as Figure 3 shows, that has not been the case.

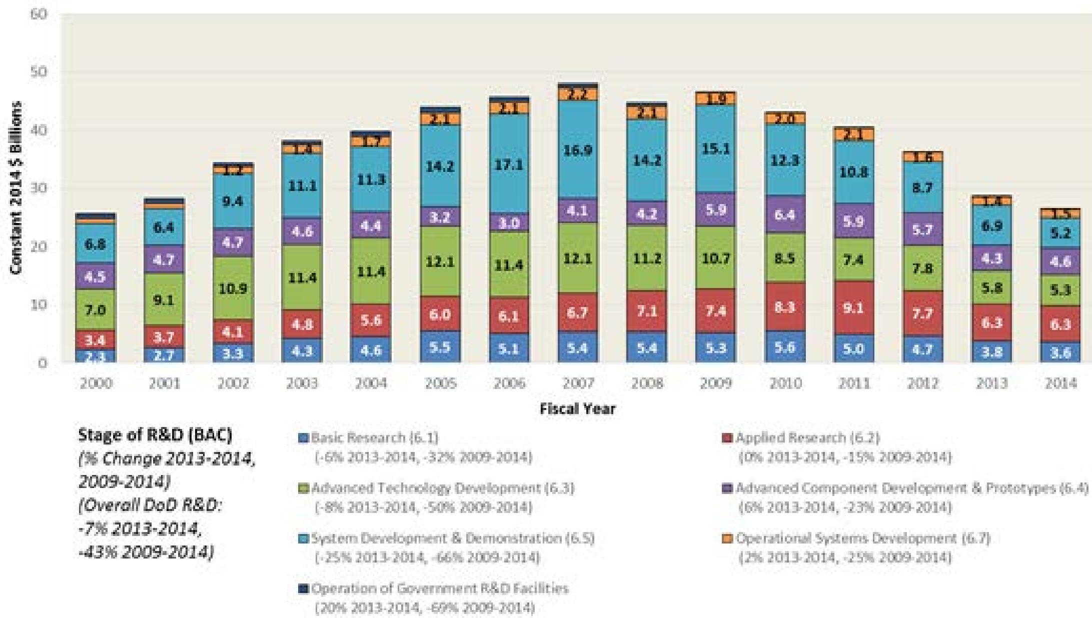

Figure 3. DoD R&D Contract Obligations by Stage of R&D, 2000–2014
(FPDS; CSIS analysis)

Since 2009, as overall DoD R&D contract obligations declined by 43%, obligations for Applied Research declined by just over one-third that rate (-15%),[4] while obligations for Basic Research declined by only 32%. As a share of DoD R&D contract obligations, the two “seed corn” categories rose from 27% in 2009 to 38% in 2014, the highest share in the 2000–2014 period. Basic Research contract obligations have declined at a rate that more closely parallels the overall decline in DoD R&D contract obligations since 2012, but Applied Research obligations have continued to be relatively preserved (-18% decline since 2012, compared to -27% for overall DoD R&D.)

Contract obligations for ACD&P (-23%) and Operational Systems Development (-25%) have similarly been relatively preserved since 2009. But ATD (-50%) and SD&D (-66%) have seen massive declines in recent years. The declines in those two stages of R&D accounted for over three-quarters of the total decline in DoD R&D contract obligations during the current drawdown.

The enormous decline in SD&D is particularly telling and speaks to the larger trend in DoD R&D contracting—over the last several years, as R&D programs related to MDAPs

[4] DoD contract obligations for Applied Research actually saw a notable spike between 2009 and 2011, due primarily to a one-year spike for space-related R&D, but obligations returned to prior levels in 2012.

have either been canceled or matured into production, the DoD has been largely unable to start and sustain new development programs, either due to budgetary pressures or to programmatic difficulties. The decline in R&D contract obligations during the budget drawdown is being driven by a five-year trough in the pipeline of new major weapons systems.

The following sections will briefly examine trends in R&D contracting within the three military services.

Army

The key factor in the massive decline in Army R&D contract obligations (-61% since 2009, compared to -52% for Army contracts overall) has been the cancellation of the Army's Future Combat Systems (FCS) program. Nearly the entirety of the decline in Army R&D contract obligations between 2009 and 2012 is directly attributable to the cancellation and winding-down of the FCS. In particular, obligations for SD&D have declined by an incredible 94% since 2009 as the Army has struggled to start and sustain new development programs for major weapons systems in the wake of the FCS's cancellation. The result of these struggles is the current five-year trough in the Army's development pipeline for major weapons systems.

In terms of "seed corn" R&D, the trend within the Army is mixed. Both Basic Research (-45%) and Applied Research (-49%) have been relatively preserved since 2009. While Basic Research fell more slowly than overall R&D throughout the period, Army obligations for Applied Research actually grew between 2009 and 2011, before declining by nearly half in 2013. In 2014, combined obligations for the two "seed corn" categories are at their lowest level ($1.6 billion) in the 2000–2014 period.

This interruption of the developmental pipeline for new major weapons systems presents an unusual opportunity for the DoD and, particularly, for the Army. As spending on war materiel continues to be replaced by funding for next-generation priorities, the Army has little to no developmental money already committed to projects. Thus, the Army has an opportunity to take a step back, draw lessons from the wars in Iraq and Afghanistan, evaluate potential future threats and missions, and direct their requirements and developmental priorities accordingly.

Navy

While overall Navy contract obligations were relatively preserved (-19%) since 2009, Navy R&D contract obligations fell by 47% over that same period. As a share of overall Navy contract obligations, R&D fell from 14% in 2009 to 9% in 2014, the lowest share for the Navy in the 2000–2014 period.

Whereas obligations for Advanced Research have increased by 3% over the 2009–2014 period, obligations for Basic Research have declined by two-thirds since 2009. As with the Army, the Navy saw disproportionate declines in obligations for ATD (-68%) and SD&D (-53%). Unlike the Army, the Navy has major development programs in the pipeline, such as the Ohio-class ballistic missile submarine replacement. However, to preserve funding for current priorities, the Navy has been forced to push back the timelines for some of its efforts due to budgetary constraints, resulting in the ongoing trough in the Navy's development pipeline.

Air Force

As with the Navy, while overall Air Force contract obligations were relatively preserved (-24%) since 2009, R&D contract obligations within the Air Force declined more steeply (-37%) over that same period. Analogous to the Army and Navy, Air Force contract obligations for Applied Research were relatively preserved since 2009 (-3%); unlike the Navy, Basic Research was also relatively preserved (-25%) and actually increased by 11% in 2014. As a share of Air Force R&D contract obligations, “seed corn R&D” rose from 41% in 2009 to 58% in 2014, the highest share in the 2000–2014 period.

Both ATD (-64%) and SD&D (-58%) declined heavily, with most of the declines coming in the wake of sequestration between 2012 and 2013. Unlike both the Army and Navy, however, Air Force contract obligations for ACD&P also declined heavily (-60%) since 2009. The Air Force is also in the midst of a trough in their development pipeline for new major weapons systems, but with contracts recently awarded for major programs like the Long Range Strike Bomber, the Air Force seems like it will be the first of the military services to emerge from this trough.

NASA

NASA’s R&D contract portfolio is the most comparable with the DoD’s in terms of the types of projects undertaken, if not in overall scale. Basic Research and Applied Research have combined to account for over half of NASA contract obligations in all but one year in the 2000–2014 period, peaking at 73% in 2005. In recent years, Applied Research has accounted for around 40% of overall NASA R&D contract obligations, with ATD and ACD&P declining as a share as SD&D obligations grew. Figure 4 shows NASA R&D contract obligations by stage of R&D.

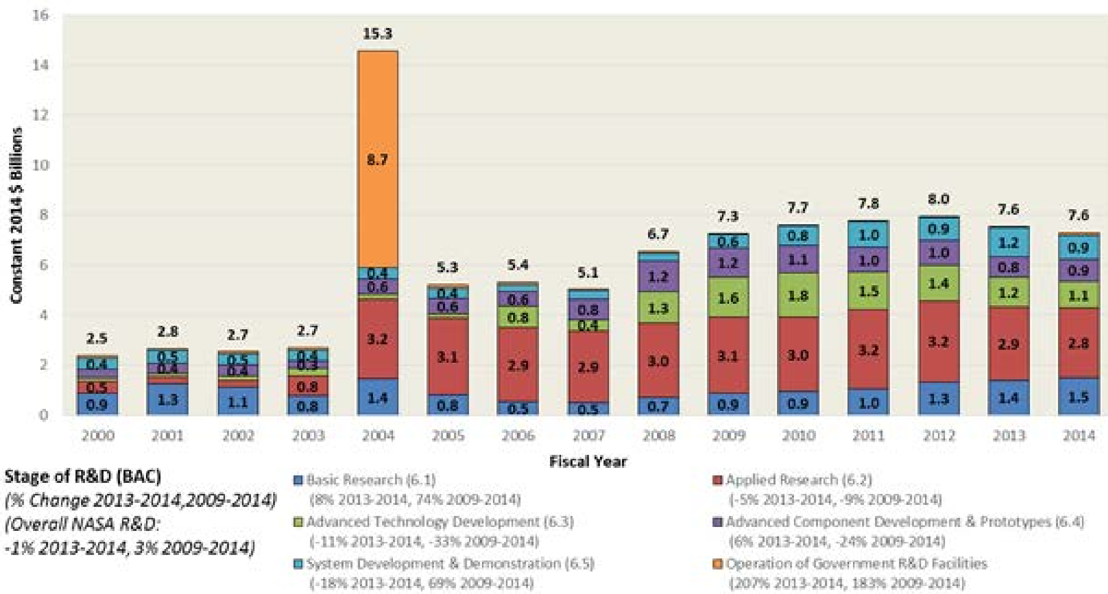

Figure 4. NASA R&D Contract Obligations by Stage of R&D, 2000–2014[5]
(FPDS; CSIS analysis)

Unlike the DoD, NASA R&D contract obligations have risen steadily since 2007, with the most significant growth occurring between 2007 and 2009, primarily in ATD. NASA R&D contract obligations grew by 9% between 2009 and 2012, fell by 6% in 2013, and by a further 1% in 2014; for the entire 2009–2014 period, NASA contract obligations grew by 3%, even as overall NASA contract obligations fell by 10%. Since 2012, R&D has accounted for over half of NASA contract obligations, the highest shares (excluding the anomalous 2004) in the 2000–2014 period.

The increase in R&D contract obligations within NASA since 2009 has been driven by significant increases in Basic Research (74%) and SD&D (69%), while obligations for Applied Research (-9%), ATD (-33%), and ACD&P (-24%) declined notably.

Department of Health and Human Services

The R&D contracting portfolio of the HHS has diversified notably in recent years. In 2000, Basic Research and Applied Research combined to account for 86% of HHS R&D contract obligations; by 2014, that share had declined to 57%. Obligations for the two categories of "seed corn" R&D have both been relatively stable over the 2000–2014 period;

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[5] The $8.7 billion in 2004 for "Operation of Government R&D Facilities" is a data anomaly related to NASA's migration from their previous contract data system into FPDS. In the prior system, large, multiyear contracts were entered as a single aggregated entry at the end of the contract; this entry represents the prior five years of obligations for NASA's contract with the Jet Propulsion Lab (JPL). CSIS has worked with NASA contract officials at the JPL and has determined that while separating out the aggregated total is not feasible, the $8.7 billion will be moved back to 2003, which was the last year of the contract. CSIS would like to thank the contract officials at NASA HQ and at the JPL for their diligence and assistance in tracking down this data anomaly.

the decline in share is primarily the result of increasing obligations for ATD and "Operation of Government R&D Facilities" starting in the mid-to-late 2000s. As a share of overall HHS contract obligations, R&D has declined steadily throughout the period, from a high of 26% in 2004 to 13% in 2014. Figure 5 shows HHS R&D contract obligations by stage of R&D.

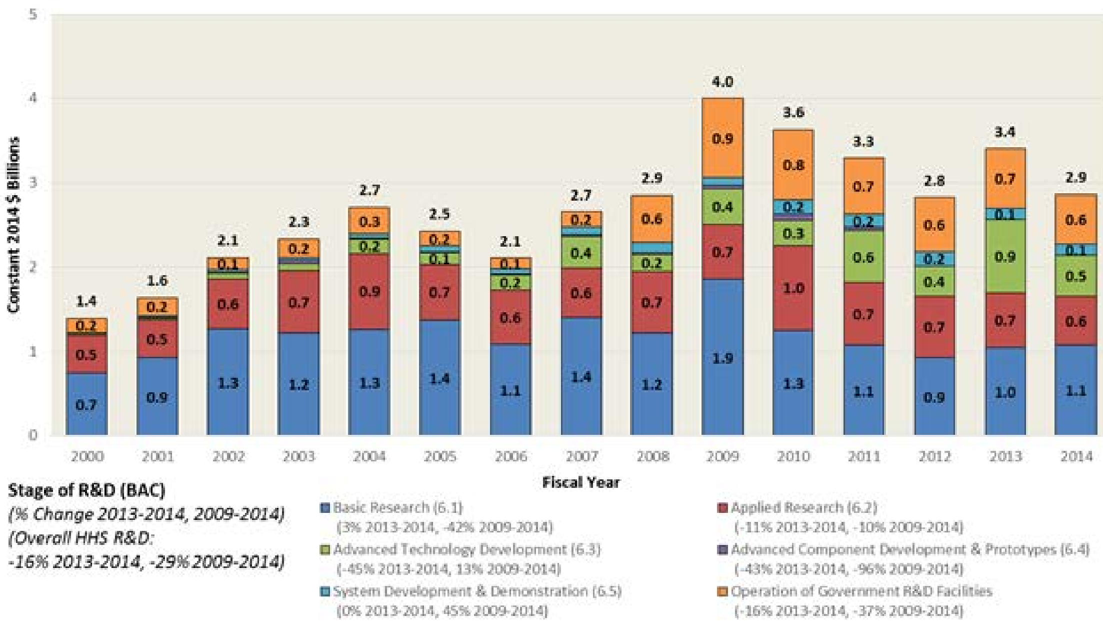

Figure 5. HHS R&D Contract Obligations by Stage of R&D, 2000–2014
(FPDS; CSIS analysis)

Since 2009, as overall HHS contract obligations fell by 3%, HHS R&D contract obligations fell by 29%, albeit after a 33% increase between 2008 and 2009. Basic Research declined by 42% between 2009 and 2014, but that was primarily the result of a return to normal obligation levels after a one-year spike in 2009; between 2012 and 2014, as overall HHS R&D contract obligations were virtually flat, obligations for Basic Research increased by 16%. Obligations for Applied Research were relatively preserved (-10%), while obligations for ATD increased by 13%. ATD obligations were notably volatile during this period, doubling between 2010 and 2011, falling by a third in 2012, increasing by 144% in 2013, and then falling by 45% in 2014.

Department of Energy

The DoE is unique among the major federal R&D contracting agencies in that only a small percentage of its R&D contracting portfolio actually goes to direct contracts for R&D. Rather, the vast majority of the DoE's R&D contract obligations go to "Operation of Federal R&D Facilities," mainly the various National Laboratories. Because of the nature of these contracts, CSIS has limited visibility to the nature of the R&D being performed, although conversations with experts have indicated that most of the R&D activity in the National Laboratories would probably be categorized as Basic Research or Applied Research.[6]

The DoE's R&D contracting portfolio is also unique in that almost all of the obligations in recent years are under contracts that originated in 2008 or earlier. In 2014, for example, less than 2% of the $14.5 billion in DoE R&D contract obligations came from contracts signed after 2008, and 35% came from contracts that originated in 2000 or earlier. As such, DoE R&D contracting data has limited explanatory value regarding the effects of the current drawdown, since almost all of the obligations in recent years come from options being exercised under contracts that originated before the drawdown began.

How Has the Budget Drawdown Affected Federal R&D Contracting?

As part of this research effort, CSIS has conducted a review of the relevant literature, involving both the public and private sectors, to identify current theories on how declining resources would affect R&D contract spending. CSIS also consulted with experts in federal contracting and budgeting to validate the theories identified in the course of the literature review. From this analysis, the study team developed a number of hypotheses regarding how declining resources would affect federal R&D contracting overall, and the R&D contracting portfolios within agencies specifically.

This section looks at a selection of these identified hypotheses and evaluates whether the predictions made by the study team (based on the current understanding of the issue from the available literature) were borne out by the data on the current budget drawdown. The following are the five hypotheses that this section will examine:

1. Cuts in R&D due to budget drawdown will be done on a "salami slice" basis, rather than reflecting a thoughtful prioritization of resources.
2. Newer R&D contracts will bear a disproportionate share of cuts during budget drawdowns.
3. Budget drawdowns will lead to shifts away from early-stage, "seed corn" R&D towards mid-to-late-stage R&D tied to high-profile programs.
4. Large prime vendors will account for increasing shares of federal R&D during budget drawdowns.
5. During budget drawdowns, R&D will be increasingly funded out of non-R&D-focused budget accounts.

Hypothesis 1: Cuts in R&D Due to Budget Drawdown Will Be Done on a "Salami Slice" Basis, Rather Than Reflecting a Thoughtful Prioritization of Resources.

For the purposes of this hypothesis, the study team uses the term "salami slice" to refer to a series of cuts where a roughly equal portion is cut across the board, rather than having some portions of the portfolio relatively preserved or impacted. Given that sequestration, in particular, was implemented as an across-the-board cut, CSIS hypothesized that agencies would respond to budgetary pressures by taking roughly equal

[6] The DoE totals for "Operation of Federal R&D Facilities" also likely include some production activity related to nuclear weapons, but CSIS has no way to reliably separate these out from the R&D activity undertaken as part of these contracts. As such, for the purposes of this analysis, CSIS will categorize the "Operation of Federal R&D Facilities" obligations in their entirety as R&D.

cuts across their R&D contracting portfolios. If this hypothesis were to hold true, the study team would expect to find that across the different stages of R&D and within different major components, cuts to R&D were roughly in parallel to the overall decline over the period, if not necessarily in each particular year.

Department of Defense

The overall DoD R&D contracting portfolio did not show evidence that cuts were done on a "salami slice" basis. While Basic Research has declined roughly in parallel to overall DoD R&D contract obligations since 2012, Applied Research, ACD&P, and Operational Systems Development have all declined notably more slowly than overall DoD R&D. At the same time, contract obligations for ATD and SD&D have declined significantly more steeply than overall DoD R&D. As discussed in the Federal R&D Contracting in Context section, this does not appear to be the result of "thoughtful prioritization of resources;" rather, it appears that the disparate levels of cuts across the DoD's R&D contracting portfolio are primarily the result of late-stage development programs for major weapons systems either maturing out of development or being cancelled, with a dearth of new major development programs starting in recent years.

Within the Army, R&D contract obligations declined notably more steeply than in the DoD overall since 2012. Army contract obligations for Basic Research and ACD&P have declined notably more slowly than overall Army R&D under sequestration and its aftermath. SD&D was nearly steady over that same period, but that is a factor of the near-complete disappearance of SD&D contract obligations prior to 2012 due to the cancellation of the FCS program and the Army's inability to start and sustain new development programs for major weapons systems in recent years. Meanwhile, contract obligations for Applied Research, ATD, and Operational Systems Development all declined significantly more steeply than overall Army R&D.

Although the distribution of cuts is different within the Navy's R&D contracting portfolio since 2012, the degree to which the cuts are unevenly distributed is similar to the Army. Between 2012 and 2014, Navy contract obligations for SD&D and Operational Systems Development declined roughly in parallel to overall Navy R&D. Obligations for Applied Research and ACD&P were relatively preserved, with Applied Research, in particular, declining at less than one-third the rate of overall Navy R&D. By contrast, obligations for Basic Research and ATD declined more steeply than overall Navy R&D.

Within the Air Force, contract obligations for Basic Research and Applied Research both declined at less than half the rate of overall Air Force R&D since 2012, while Operational Systems Development actually increased significantly. Meanwhile, obligations for ATD, ACD&P, and SD&D all declined notably more steeply than overall Air Force R&D, with SD&D declining at nearly double the rate.

Within the MDA's R&D contracting portfolio, ACD&P declined at double the rate over overall MDA R&D since 2012, while Basic Research fell by over five times the overall MDA R&D rate of decline. During the same 2012–2014 period, both Applied Research and ATD saw notable increases.

NASA

NASA's R&D contracting portfolio saw a mild decline between 2012 and 2014, but much like the DoD and its major components, the cuts to NASA do not appear to have been done on a "salami slice" basis. Obligations for Basic Research and SD&D saw notable increases, while obligations for Applied Research, ATD, and ACD&P declined at rates between two and four times as steep as for overall NASA R&D.

HHS

In the wake of sequestration and its aftermath, HHS R&D contract obligations were virtually stable between 2012 and 2014. But this stability masks wildly disparate increases and decreases between the categories of R&D that make up significant portions of the HHS R&D contracting portfolio. Obligations for Basic Research and ATD both increased significantly from 2012–2014, with the latter increasing by more than a third. Obligations for Applied Research declined steeply over the same period, while obligations for GOCO saw a moderate decline.

Initial Findings

The data provides no evidence to support the hypothesis the cuts in the wake of sequestration and its aftermath would be done on a “salami slice” basis; in fact, the data shows wildly divergent trends between different stages of R&D.

Hypothesis 2: Newer R&D Contracts Will Bear a Disproportionate Share of Cuts During Budget Drawdowns.

The basis of this hypothesis is the idea that established, ongoing R&D programs develop constituencies and stakeholders, both inside and outside of government, that have an interest in seeing the program continue and succeed. As such, when cuts have to be made during a budget drawdown, it makes sense that those constituencies and stakeholders would try to protect those established programs. CSIS thus theorized that in a time of budgetary downturn, newer R&D contracts would bear a disproportionate share of the declines in R&D contract obligations. If this hypothesis were true, CSIS would expect that, within the major R&D contracting agencies and their major components, the share of R&D contract dollars obligated under “new” contracts in each fiscal year would decline during the current budget drawdown. CSIS refers to these “new” contracts in each year as “new start” contracts.

Figure 6 shows the share of contract dollars in each fiscal year that was obligated under contracts originating in that fiscal year for each of the major R&D contracting agencies.[7]

[7] Because FY2000 is the first year in the FPDS dataset that CSIS uses, it is excluded from this analysis, as all contract obligations in that year are shown as originating in FY2000, even if they come from a contract that began earlier.

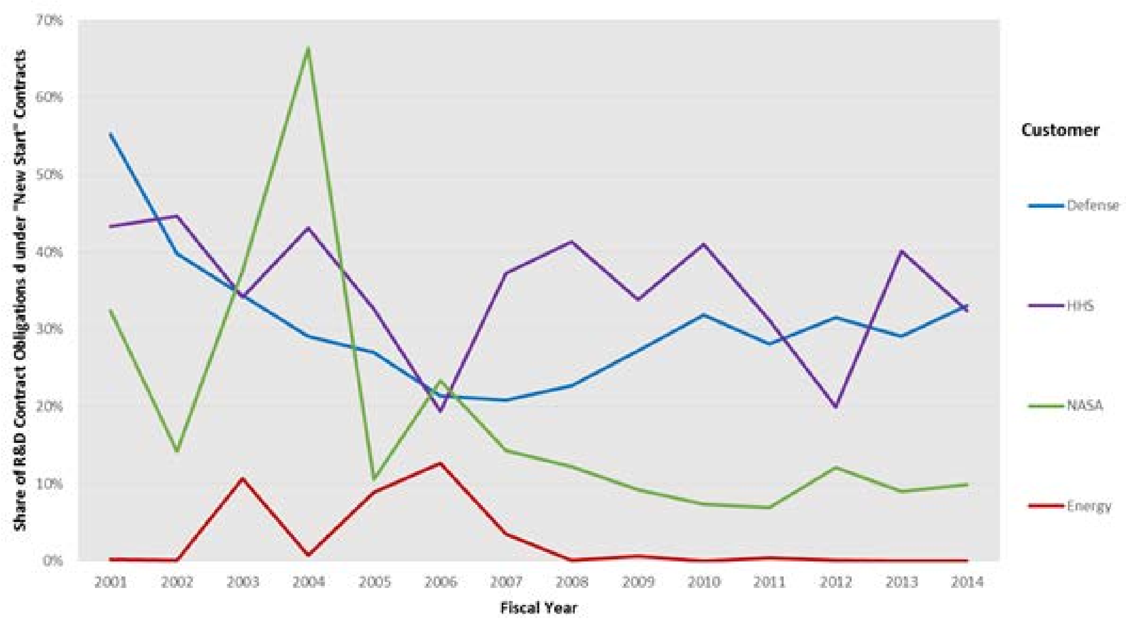

Figure 6. Share of R&D Contract Obligations Under "New Start" Contracts, by Customer, 2001–2014
(FPDS; CSIS analysis)

Department of Defense

The overall DoD R&D contracting portfolio does not show a consistent trend of reduced obligations for "new start" contracts during the current budget drawdown. The share of DoD R&D contract obligations in each year awarded under "new start" contracts declined from 55% in 2001 to a low of 21% in 2007. The share began to increase in subsequent years, and that increase continued through the early years of the budget drawdown, rising to 32% by 2010. Over the next three years, that share fluctuated between 28% and 32%, peaking at 34% in 2014.

Figure 7 shows the share of R&D contract obligations awarded under "new start" contracts for each of the major DoD R&D contracting components.

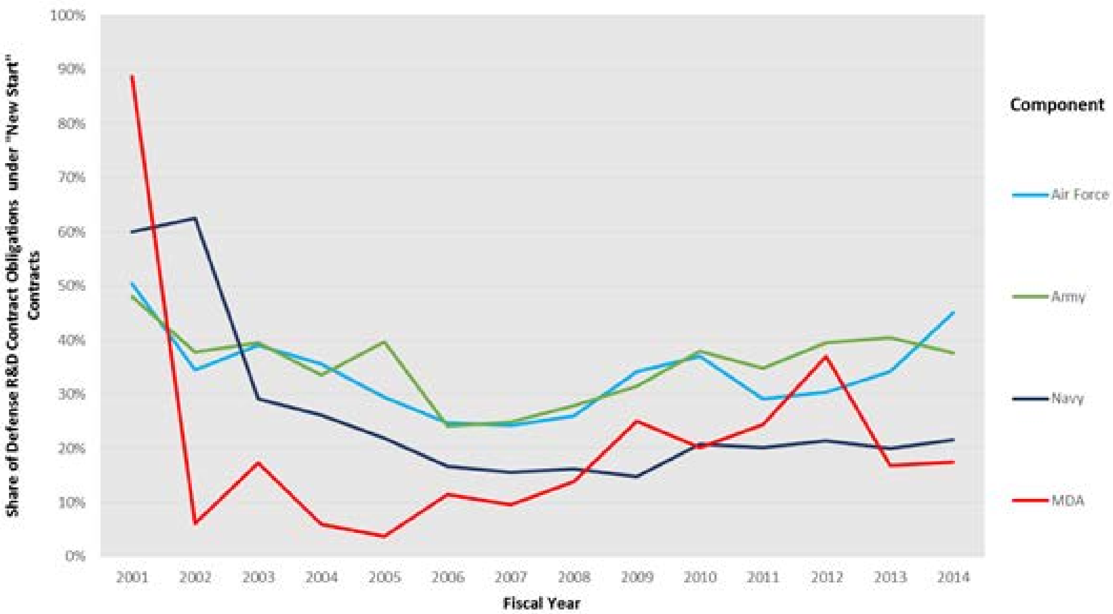

Figure 7. Share of Defense R&D Contract Obligations Under "New Start" Contracts, by Component, 2001–2014
(FPDS; CSIS analysis)

The share of Army R&D contract obligations under "new start" contracts declined, albeit not consistently, in the years prior to the current budget drawdown, falling from 48% in 2001 to 24% in 2006. The share obligated under "new start" contracts rose in subsequent years and continued to rise during the current budget drawdown, reaching a high of 41% in 2013 before falling back to 38% in 2014.

For the Navy, "new start" contract obligations accounted for over 60% of total R&D contract obligations in 2001 and 2002, but that share declined precipitously in 2003, to 29%. The share declined gradually over the next several years to 15% in 2009, but rose to 21% in 2010. Between 2010 and 2014, the share of Navy R&D contract obligations under "new start" contracts remained between 20% and 22%.

Within the Air Force's R&D contracting portfolio, the share obligated under "new start" contracts fell from 50% in 2001 to 24% in 2007. The share increased over the next few years to 37% by 2010, fell to 29% in 2011, and increased to 45% by 2014.

For the MDA, after the anomalous 2001, the share of contract obligations under "new start" contracts fluctuated below 20% until 2009, when the share rose to 25%. After a drop to 20% in 2010, the share of MDA R&D contract obligations under "new start" contracts rose to 37% by 2012 before dropping back below 20% in 2013 and 2014.

NASA

NASA's share of R&D contract obligations under "new start" contracts was highly volatile in the early-to-mid-2000s, but since 2008, that share has remained between 6% and 12% each year, with no discernable pattern (aside from relative stability) during the budget drawdown.

HHS

HHS R&D contract obligations under "new start" contracts have been highly volatile throughout the 2001–2014 period, likely a function of the smaller obligation totals involved.

Since 2008, the “new start” share has fluctuated between 32% and 41% in all but one year (20% in 2012); like NASA, aside from that relative stability, there is no discernable pattern present.

Department of Energy

The DoE data in Figure 6 shows the degree to which the DoE R&D contracting portfolio is dominated by long-running contracts. Between 2008 and 2015, “new start” contracts never exceeded 0.7% of total DoE R&D contract obligations in any year and accounted for 0.02% or less in four of the last five years.

Initial Findings

The data provides no support for the hypothesis that “new start” R&D contract obligations were disproportionally affected during the budget drawdown; rather, in each case, “new start” R&D contract obligations either were stable, increased, or else showed no discernable trend over the period.

Hypothesis 3: Large Prime Vendors Will Account for Increasing Shares of Federal R&D During Budget Drawdowns.

This hypothesis can be considered a companion to Hypothesis 3, because they could both be effects of a similar cause. Because large, high-profile, mid-to-late stage R&D programs are the most likely to have developed constituencies and stakeholders that would fight to protect them during a budget drawdown, Hypothesis 2 theorized that those R&D contracts would be relatively protected. And since those large, high profile R&D programs are likely to be performed by large, high-profile prime vendors, Hypothesis 3 theorizes that R&D contract obligations to those same large, high-profile prime vendors would be relatively preserved.

Department of Defense

Figure 8 shows DoD R&D contract obligations to prime vendors, from 2000–2014, broken down by the share going to the different vendor size categories.[8]

[8] CSIS classifies vendors into four size categories: “Small” vendors follow the government’s classification for small businesses, with a couple of adjustments implemented by the study team; “Large” vendors are any vendors with over $3 billion in annual revenue from all sources; and “Medium” vendors are any vendors that are neither small nor large. The fourth category, the “Big 5” vendors (Lockheed Martin, Boeing, Northrop Grumman, Raytheon, and General Dynamics), are separated out from “Large” due to the outsized role they play in federal contracting overall.

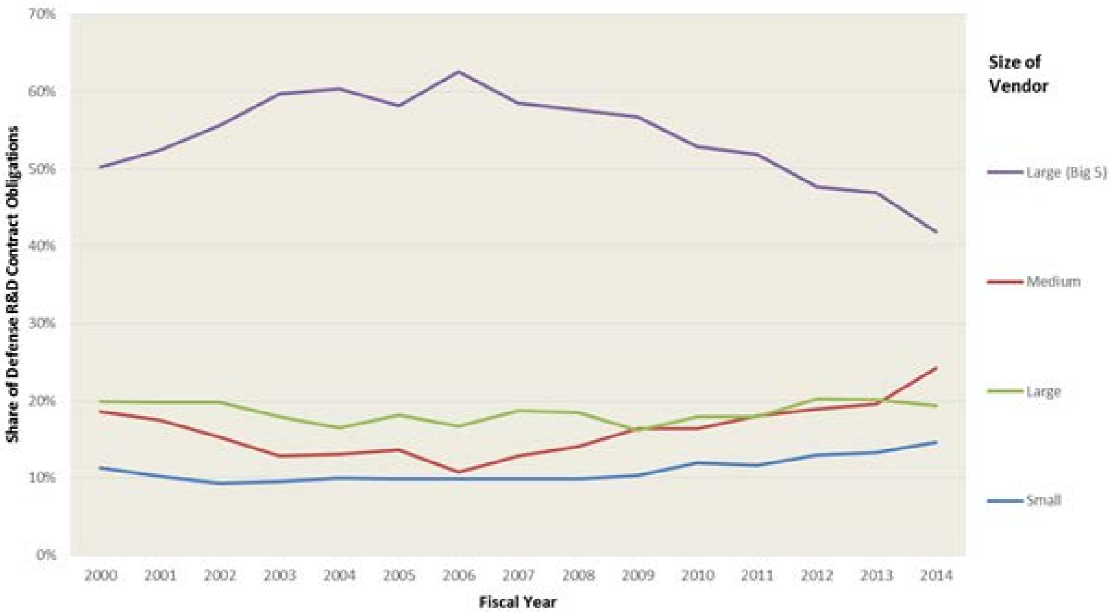

Figure 8. Defense R&D Contract Obligations by Size of Vendor, 2000–2014
(FPDS; CSIS analysis)

Contrary to Hypothesis 3, the DoD has actually seen a dramatic decline in the share of contract obligations going to large prime vendors. While the "Large" category has held steady through the drawdown and throughout most of the 2000–2014 period, the share of R&D contract obligations going to the Big 5 vendors has fallen from 57% in 2009 to 42% in 2014. This is primarily the result of the previously discussed five-year trough in the DoD's development pipeline for major weapons systems: In recent years, as many large development programs were either cancelled or matured into production, the DoD has been largely unable to start and sustain new large-scale development programs. And because those large-scale development programs for major weapons systems are predominantly performed by the Big 5 vendors, those vendors have borne the brunt of the decline in DoD R&D contract obligations.

Unsurprisingly, this trend is present to an even greater degree within Army R&D. While the share of Army R&D contract obligations awarded to large vendors has remained relatively steady in recent years (aside from a brief spike in 2012 and 2013), the share awarded to the Big 5 vendors has fallen from 48% in 2009 to just 20% in 2014. Due to the Army's particularly severe issues with starting and sustaining new development programs in recent years, this trend is unlikely to reverse in the near future.

The Navy and Air Force have seen declines in the share of R&D contract obligations to the Big 5 vendors more in line with the trend for DoD R&D overall. Within the Navy's R&D contracting portfolio, the share of R&D contract obligations going to the Big 5 vendors fell from 65% in 2009 to 37% in 2014. For the Air Force, the share going to the Big 5 vendors fell from 47% in 2009 to 31% in 2014. In both cases, the share awarded to large vendors has been relatively stable over the period.

NASA

Figure 9 shows NASA R&D contract obligations from 2000–2014, broken down by the share going to the different vendor size categories.

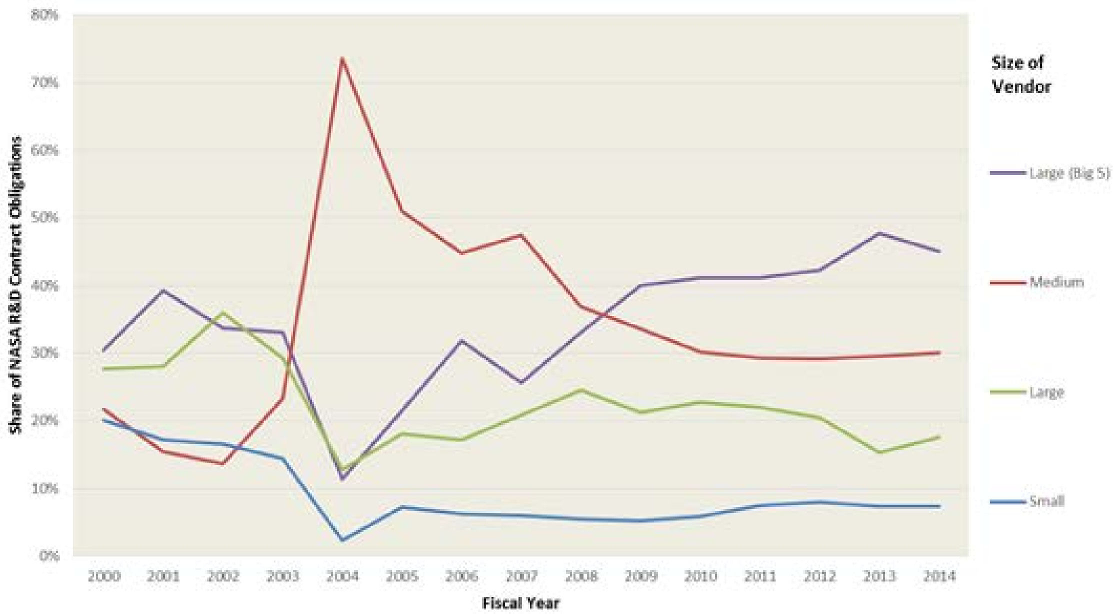

Figure 9. NASA R&D Contract Obligations by Size of Vendor, 2000–2014
(FPDS; CSIS analysis)

Unlike the DoD and its major components, NASA actually does show increasing shares of R&D contract obligations going to large prime vendors. This increase, however, began before the current budget drawdown; the Big 5 vendors accounted for only 26% of NASA contract obligations in 2007, but that share rose to 48% by 2013 before a slight decline in 2014. This increase in Big 5 share is primarily concentrated in Basic Research (from 11% in 2007 to 47% in 2013) and SD&D (from 7% in 2007 to 78% in 2014.) Thus, it appears that the rising share of NASA R&D contract obligations going to large prime vendors is not attributable to factors relating to the budget drawdown.

HHS

The Big 5 vendors have never accounted for more than 1% of HHS R&D contract obligations. The HHS has seen an increase in the share of R&D contract obligations awarded to large vendors, but this is a trend that started prior to the current budget drawdown. The primary factor in this increase is the increase in contract obligations for GOCO in 2008 and 2009, of which over three-quarters were awarded to large vendors. None of the other major categories within the HHS R&D contracting portfolio have seen consistent and notable increases or decreases in the share of obligations awarded to large prime vendors during the current drawdown.

Initial Findings

The data provides no support for the hypothesis that large prime vendors would see increasing shares of R&D contract obligations during the current budget drawdown. In fact, in most cases, the largest vendors have seen their shares decline precipitously.

Hypothesis 4: During Budget Drawdowns, R&D Will Be Increasingly Funded Out of Non-R&D-Focused Funding Accounts.

The theory of Hypothesis 4 is that, as budgets decline, agencies may look to fund R&D out of budget/funding accounts that are not traditionally R&D-focused in order to make up for funding shortfalls in the R&D-focused accounts and preserve funding levels for high-priority R&D programs. If this hypothesis were accurate, the study team would expect to see increases in the share of R&D contracting obligations funded out of particular funding accounts that were not traditionally the primary funding sources for R&D contracts within the agency.

A couple of methodological notes related to this analysis:

- The fields that allow for cross-walking between contract obligations and budget data only began to be filled in reliably in FY2011 for non-DoD agencies and FY2012 for the DoD.
- CSIS focuses on funding accounts, rather than the higher-level budget accounts, because of the increased data granularity and also because there is no consistent budget account schema between agencies.

Department of Defense

Unsurprisingly, nearly three-quarters of DoD R&D contract obligations are funded out of the various DoD Research, Development, Test, and Evaluation (RDT&E) accounts, with the Air Force and Defense-wide accounts accounting for the largest shares. Since 2012, the share of DoD R&D contract obligations funded out of the Defense-wide RDT&E account has risen from 21% to 28%, and the share funded out of the Air Force RDT&E account increased from 21% to 23%. Meanwhile, the share funded out of the Navy's RDT&E account fell from 18% to 15%, while the share funded out of the Army's RDT&E account fell from 7% to 6%.

For the other DoD funding accounts with non-trivial levels of R&D contract obligations, there was a mix of increases and decreases, though most were relatively stable. The share of R&D contract obligations funded out of the Navy's Aircraft Procurement account doubled from 2% to 4%, while the share funded out of the Air Force's Missile Procurement account fell from 4% to 1%. Additionally, the share funded out of the Army's Operations and Maintenance (O&M) account fell from 5% to 3%.

HHS

For the most part, the shares of HHS R&D contract obligations funded out of particular HHS funding accounts have been relatively consistent from 2011–2014, with a couple of exceptions. The share funded out of the National Institute of Health's (NIH) National Institute of Drug Abuse rose from 1% in 2011 to 4% in 2014, while the share funded out of the main NIH account fell from 25% in 2012 to between 19% and 20% in 2013 and 2014.

NASA

Unlike the other two agencies, there have been significant shifts in the distribution of R&D contract obligations within NASA's major funding accounts. The share of R&D contract obligations funded out of the Cross Agency Support account rose from 11% in 2011 to 22% in 2014, and the share funded out of the general Science account rose from 17% to 28%. Meanwhile, the share funded out of the Exploration account fell from 27% to 20%, the share funded out of the Human Space Flight account fell from 11% to 7%, and the share funded out of the Science (Aeronautics and Exploration) account fell from 19% to 0%.

Initial Findings

Though the data is mixed, there is no consistent trend that supports the hypothesis that R&D contract obligations are being increasingly funded out of non-traditional accounts during the current budget drawdown.

Final Thoughts and Next Steps

The data highlighted in this report clearly shows that, while federal R&D contract obligations have declined dramatically overall, that decline has not been consistent across the major R&D contracting agencies and their major components, or across the different stages of R&D. Moreover, with very narrow exceptions, none of the predictions made by the study team regarding the effect of the downturn on federal R&D contracting, based on a review of the literature and consultations with experts, have been borne out.

These initial results should give analysts pause, as the data indicates that the conventional wisdom regarding how a budget drawdown would affect agencies' R&D contracting portfolios is flawed. While CSIS found no evidence that the cuts to R&D reflect a thoughtful, top-to-bottom prioritization of resources, there is also no indication that the cuts were done on a "salami-slice" basis, or that newer or earlier-stage projects were sacrificed to protect later-stage programs with more entrenched stakeholders. As a result, the concerns about "seed corn" R&D being disproportionally affected by the budget drawdown also appear to be unfounded, and the predicted rise of market share for large prime vendors has not only not occurred, but has developed strongly in the opposite direction.

For the DoD, the key finding from this data is the existence of a five-year trough the development pipeline for major weapons systems. The Air Force looks likely to buck that trend in the coming years as spending for the Long Range Strike Bomber program ramps up. However, the Navy's continued pushing back of development timelines for programs like the Ohio-replacement ballistic submarine due to budget constraints, and the Army's continued uncertainty about future missions, requirements, and resources, indicate that the overall trough is likely to continue into the foreseeable future.

In the next stages of this project, the study team will test additional hypotheses and disaggregate federal agency and military department figures in a manner appropriate to each hypothesis, for example, breaking out annual or quarterly results, looking at individual major projects and facilities, or studying funding accounts. The study team plans to expand the analysis of federal R&D contracting trends, both in terms of contract characteristics and the supporting vendor base, as well as looking at trends in R&D-related grants to provide additional context. CSIS will also continue to work to identify and interview relevant experts to help understand the causes and effects of the trends identified within the data.

Disclaimer

The Center for Strategic and International Studies (CSIS) does not take specific policy positions; accordingly, all views expressed in this presentation should be understood to be solely those of the author(s).

Identifying and Mitigating the Impact of the Budget Control Act on High Risk Sectors and Tiers of the Defense Industrial Base: Assessment Approach to Industrial Base Risks

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Abstract

The Department of Defense (DoD) requires insight into the risks that the Budget Control Act (BCA) is placing on the defense industrial base (DIB), particularly in those sectors that have been previously identified as critical and at high-risk of losing critical capabilities. The Office of the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy (ODASD[MIBP]) has developed a methodology to identify the impact of budget cuts on the DIB. During 2014 and 2015, the MIBP identified capabilities provided by the DIB that were at high risk of being compromised or unavailable to the warfighter using the fragility and criticality methodology and implemented mitigation plans to sustain the industrial base. Funding to execute mitigation plans was included in the FY16 Presidential Budget. The MIBP created an assessment approach to evaluate the impact of the BCA on the DIB. Only the sectors and tiers previously identified as high risk were assessed. The framework evaluates

the loss of design and manufacturing skills, loss of innovation, loss of competition, and loss of infrastructure. In addition, potential DoD steps to sustain high risk sectors, sub-sectors, and tiers under a BCA environment were identified. DoD leadership is using the results to inform resource decision making.

Introduction

The industrial base is an integral part of the Department of Defense (DoD) force structure needed to provide the highest performance and innovative capabilities to the warfighter. However, the current budgetary situation is forcing industry to make business decisions that will have long term consequences in the nation's ability to advance its technological capabilities. Defense industry consolidations, challenges incentivizing new entrants to the DoD's critical markets, and loss of design teams and manufacturing skills due to procurement reductions are some of the main factors threatening the industrial base. Consolidation trends have led to the creation of six "mega-prime" providers today—reducing competition and creating barriers to entry due to their sheer financial size. Budget uncertainty and industry's perception of DoD contracting practices and intellectual property protection limit the interest of non-traditional companies from working with the DoD. Procurement and research and development (R&D) programs, which have been delayed or cancelled, also have an impact on industry's ability to retain its design teams and exercise the critical manufacturing skills for defense-unique products.

While budget swings are not new to the DoD, the trends and challenges discussed above are impacting today's defense industrial base (DIB) and limiting its ability to support the technological superiority requirements of the Department. In addition, appropriations have consistently fallen short of carefully planned President's Budgets.

As illustrated in Figure 1, the DoD and industry will have to overcome several budgetary challenges:

- The Services need to balance force structure, readiness, and capability to meet national security commitments in their President's Budget submissions. Programs like the Ohio Replacement and Long Range Strike Bombers are part of the U.S. strategy to modernize nuclear weapons systems and the number one priority for the Navy and AF, respectively. In order to fund these programs, the Services will have to make other procurement, readiness, or force structure trade-offs. These decisions are extremely difficult due to competing priorities and their effect on the long-term strategies.
- Current programs are moving from design and manufacturing stages to operations and maintenance. This situation creates a design and manufacturing gap that puts at risk the industry's ability to sustain and exercise the critical skills for the advanced weapons systems required in the future.
- As the war winds down and U.S. forces reduce their role in active combat, the declining demand for some defense-unique products adds pressure to mid and lower tiers of the industrial base that depend on DoD business to achieve their minimum sustainment rates.
- Budgetary uncertainty has contributed to companies' adoption of an income-focused strategy as defense firms invest in share buy-backs, dividends, and mergers or divestitures to create income and improve profitability. Without the ability to plan for future programs, industry is reluctant to invest in R&D, yet

the DoD relies on industry's R&D for innovation, technical dominance, and increased efficiency.

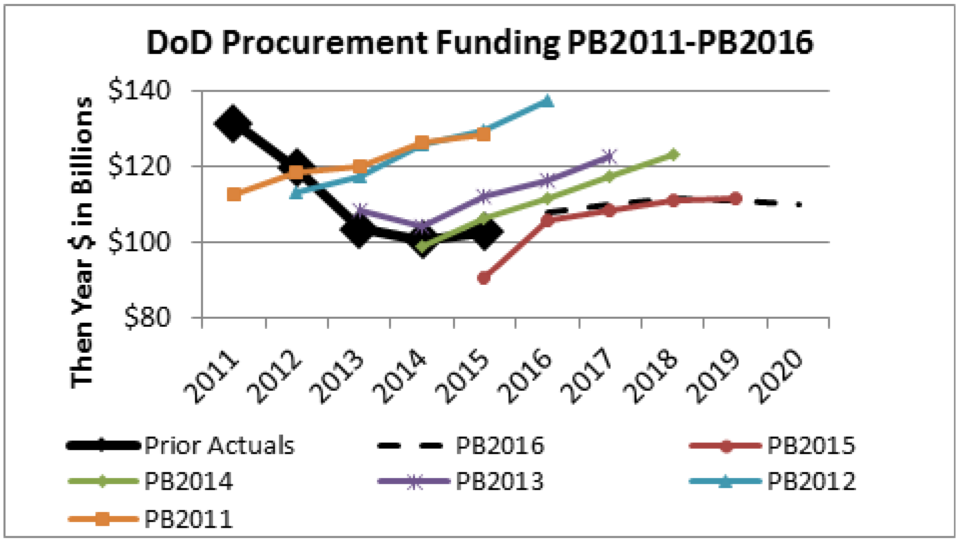

Figure 1. DoD Investments on Procurement—Actuals vs. Presidential Budget (PB)

The current situation of the defense industrial base is exacerbated by the Budget Control Act (BCA) of 2011, which proposed DoD spending reductions of approximately 10% annually for the next 10 years. Figure 2 provides a summary of the events related to the BCA and the effect on the FY16 PB for the DoD. In the National Defense Authorization Act of FY15, Congress expressed concerns about the effect of the BCA on the industrial base. Consequently, Congress requested the Office of the Secretary of Defense to provide an analysis of sectors and tiers of the private industrial base found to be at highest risk, and how the risk assessment has changed since enactment of the BCA of 2011. This paper outlines the framework developed by the Manufacturing and Industrial Base Policy (MIBP) Office to assess the industrial base risks and provides a summary of the results.

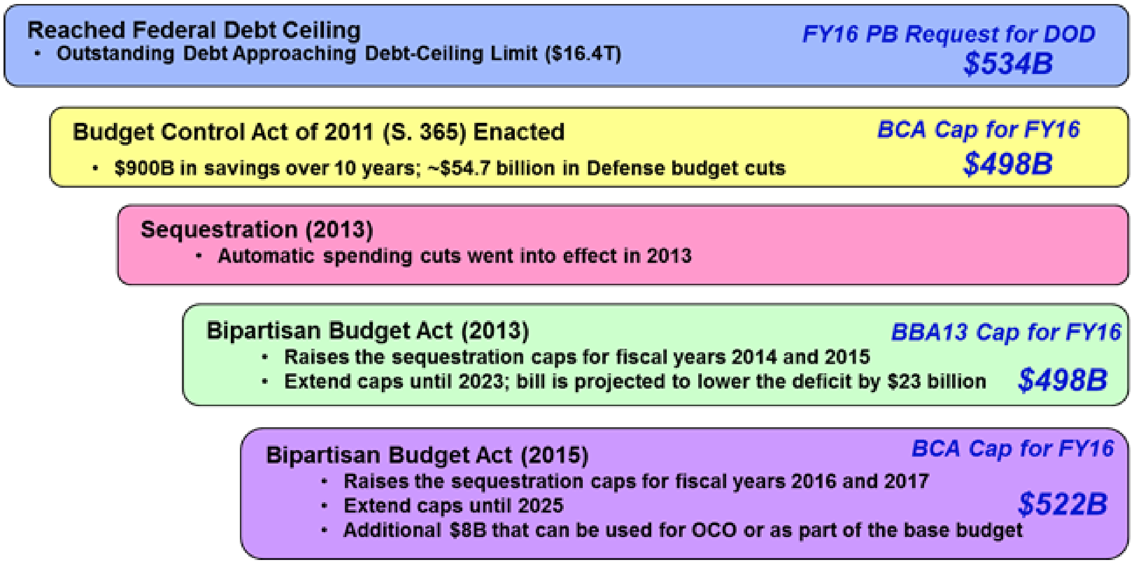

Figure 2. Budget Control Act Events and Effect on FY16 Presidential Budget (PB) for the DoD

Defining Industrial Base Risks

The DoD defines industrial base risks as uncertainties regarding industry's ability to design, manufacture, and sustain the DoD's present and future critical capabilities. A critical capability is defined as a capability difficult to replace if disrupted. A critical capability will have a combination of the following characteristics: defense-unique; requires specialized skills to integrate, manufacture, or maintain the capability; requires defense-specific knowledge to reproduce this capability, an alternative, or the next generation design; requires the use of specialized equipment and/or facilities for manufacturing and sustainment; the time required to restore the capability will have a negative impact on the mission; and the availability of alternatives to meet DoD needs without the capability. The Office of the Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy (ODASD[MIBP]) uses FaC[1] assessments to identify critical capabilities.

The MIBP developed risk definitions (see Tables 1 and 2) to assess the industrial base risks for each sector, sub-sector, tier, and sub-tier, as required. In some cases, the evaluation considered a sub-sector, while in other cases, a tier or sub-tier was assessed. A sector refers to the big segments of the industrial base providing similar or related products and services in a given market. A sub-sector divides the sectors based on more specific activities and/or products. Tiers define the specific components and services required to manufacture a final product. Sub-tiers divide the components and services into specific

[1] In 2011, the MIBP was tasked with developing a forward-leaning approach that could identify the cumulative effect on vital capabilities of procurement decisions across programs and Services. The organization used the existing 1996 framework to develop a methodology that could be used proactively, across Services and industrial sectors, that is rigorous, repeatable, and transparent. That methodology to assess the industrial base is known as the Fragility and Criticality assessment process, or FaC for short.

products, similar to those found in a bill of material. Figure 3 provides an example of the relationship between sectors, sub-sectors, and tiers.

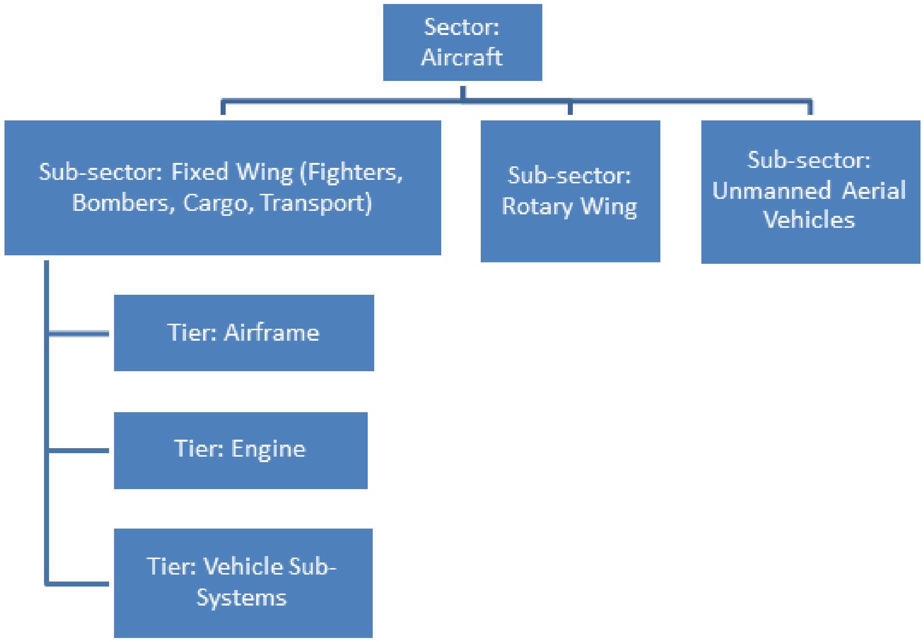

Figure 3. Aircraft—Sector, Sub-Sectors, and Tiers

The analysis framework was based on the two risk components: likelihood and consequence. The risk level ranges from low to high based on the likelihood of losing a critical capability and the ability to reconstitute the capability once it is lost.

Table 1. Industrial Base Risk Definition—Likelihood

Risk Level	Definition
Low	Low expectation that a critical capability will be lost, and, if lost, the capability is easily reconstituted. • Industry can quickly respond to DoD requirements on time and at reasonable cost • Competition exists; design and manufacturing skills are being exercised through multiple programs; R&D programs are funded • Adequate infrastructure is available to meet requirements
Medium	Medium expectation that a critical capability may be lost and, if lost, will not easily be reconstituted. • Industry has few qualified companies for a capability; declining procurement may reduce domestic competition • Mitigation plans are in place to address a capability where reconstitution would be very costly or to maintain domestic source of supply
High	High expectation that a critical capability will be lost, and, if lost, will be difficult or impossible to reconstitute. • Industry has one source of supply, and declining procurement increases the chances of exit • No mitigation action in place; reconstitution would significantly increase cost and schedule • Industry will have difficulty responding to DoD requirements on time and/or at a reasonable cost

Table 2 describes the consequences of losing a critical capability. Consequences are defined according to five main areas that are critical to design, develop, test, and sustain current and future weapons systems: design skills, manufacturing skills, innovation, competition, and infrastructure. One risk may have consequences in multiple areas.

Table 2. Industrial Base Risks Definitions—Consequences

Industrial Base Risks Consequences	Definition
Loss of Design Skills	Loss of defense-specific knowledge required to reproduce a critical capacity, an alternative, or the next generation design
Loss of Manufacturing Skills	Loss of specialized skills needed to integrate, produce, or sustain a critical capability
Loss of Innovation	Reductions in RDT&E funding that will jeopardize technology-based programs. Industry is focusing R&D investments on near-term payoffs.
Loss of Competition	Procurement levels that cannot sustain multiple suppliers will lead companies to exit the market. Markets also may consolidate through increased mergers and acquisitions and partnerships between primes and suppliers.
Loss of Infrastructure	Loss of specialized equipment or facilities needed to integrate, manufacture, or maintain a critical capability. Lack of investment to maintain and modernize the equipment, tooling, and facilities needed to sustain the capability.

Defining Industrial Base Sectors at Risk

The MIBP used the results of FaC assessments conducted between 2013 and 2014, industrial base reports, and inputs from subject matter experts to identify sectors at high risk of losing critical capabilities, considering factors like current and future demand, acquisition phase of major programs, and mitigation strategies. The following sectors were identified at higher risk:

- **Missiles and Munitions Sector**—The missile and munitions sector is comprised of the DoD's smart bombs and tactical and strategic missiles. This sector is primarily a defense-unique industrial sector and, therefore, is highly dependent on the DoD's demand. Over the past decade, the munitions and missile sector has provided no new-start missile opportunities, as all "new" missile programs have been designated as, or have become, upgrades to existing systems.
- **Space Sector**—The space sector is primarily driven by the commercial market and includes satellites, launch services, ground systems, networks, payloads, propulsion, and electronics. Although the commercial focus of this sector allows leveraging the commercial technology advancement, security restrictions limit the benefits. Therefore, the DoD must remain vigilant in order to maintain critical capabilities that are specialized for military applications and have very low demand compared with commercial products.
- **Aircraft Sector**—The aircraft sector is comprised of commercial and defense aircraft. Defense aircraft are divided in three main sub-sectors: fixed-wing, rotary wing, and unmanned systems. The fixed-wing sub-sector includes

fighters, bombers, cargo, and transportation aircraft. The rotary wing sub-sector includes helicopters used for combat, combat support, and services. Unmanned aircraft systems include the necessary components, network, and personnel to control an unmanned aircraft, including a launching element, if needed. There has been a steady decline in the number of defense development programs for fixed-wing and rotary wing aircraft. Modernization programs will help sustain important capabilities, but will not provide opportunities for major design, development, and integration work. Design shortfalls are also projected because much of the defense aerospace workforce is close to retirement, and the pool of young engineers available to replace them is migrating to other industries.

- **Shipbuilding Sector**—The defense shipbuilding sector is comprised of seven shipyards and other shipyards which concentrate on commercial ships, but will periodically enter and exit the naval market. The U.S. shipbuilding industrial base depends on DoD business to sustain critical design and manufacturing skills, as well as to maintain their current infrastructure.
- **Combat Vehicles Sector**—The ground vehicle sector is generally categorized in two broad vehicle classes: tactical wheeled vehicles (TWV) and combat vehicles. The TWV are usually commercial trucks modified for military use in demanding environments and/or missions. This type of truck benefits from dual-use or commercial demand. Combat vehicles, on the other hand, are typically heavily armored and integrated with complex weapons and systems; therefore, they have limited commercial application. This sector faces a number of industrial base challenges, including retaining critical design and integration skills, as well as sustaining critical suppliers in the sub-sector tiers.

Specific sub-sectors, tiers, and sub-tiers were identified in each of the sectors previously mentioned. Information about the specific risk is not discussed in this paper to protect business sensitive and pre-decisional information used in the analysis. However, an example of the aircraft sector, which has been openly discussed by DoD leadership, is provided in the next sections.

Risk Level Assessment

Risk level assessments for each of the sectors, sub-sectors, and tiers identified at high risk were conducted using the following timeframes:

- FY11 (baseline) – BCA enactment
- FY13 – Bipartisan Budget Act enactment
- FY15 – Current FY at the time of the assessment
- FY16 – Most current guidance for investment on the next five years at the time of the analysis

The assessment was based on the number of DoD programs supporting the sectors at high risk over the time periods under evaluation and the acquisition phase of those programs.

The final product was a risk level matrix for each of the industrial areas. Figure 4 provides an example of the aircraft sector assessment. In this case, the assessment was done at the sub-sector level, fixed-wing-fighter aircraft. In 2011, there were multiple programs in manufacturing, and the F-35 program was supporting development activities. In

2013, there were still multiple programs in production, but the F-22 closed their production line and the F-35 development activities decreased. By 2015, most of the fighter programs were transitioning from a manufacturing phase to operations and sustainment. In addition, no new design work for fighters was expected, creating a development gap until the 2020s, when new fighter programs are expected to start. The FY16 PB included funds to start a program known as the Aerospace Innovation Initiative (AII). This program will help to sustain the development skills required to produce the next-generation of fighters, maintain competition in the sector, and promote innovation.

Although the medium level indicates that mitigation plans are in place to address the risk, capabilities in the medium risk level will be highly dependent on budget decisions. Funding for mitigation plans may be transferred or delayed in order to fund higher priorities within the Department. Sub-sectors in this risk level should be monitored constantly.

Figure 4. Industrial Base Risk Level (Likelihood)—Aircraft Example

Identifying the Effect of the BCA on the Defense Industrial Base

Funding cuts due to the BCA will create additional barriers to overcome the current challenges. However, the impact of the BCA cannot be assessed in isolation. Decreasing procurement and R&D funds, Services' priorities, the scheduled end of multiple DoD programs, and corporate strategic plans are other factors that will impact the industrial base and are considered when making decisions related to the BCA.

The MIBP used the following sources to determine the impact of the BCA:

- Presidential Budget—PB16 projects funding levels for FY16 to FY20. The trends in procurement and R&D budgets provide a good indication of the expected investments in the defense aircraft sector (see Figures 5 and 6). The fighter procurement and RDT&E funding stay relatively steady from 2018 to 2020 due to the F-35 program. However, there is no new fighter development or procurement during that period of time. The decreasing trend in procurement and RDT&E investment may be worsened by the implementation of BCA cuts.

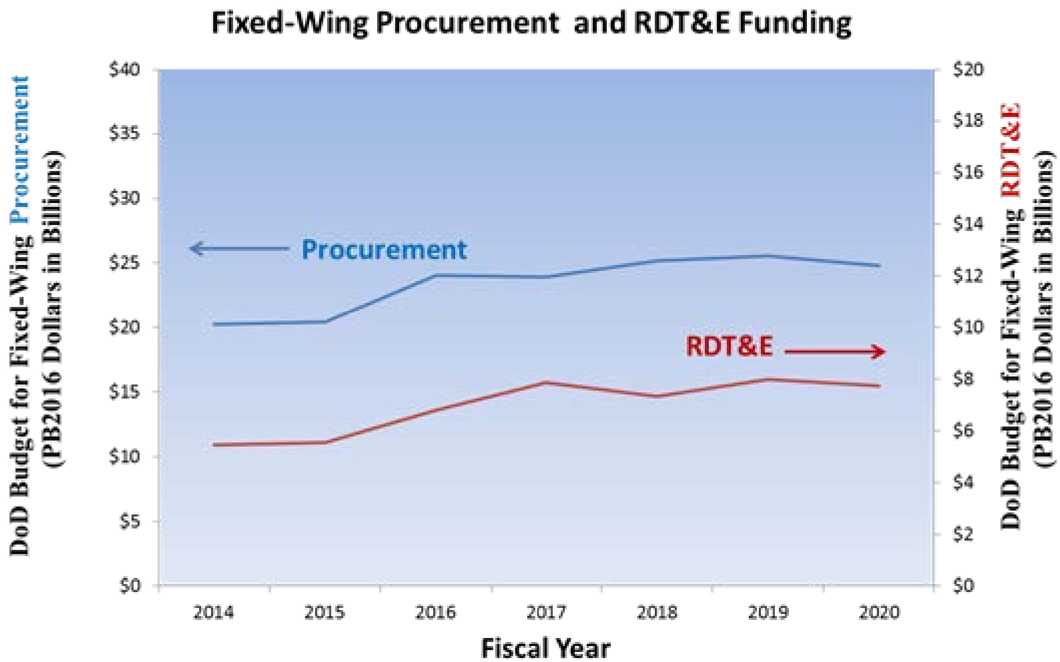

Figure 5. DoD Investments in Fixed-Wing Procurement and RDT&E (PB16)

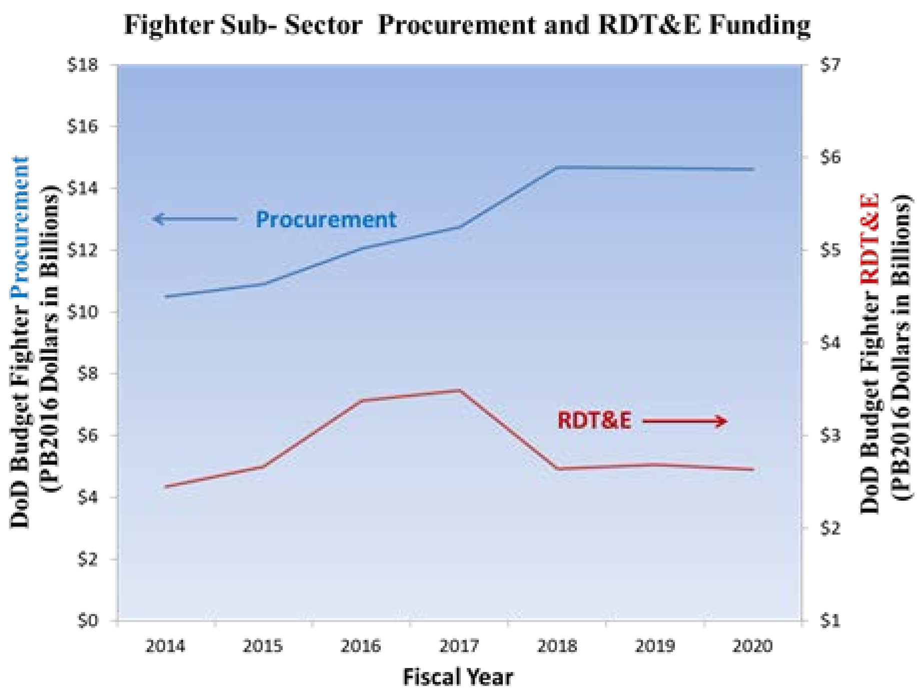

Figure 6. DoD Investments in Fighter Aircraft Procurement and RDT&E (PB16)

- Subject matter experts (SMEs) from the Services and representatives of multiple DoD offices evaluated the potential impact of BCA enactment in FY16 to their current programs and plans. The following potential impacts were identified for the fixed-wing-fighter sub-sector:

- o Aerospace Innovation Initiative (AII) funds may be eliminated.
- o RDT&E programs to advance sixth generation fighter technology may be reduced or eliminated.
- o BCA16-driven divestiture or reduction of aircraft fleets may affect primes and lower tier suppliers that are essential to capabilities sustainment.

- SMEs applied the definitions in Table 2, industrial Base Consequences, to assess expected consequences if a capability is lost due to a BCA cut implementation.

Sector: Aircraft	Loss of Design Skills	Loss of Manufacturing Skills	Loss of Innovation	Loss of Competition	Loss of Infrastructure
Sub-Sector: Fixed Wing - Fighters	√	√	√	√	√

Figure 7. Industrial Base Risks (Consequences)

Updated Risk Assessment—The risk level was updated to reflect the potential impact of the BCA in FY16. It is important to note that the actual BCA impacts will depend on the Services' budget and decision priorities at the time of the BCA cuts implementation. In the case of the fixed-wing-fighters sub-sector, the likelihood of losing critical capabilities increased.

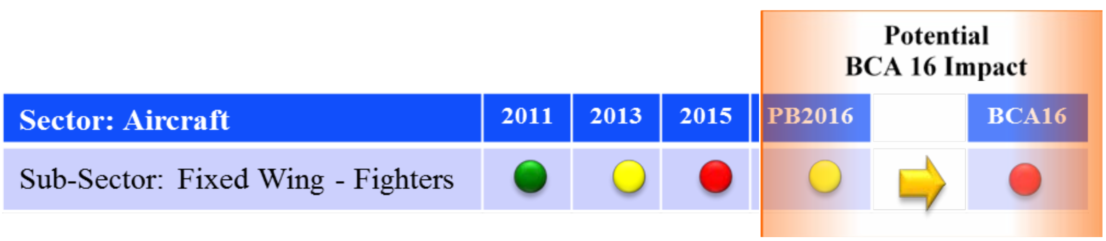

Figure 8. Industrial Base Risk Assessment Including Potential BCA Impact

The Final Outcome

To finalize the analysis, a combination of all the factors assessed was provided for each sector and its respective sub-sectors and tiers (see Figure 9). DoD leadership will use this combination of factors to determine the industrial base risk levels and consequences in specific areas of the industrial base and make decisions about the potential cuts. For example, in Figure 8, the fighter aircraft risk level is expected to change from medium to high if BCA cuts are implemented. This could represent the elimination or delay of funds for a new program or implementation of a mitigation strategy. BCA implementation will require reducing or re-programming funds based on priorities. Leadership will use these data to establish priorities based on the risk level and consequences they are willing to accept. The risk level needs to be paired with the consequence when establishing priorities.

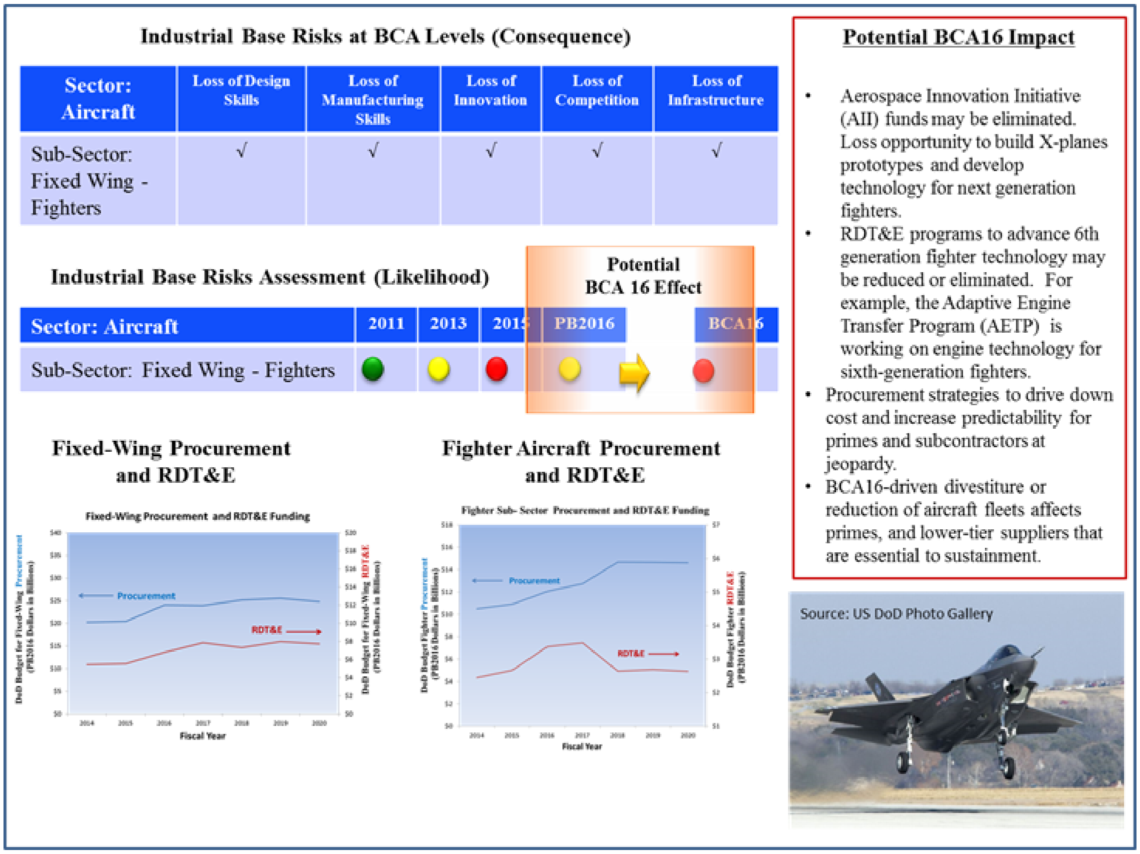

Figure 9. Potential Impact of BCA on Industrial Base—Fixed-Wing Fighters Example

Conclusion

The results of the analysis provided the following conclusions:

- BCA levels would have a significant negative impact on major sectors of the defense industrial base: The FY16 Presidential Budget included considerations and mitigation strategies necessary for a healthy industrial base capable of providing critical capabilities to the DoD. However, many of the DoD's remediation efforts to protect high risk sectors and tiers may be at risk under the BCA.
- The DoD's future actions to reduce the potential impact of BCA16 on the industrial base will depend on the cuts across the Services to reduce costs while balancing force structure, readiness, and capability to meet current and future national security demands.
- Policy changes and additional actions may be necessary to sustain the industrial base.

- The DoD can take the following steps to help sustain high-risk sectors and tiers under a BCA environment:
    - Develop acquisition strategies that promote competition while sustaining design and manufacturing skills.
    - Expand the use of available tools and program[2] to mitigate industrial base risks.
    - Continue working on FaC assessment to identify critical capabilities at risk and develop mitigation strategies through groups like the Joint Industrial Base Working Group (JIBWG)[3] and the Industrial Base Counsel (IBC).[4]

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[2] Examples of industrial base tools and programs include the Industrial Base Analysis and Sustainment (IBAS) funds, the ManTech program, and Title III. IBAS provides temporary sustainment for critical defense-related industrial capabilities that are temporarily at risk of being lost. ManTech provides the primary investment mechanism for enabling defense essential manufacturing capability. Title III authorizes economic incentives to create, expand, or preserve critical domestic industrial manufacturing resources.

[3] The JIBWG conducts industrial base assessments and recommends investment priorities.

[4] The purpose of the IBC is to drive a forward-looking view of the defense industrial base enterprise, ensure alignment to overarching objectives, and enable more effective decision making at all levels. This group is comprised of executive leadership who will set priorities for the defense industrial base, including assessments, risk mitigation, and a clear pathway for escalation of issues.

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