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DEFENSE ACQUISITION RESEARCH JOURNAL
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RISK IN BUSINESS

DAU

October 2022 Vol. 29 No. 4 | ISSUE 102

ARTICLE LIST

ARJ EXTRA

Innovation Transition Success: Practice Doesn't Make Perfect

Maj Kaitlyn Ryan, USAF, Lt Col Amy Cox, USAF, 1st Lt Ethan Blake, USAF, Lt Col Clay Koschnick, USAF, and Alfred E. Thal

Assessing Policy Changes on the Cost of Husbanding Services for Navy Ships

Margaret Hauser, Geraldo Ferrer, and COL Robert F. Mortlock, USA (Ret.)

Phasing Risk in Aircraft Development Programs

Gregory E. Brown

The Defense Acquisition Professional Reading List

A History of Government Contracting (2nd ed)
Written by James F. Nagle and reviewed by John Krieger

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Written by Robert Foxcurran and reviewed by Paul Spitzer

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ISSN 2156-8391 (print) and ISSN 2156-8405 (online)
DOI: https://doi.org/10.22594/dau.102022-102.29.04

The *Defense Acquisition Research Journal*, formerly the *Defense Acquisition Review Journal*, is published quarterly by the DAU Press and is an official publication of the Department of Defense. Postage is paid at the U.S. Postal facility, Fort Belvoir, VA, and at additional U.S. Postal facilities. Postmaster, send address changes to: Editor, *Defense Acquisition Research Journal*, DAU Press, 9820 Belvoir Road, Suite 3, Fort Belvoir, VA 22060-5565. The journal-level DOI is: https://doi.org/10.22594/dauARJ.issn.2156-8391. Some photos appearing in this publication may be digitally enhanced.

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Phasing Risk in Aircraft Development Programs

Gregory E. Brown

In this article, the author uses historic cost growth patterns to forecast the phasing of risk dollars for new development programs. Data taken from 21 completed aircraft programs show that, on average, 85% of cost growth happens in the second half of the planned development schedule, indicating that risk dollars should generally be "backloaded" for new programs.

CONTENTS | Featured Research

FROM THE CHAIRMAN AND EXECUTIVE EDITOR

Dr. Larrie D. Ferreiro

The theme for this issue is “Risk in Business,” a nod to the 1983 film with Tom Cruise, who this summer (2022) stars in *Top Gun: Maverick*, which begins with a high-stakes defense acquisition scenario involving a prototype hypersonic aircraft. That film, as well as the articles and book reviews in this issue, all touch on the inherent nature of defense acquisition, which is to identify and manage the unknowns.

The first paper, “Innovation Transition Success: Practice Doesn’t Make Perfect” by Kaitlyn Ryan, Amy Cox, Ethan Blake, Clay Koschnick, and Alfred Thal, discusses Small Business Innovation Research (SBIR) programs. The authors analyze the effectiveness of SBIR investments for encouraging innovation and development. They find that compared with large enterprises, small businesses have a small but significant increase in commercialization rate (2.6% greater).

The second paper, by Margaret Hauser, Geraldo Ferrer, and Robert Mortlock, is “Assessing Policy Changes on the Cost of Husbanding Services for Navy Ships.” It reflects on some of the changes and reforms to the Navy’s husbanding service protocols in the wake of the Fat Leonard Scandal. The authors demonstrate that more formalized processes and increased competition in awards have netted an overall decrease in the cost of these services.

The third paper is "Phasing Risk in Aircraft Development Programs," by Gregory Brown. It presents a method of modeling and projecting the effectiveness of risk dollars. Given that most program growth occurs in the second half of the planned development schedule, the author recommends allocating risk dollars for new programs in phases that increase later in the program schedule.

This issue's Current Research Resources in Defense Acquisition focuses on Great Power Competition.

The first featured work in the Defense Acquisition Reading List book review is *A History of Government Contracting (2nd ed.)* by James F. Nagle, reviewed by John Krieger. The second work is *NATO: A Business History* by Robert Foxcurran, reviewed by Dr. Paul Spitzer.

Dr. Mary Redshaw has left the Editorial Board. We thank her for her service.

We welcome COL Robert L. Ralston, USA, to the Editorial Board.

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RESEARCH AGENDA 2022

This Research Agenda is intended to make researchers aware of the topics that are, or should be, of particular concern to the broad defense acquisition community in the government, academic, and industrial sectors. It is compiled using inputs from subject matter experts (SMEs) across those sectors. These topics are periodically vetted and updated as needed to ensure they address current areas of strategic interest.

The purpose of conducting research in these areas is to provide solid, empirically based findings to create a broad body of knowledge that can inform the development of policies, procedures, and processes in defense acquisition, and to help shape the thought leadership for the acquisition community. These research topics should be considered guidelines to help investigators form their own research questions. Some questions may cross topics and thus appear in multiple research areas.

Potential researchers are encouraged to contact the DAU Director of Research (research@dau.edu) to suggest additional research questions and topics, or with any questions on the topics.

Affordability and Cost Growth

- Define or bound “affordability” in the defense portfolio. What is it? How will we know if something is affordable or unaffordable?

- What means are there (or can be developed) to measure, manage, and control "affordability" at the Program Office level? At the industry level? How do we determine their effectiveness?
- What means are there (or can be developed) to measure, manage, and control "Should Cost" estimates at the Service, component, program executive, program office, and industry levels? How do we determine their effectiveness?
- What means are there (or can be developed) to evaluate and compare incentives for achieving "Should Cost" at the Service, component, program executive, program office, and industry levels?
- Recent acquisition studies have noted the vast number of programs and projects that don't make it through the acquisition system and are subsequently cancelled. What would systematic root cause analyses reveal about the underlying reasons, whether and how these cancellations are detrimental, and how acquisition leaders might rectify problems?
- Do joint programs—at the inter-Service and international levels—result in cost growth or cost savings compared with single-Service (or single-nation) acquisition? What are the specific mechanisms for cost savings or growth at each stage of acquisition? Do the data lend support to "jointness" across the board, or only at specific stages of a program (e.g., only at Research and Development [R&D]), or only with specific aspects, such as critical systems or logistics?
- Can we compare systems with significantly increased capability developed in the commercial market to Department of Defense (DoD)-developed systems of similar characteristics?
- Is there a misalignment between industry and government priorities that causes the cost of such systems to grow significantly faster than inflation?
- If so, can we identify why this misalignment arises? What relationship (if any) does it have to industry's required focus on shareholder value and/or profit, versus the government's charter to deliver specific capabilities for the least total ownership costs?

Industrial Productivity and Innovation

Industry insight and oversight

- What means are there (or can be developed) to measure the level of oversight and/or control that government has over subcontractors?
- What means are there (or can be developed) to measure costs of enforcement (e.g., auditors) versus actual savings from enforcement?
- What means are there (or can be developed) to evaluate and compare incentives for subcontractor/supply chain competition and efficiencies?
- What means are there (or can be developed) to evaluate and compare market-based incentives with regulatory incentives?
- How can we perform institutional analyses of the behaviors of acquisition organizations that incentivize productivity?
- What means are there (or can be developed) to evaluate and compare the barriers of entry for SMEs in defense acquisition versus other industrial sectors?
- Is there a way to measure how and where market incentives are more effective than regulation, and vice versa?
- Do we have (or can we develop) methods to measure the effect of government requirements on increased overhead costs, at both government and industrial levels?

- Examine the possibilities to rationalize and balance the portfolio of capabilities through buying larger quantities of common systems/subsystems/components across Defense Agencies and Services. Are there examples from commercial procurement and international defense acquisition that have produced positive outcomes?
- Can principal-agent theory be used to analyze defense procurement realities? How?
- What means are there (or can be developed) to measure the effect on defense acquisition costs of maintaining the industrial base in various sectors?
- What means are there (or can be developed) of measuring the effect of utilizing defense industrial infrastructure for commercial manufacture, particularly in growth industries? In other words, can we measure the effect of using defense manufacturing to expand the buyer base?
- What means are there (or can be developed) to measure the breadth and depth of the industrial base in various sectors that go beyond a simple head count of providers?
- Has change in the industrial base resulted in actual change in output? How is that measured?

Independent Research and Development

- What means do we require to measure the cost-effectiveness or return on investment (ROI) for DoD-reimbursed independent research and development (IR&D)?
- Can we properly account for sales and revenues that are products of IR&D?
- Can we properly account for the barriers to entry for SMEs in terms of IR&D?
- Examine industry trends in IR&D, for example, percentage of revenue devoted to IR&D, collaboration with academia. How do they vary by industry sector—in particular, those associated with defense acquisition?
- What means are there (or can be developed) to measure the ROI for DoD-reimbursed IR&D versus directly funded defense R&D?
- What incentive structures will motivate industry to focus on and fund disruptive technologies?
- What impact has IR&D had on the development of disruptive technologies?

Competition

Measuring the effects of competition

- What means are there (or can be developed) to measure the effect on defense acquisition costs of maintaining an industrial base in various sectors?
- What means are there (or can be developed) for measuring the effect of utilizing defense industrial infrastructure for commercial manufacture, particularly in growth industries? In other words, can we measure the effect of using defense manufacturing to expand the buyer base?
- What means are there (or can be developed) to determine the degree of openness that exists in competitive awards?
- What are the different effects of the two, best value, source selection processes (trade-off versus lowest price technically acceptable) on program cost, schedule, and performance?

Strategic competition

- Is there evidence that competition between system portfolios is an effective means of controlling price and costs?
- Does lack of competition automatically mean higher prices? For example, can sole source reduce overall administrative costs at both the government and industry levels, thereby lowering total costs?
- Describe the long-term historical trends for competition guidance and practice in defense acquisition policies and practices.
- To what extent are contracts awarded noncompetitively by congressional mandate for policy interest reasons? What is the effect on contract price and performance?
- What means exist (or can be developed) to determine the degree to which competitive program costs are negatively affected by laws and regulations such as the Berry Amendment, Buy American Act, etc.?
- The DoD should have enormous buying power and the ability to influence supplier prices. Is this the case? Examine the potential change in cost performance due to greater centralization of buying organizations or strategies.

Effects of industrial base

- What are the effects on program cost, schedule, and performance of having more or fewer competitors? What measures are there to determine these effects?
- What means are there (or can be developed) to measure the breadth and depth of the industrial base in various sectors, that go beyond a simple head count of providers?
- Has the change in industrial base changed the output? How is that measured?

Competitive contracting

- Commercial industry often cultivates long-term, exclusive (noncompetitive) supply chain relationships. Does this model have any application to defense acquisition? Under what conditions/circumstances?
- What is the effect on program cost performance of awards based on varying levels of competition: (a) “Effective Competition” (two or more offers); (b) “Ineffective Competition” (only one offer received in response to competitive solicitation); (c) “Split Awards” versus winner take all; and (d) “Sole Source.”

Improve DoD outreach for technology and products from global markets

- How have militaries in the past benefitted from global technology development?
- How/why have militaries missed the largest technological advances?
- What are the key areas that require DoD focus and attention in the coming years to maintain or enhance the technological advantage of its weapons systems and equipment?
- What types of efforts should DoD consider pursuing to increase the breadth and depth of technology push efforts in DoD acquisition programs?
- How effectively are DoD's global Science and Technology (S&T) investments transitioned into DoD acquisition programs?

- Are managers of DoD's applied R&D (i.e., acquisition program) investments effectively pursuing and using sources of global technology to affordably meet current and future DoD acquisition program requirements? If not, what steps could DoD take to improve its performance in these two areas?
- What are the strengths and weaknesses of DoD's global defense technology investment approach as compared to the approaches used by other nations?
- What are the strengths and weaknesses of DoD's global defense technology investment approach as compared to the approaches used by the private sector—both domestic and foreign entities (companies, universities, private-public partnerships, think tanks, etc.)?
- How does DoD currently assess the relative benefits and risks associated with global versus U.S. sourcing of key technologies used in DoD acquisition programs? How could DoD improve its policies and procedures in this area to enhance the benefits of global technology sourcing while minimizing potential risks?
- How could current DoD/U.S. Government Technology Security and Foreign Disclosure (TSFD) decision-making policies and processes be improved to help DoD better balance the benefits and risks associated with potential global sourcing of key technologies used in current and future DoD acquisition programs?
- How do DoD primes and key subcontractors currently assess the relative benefits and risks associated with global versus U.S. sourcing of key technologies used in DoD acquisition programs? How could they improve their contractor policies and procedures in this area to enhance the benefits of global technology sourcing while minimizing potential risks?
- How could current U.S. Government Export Control system decision-making policies and processes be improved to help DoD better balance the benefits and risks associated with potential global sourcing of key technologies used in current and future DoD acquisition programs?

Comparative studies

- Compare the industrial policies of military acquisition in different nations and the policy impacts on acquisition outcomes.
- Compare the cost and contract performance of highly regulated public utilities with nonregulated “natural monopolies” (e.g., military satellites, warship building).
- Compare contracting/competition practices of DoD with the commercial sector in regard to complex, custom-built products (e.g., offshore oil platforms).
- Compare program cost performance in various market sectors: highly competitive (multiple offerors), limited (two of three offerors), or monopoly?
- Compare the cost and contract performance of military acquisition programs in nations having single “purple” acquisition organizations with those having Service-level acquisition agencies.

Cybersecurity

General questions

- How can we perform analyses of the investment savings associated with implementation of robust cybersecurity measures?

- How can we measure the cybersecurity benefits associated with using continuous integration and continuous deployment methodologies?
- How can we cost the discrete elements of cybersecurity that ensure operational effectiveness within the categories of system functions, mission execution, system performance, and system resilience?
- How can we assess the most effective methodologies for identifying threats quickly, assessing system risk, and developing countermeasures?
- How can we establish a repeatable process for incorporating a continuous Authorization to Operate (ATO) construct for all software-centric acquisition programs?
- How can we articulate cyber risk versus operational risk so Combatant Commands (COCOMs) can be better informed when accepting new software?

Costs associated with cybersecurity

- What are the cost implications of (adding) cybersecurity to a program?
- What are reasonable benchmarks for cybersecurity cost as a percentage of Prime Mission Product (PMP)?
- What are the key cost drivers associated with cybersecurity?
- Is cybersecurity best estimated as a below-the-line common element (similar to Systems Engineering/Program Management or Training) or a PMP element?
- How are risks associated with not incorporating cybersecurity appropriately best quantified/monetized?

Acquisition of Services

Metrics

- What metrics are currently collected and available on services acquisition:
    - Within the DoD?
    - Within the U.S. Government?
    - Outside of the U.S. Government?
- What and how much do these metrics tell us about services acquisition in general and about the specific programs for which the metrics are collected?
- What are the possible metrics that could be used in evaluating services acquisition programs?
    - How many metrics should be used?
    - What is the efficacy of each metric?
    - What is the predictive power of each metric?
    - What is the interdependence (overlap) between metrics?
- How do we collect data for services acquisition metrics?
    - What is being done with the data currently being collected?
    - Are the data being collected on services acquisition reliable?
    - Is the collection process affecting the data collected for services acquisition?
- How do we measure the impact of different government requirements on overhead costs and rates on services contracts?

Industrial base

- What is the right amount of contracted services for government organizations?
    - What are the parameters that affect Make/Buy decisions in government services?
    - How do the different parameters interact and affect government force management and industry research availability?
- What are the advantages, disadvantages, and impacts of capping pass-through costs, and how do they change with the value of the pass-through costs?
- Do Base Operations and Support (BOS) contracts have a best size? Should large BOS contracts be broken up? What are the parameters that should be considered?
- In the management of large service contracts, what is the best organization? Is the System Program Office a good model? What parameters should be used in evaluating the advantages and disadvantages of an organization to manage large service contracts?
- What effect does strategic sourcing and category management have on small business if the small business is a strategic source or whether the small business is not a strategic source?
- Do the on-ramping and off-ramping requirements of some service contracts have an effect on the industrial base? If so, what are the impacts?

Industry practices

- What private sector business practices, other than maximizing profit, can the government effectively use to incentivize performance and otherwise improve business relationships with vendors?
- What are the best methods for evaluating different incentives to encourage small businesses to participate in government services contracts?
- What potential benefits can the government achieve from long-term supply chain relationships? What are the disadvantages?
- What benefits does industry get from the use of category managers and functional domain experts, and can the government achieve the same benefits?
- How can the government best capture, validate, and use demand management strategies?
- Are current service acquisition taxonomies comprehensive, or can they be improved?

Make/Buy

- What methods can best be used to define the cost-value relationship in different classes of service contracts?
- Can we develop a method for determining the “should cost” of different services?
- Can we define and bound affordability of specific services?
- What are the characteristics of “inherently governmental” activities, and how can we evaluate the value of these services based on comparable characteristics in a competitive labor market?

- In service contracts, what are the inherent life-cycle costs, and how do we capture the life-cycle costs in Make/Buy decision making?
- In the case of government services contracting, what are the factors that contribute to less-than-optimum Make/Buy decision making?

Category management/strategic sourcing

- What effect does strategic sourcing/category management have on competition?
  - Effects on short term versus long term.
  - Effects on competition outside of the strategic sourcing/category management area of consideration.
- What metrics do different industries use for measuring the effectiveness of their supply chain management?
- Would the centralization of service acquisition contracts have measurable impacts on cost performance? Why or why not?
- What are the fundamental differences between the service taxonomy and the category management taxonomy, and are there means and good reasons to align the two taxonomies?

Contract management/efficacy

- What are the best ways to address the service parts of contracts that include both services and products (goods)?
- In the management of service contracts, what are the non-value-added tasks, and are there realistic ways to reduce the impact of these tasks on our process?
- When funds for services are provided via pass-throughs (i.e., from another organization), how are the requirements tracked, validated, and reviewed?
- Do Undefinitized Contract Actions have an effect on contractor pricing and willingness, or lack of willingness to provide support during proposal analysis?
- For multiaward, Indefinite-Delivery, Indefinite-Quantity (IDIQ)-type contracts, is there a method for optimizing the different characteristics (number of vendors, timelines, on-ramping, off-ramping, etc.) of these contracts?

Policy

- What current government policies inhibit alignment of contractors' approaches with the government's service acquisition programs?

Administrative Processes

- What means are there (or can be developed) to measure the efficiency and effectiveness of DoD oversight, at the Component, Service, and Office of the Secretary of Defense levels?
- What measures are there (or can be developed) to evaluate and compare the costs of oversight versus the cost savings from improved processes?
- What means are there (or can be developed) to empirically establish oversight process metrics as a basis for comparison? Can these be used to establish the relationship of oversight to cost/schedule/performance outcomes?
- What means are there (or can be developed) to study the organizational and governance frameworks, resulting in successful change management?

- To what extent (investment and performance) can scenario/simulation testing improve the delivery of complex projects?
- Is there a comparative statistical divergence between organizational honesty (reality) and contractual relationships (intent) in tendering?
- How does one formulate relational contracting frameworks to better account for and manage risk and liability in a collaborative environment?

Human Capital of Acquisition Workforce

- What means are there (or can be developed) to measure return on investment (ROI) for acquisition workforce training?
- What elements of the Professional Military Education framework can be applied to improve the professionalism of the civilian Defense Acquisition Workforce?
- What factors contribute to the management and successful delivery of modern complex project management, including performance over the project life cycle?
- What behavioral leadership characteristics can be commonly observed in successful complex projects, contrasted against unsuccessful complex projects?
- What is the functional role of talent management in building organizational sustainability, performance, and leadership?
- How do we create incentives in the acquisition workforce (management, career, social, organizational) that provide real cost reductions?

Defense Business Systems

Organizational structure and culture in support of Agile software development methodologies

- At the beginning of the Business Capability Acquisition Cycle (BCAC) process, various steps are used to ensure accurate requirements are thoroughly documented and supported throughout the software development life cycle. How can these documentation requirements and processes be streamlined to support more direct-line communication between the end-user and software engineers? What are the hurdles to implementing these changes and how are they overcome? What are the effects of these changes on the organization or agency?
- Regarding new starts, how can the BCAC be modified specifically to support Agile development? How are these changes advantageous or disadvantageous to the customer and organization? Would these changes be helpful or detrimental to R&D versus a concurrent design and engineering software project?
- Generally, readiness review briefings within the BCAC are used to determine if a project is at an acceptable state to go to the next step in the process. If software is developed and released to production within a single sprint (potentially every 2 weeks), how are test readiness reviews, systems requirements reviews, and production readiness reviews handled? How have the changes to these events made them more or less relevant?

- How are organizations and agencies structured to support concurrent software design and development? What organizational structure would support R&D and non-R&D information technology (IT) capabilities?
- What steps are used to choose Agile as the default software development process versus any other software development methodology (e.g., Waterfall, Spiral, or Incremental) for your organization? What are the effects on project cost, schedule, and performance?
- Within DoD agencies and military branches, has the adoption of Agile resulted in faster deployment of new IT capabilities to the customer? How is this determined and measured?
- Industry often produces software using Agile. The DoD's BCAC process can produce an abundance of bureaucracy counter to Agile principles. How does hiring a contractor to implement or maintain IT capabilities and introducing Agile software development methods within a BCAC non-Agile process create conflict? How are these conflicts resolved or reconciled?
- How is IT engineering investment and innovation supported throughout DoD? What organizational or cultural aspects of an agency are specific to that support?

Defense Acquisition and Society

- To what extent should the DoD use the defense acquisition process to effectuate various social policies? The existing procurement regime favors a dizzying array of private interests ranging from organized labor; domestic manufacturers and firms located in areas of high unemployment; small businesses, including disadvantaged and women-owned firms; blind, severely handicapped, and prison industries; and, most recently, environmentally friendly vendors. Affirmatively steering the government's business from the open marketplace to preferred providers adds complexity, thus increasing transaction costs throughout the procurement process, which absorbs scarce resources. (Source: IBM Center for the Business of Government, http://www.businessofgovernment.org)
- How significant are the transaction costs resulting from the administration's commitment to transparency (generally, and specifically in the context of stimulus or recovery spending)? In a representative democracy, transparency is critical. But transparency is expensive and time-consuming, and the additional resources required to comply with the recently enhanced disclosure standards remain an unfunded mandate. Thus, the existing acquisition workforce must devote scarce resources to an (admittedly legitimate) end other than the pursuit of value for money or customer satisfaction. Is there an optimal balance or a point of diminishing returns? In other words, at what point does the cost of developing transparent systems and measures exceed the benefits of that transparency? (Source: IBM Center for the Business of Government, http://www.businessofgovernment.org)

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ISSUE 102
OCTOBER 2022
VOL. 29 NO. 4

INNOVATION TRANSITION SUCCESS: Practice DOESN'T MAKE Perfect

Maj Kaitlyn Ryan, USAF, Lt Col Amy Cox, USAF, 1st Lt Ethan Blake, USAF, Lt Col Clay Koschnick, USAF, and Alfred E. Thal

The authors of this research examine and evaluate organizational factors associated with commercialization under the Air Force Small Business Innovation Research (SBIR) program. Their objective is to improve return on investment.

The data set used was the SBIR Phase II program data set, which contains information on 433 SBIR topics with closed contracts reported during Department of Defense (DoD) fiscal years (FYs) 2015 to 2018. Each data point contained characteristics of the topic, including commercialization. Military capability or topic areas were hypothesized to have varying commercialization rates. Incumbency was theorized to be a characteristic of successful programs, while increased company size was theorized as a characteristic of unsuccessful programs. Variables were analyzed through graphs and logistic regression.

Image designed by Nicole Brate

Small businesses (1 to 31 employees) have a 2.6% increased commercialization rate compared to large businesses (32 to 499 employees); this increase is significant when compared to the 8.8% global success rate of SBIR projects. No learning effect or improved performance was observed between companies new to the SBIR program (fewer than 14 contracts) and incumbents (15–419 contracts). The opposite—learning—was observed with new entrants outperforming incumbents. A bump in the data appears for newer entrants with some experience.

In FY 2019, DoD obligated $1.8 billion in SBIR funding, and previous research indicated the commercialization rate of SBIR Phase II contracts is approximately 8.8%. This exploratory research looks at factors and trends seen in successful programs. Findings indicate factors that may guide investment choices to improve commercialization rates.

DOI: https://doi.org/10.22594/dau.21-872.29.04

Keywords: *Small Business, Small Business Innovation Research (SBIR), Commercialization, Company Characteristics, Acquisition, Defense Innovation*

This research focuses on the performance of Small Business Innovation Research (SBIR) investments in defense-related technologies. Understanding the performance of SBIR investments can provide insight into better investment strategies, and thus more effective interaction with the commercial sector. The National Defense Strategy recognizes that many technological developments will come from the commercial sector (Mattis, 2018). Innovation has the potential to drive economic growth and international competitiveness (Balzat, 2006). While innovation involves the generation, adoption, implementation, and incorporation of new ideas, practices, and artifacts (Van de Ven & Poole, 1989), our measure of performance considers the actual commercialization of innovation beyond early investment.

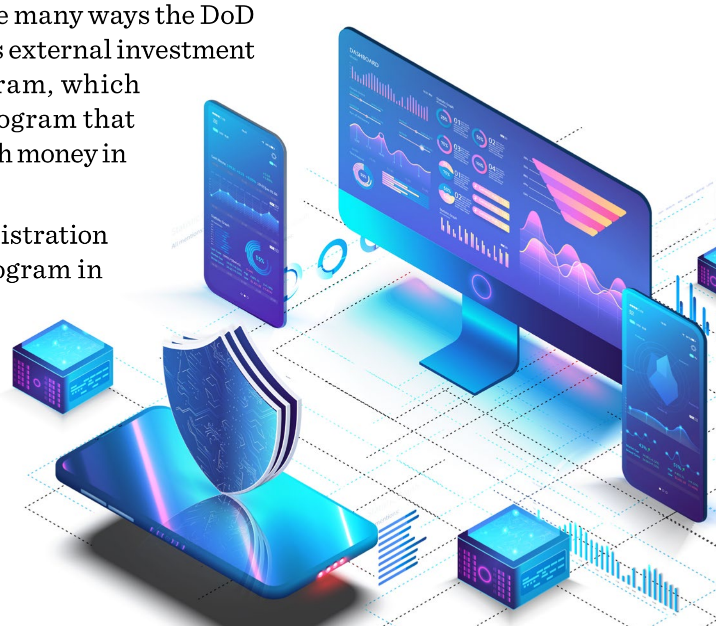
Our ability to innovate effectively has strategic importance. The national security of the United States depends on the ability to gain access to and make the best use of innovations. The 2018 National Defense Strategy (Mattis, 2018) highlights this role of innovation.

> Success no longer goes to the country that develops a new technology first, but rather to the one that better integrates it and adapts its way of fighting. (p. 10)
>
> —James Mattis, Secretary of Defense

Regardless of strategic focus, whether international terrorism or the rival powers of Russia and China, our ability to develop and infuse innovation is crucial to our nation's defense.

While internal investments (e.g., Air Force Research Laboratory) are important to developing defense-focused technologies, our ability to foster and leverage innovation in our industrial base is vital. The Department of Defense (DoD) faces the challenges of attracting these external innovators and bringing their ideas to fruition in a way that enhances the capability of the armed forces. One of the many ways the DoD attempts to accomplish this external investment is through the SBIR program, which is a federal government program that deliberately invests research money in small businesses.

The Small Business Administration (SBA) started the SBIR program in 1977 to support innovation through the investment of federal research funds



in critical American priorities to build a strong national economy. The SBA (n.d.) explains how the program was established under the Small Business Innovation Development Act of 1982 (Small Business Innovation Development Act, 1982), with the purpose of strengthening the role of innovative small business concerns in federally funded research and development (R&D). Through a competitive awards-based program, SBIR allows "small businesses to explore their technological potential and provides the incentive to profit from its commercialization" (SBIR | STTR, n.d., para. 1). Beyond the critical technologies and access to external innovators, SBIR investments serve as an economic stimulus to strengthen the industrial base. Known as "America's Seed Fund," SBIR works to stimulate high-tech innovation in the United States while targeting specific research and development needs of the government (SBIR | STTR, n.d.). SBIR is one of the largest DoD-backed innovation programs in operation. In Fiscal Year (FY) 2019, the DoD obligated $1.8 billion in SBIR funding. SBIR investments target a specific segment of innovators within the domestic economy—small businesses.

To participate in the SBIR program, firms must be eligible, have an adequate plan to accomplish the required research, and conduct the research within the United States.

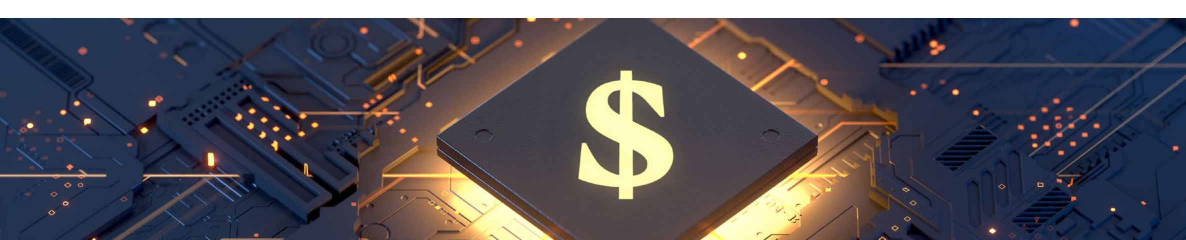
Traditionally, the Air Force has followed a "pull" model of innovation with SBIR investments by broadcasting its needs to participating small businesses. These needs are based on topics generated throughout the Air Force. Capability needs (i.e., SBIR topics) are published and small businesses reply with proposals. Accepted proposals, regardless of sponsor, follow a three-phase program. Table 1 provides descriptions of the phases, along with their funding and timing. To participate in the SBIR program, firms must be eligible, have an adequate plan to accomplish the required research, and conduct the research within the United States. Eligibility is restricted to businesses with 500 or fewer employees and is established on initial application as well as through certifications at other times during participation. Participating firms must also provide plans to meet research requirements for Phase I and II. The research must be done in the United States unless the funding agreement officer recognizes a unique circumstance that demands otherwise. If the small business qualifies, then the business will be eligible to participate.

TABLE 1. PHASES OF SBIR PROGRAMS

Phase	Objective	Funding	Period of Performance
Phase I	Establish technical merit, feasibility, and commercial potential; complete at least one third of required research.	<$150,000 (SBIR)	6 months
Phase II	Assess scientific and technical merit and commercial potential; complete an additional half of the required research for the program.	<$1,000,000 (SBIR)	24 months
Phase III	Commercialization	Other sources	N/A

This research considered programs that met the basic eligibility and planning for Phase I; additionally, researchers met more rigorous requirements established for Phase II. To secure Phase II award, all programs developed commercialization plans. Elements of SBIR commercialization plans can include company information, customer data, data on competition, market assessments, data regarding intellectual property, and financing. Further, award of Phase II requires the submittal of a business plan, executive summary, cost proposal, and technical proposal. This documentation undergoes a rigorous review process to ensure that only the most meritorious scientific proposals are funded (Kelly & Sensenig, 2019).

An SBIR project is considered successful when the product is commercialized. Commercialization occurs when a project progresses beyond seed funding through SBIR to longer term governmental or commercial funding (SBIR | STTR, n.d.). Transition into Phase III represents this commercialization; programs in Phase III transition into the broader Service branches or agencies that need them (Bresler, 2018). Air Force SBIR programs from 2015 to 2018, which represents our data set, had a Phase II to Phase III transition rate of 8.8% (Blake, 2020; Rask, 2019).



Considering the degree of need for DoD investment and innovation throughout the nation, understanding the factors that can influence the success or failure of these programs is valuable. Success in SBIR programs occurs when the programs transition from government seed funds to external funds or non-SBIR funds, whether governmental or commercial. While ideation and prototyping are outputs of this process, innovation is considered successful when the invention is implemented and adopted (Fagerberg & Mowery, 2006). This transition, from seed funds to external funds, is defined as commercialization, and it is the accepted measure of success for SBIR programs (SBIR | STTR, n.d.).

This research analyzes 433 Air Force SBIR projects from 2015 to 2018 to discern factors related to their transition success. This set includes only programs that have successfully demonstrated technical feasibility and have completed a contracted research and development phase (e.g., Phase I and II completed). This 3-year baseline represents a time of relative stability, before the more recent phase of experimentation witnessed with AFWERX and other organizations. The stability of this baseline allows for a factor analysis across this broad set of projects; it also enables a stable point of comparison for recent efforts. Air Force SBIR projects were selected due to availability of data and sponsorship by the Air Force SBIR office.

> **Success in SBIR programs occurs when the programs transition from government seed funds to external funds or non-SBIR funds, whether governmental or commercial.**

We consider two levels of analysis: the entire portfolio and capability-based segments. Air Force investments are diverse, ranging from landing gear corrosion prevention to artificial intelligence algorithms to bolster battlespace awareness. Segmentation permits a more nuanced comparison of investments and transition both within the portfolio and across military capability. Capability-based portfolio segmentation was accomplished in previous research (Rask, 2019) and leveraged the well-established Joint Capability Area (JCA) taxonomy, which provides common language for DoD capabilities (Joint Chiefs of Staff, 2018).

Our focus is on factors that are known preaward: What factors can we know in advance of award that may influence the decision of the Air Force SBIR office? Based on what we can know, can we make choices that improve our success? Previous analysis found a commercialization rate of 8.8% (Blake, 2020; Rask, 2019). Considering the number of projects and investments, small improvements matter in this space. As an example, achieving a transition rate of 10% represents five additional capabilities transitioning to use. If factors that correlate to success can be determined, policy can be shaped to target improvements and increase the commercialization rate for our SBIR investments.

Two independent factors are considered: the size (number of employees) of the small business and experience (history of working with the government). The primary finding of this article relates to small business size; smaller businesses have a statistically significant transition advantage over their larger counterparts. Firms with 31 or fewer employees (n = 217) had a transition rate 2.6% higher than firms with 32 to 499 employees (n = 215). Our second finding relates to experience: no evidence supports a hypothesis that experience working with the government improves a firm's transition performance. Firms with an average of five contracts with the government (n = 217 contracts) had significant improvement in performance (commercialization) when compared to those with an average of 73 or more contracts with the government (n = 215 contracts).

Data Set

This research analyzes 433 Air Force SBIR projects from 2015 to 2018. This set includes only programs that both successfully demonstrated technical feasibility and completed a contracted research and development phase (e.g., Phase I and II completed). Further, the set considers only programs that reached the point of transition to Phase III and included programs that were either commercialized or not.

The 3-year baseline from 2015 to 2018 represents a time of relative stability. More recent innovation efforts have witnessed experimentation in investment strategies (e.g., AFWERX). The stability of this baseline allows for a factor analysis across this broad set of projects; it also provides a stable point of comparison for recent experimentation efforts. Additionally, since these data are less than 10 years old, relevant follow-on research, as needed, is facilitated. Ten years is considered recent enough to preserve accurate memories of key informants in the event that follow-on interviews or interaction are required.

This population provided for a consideration of the performance of external investments across a broad range of military capabilities and technologies. Consistent trends across the set and within capabilities permit generalization of the results beyond idiosyncrasies that may be present in certain technologies. The distribution of these investments across areas of military capability and their relative success are shown in Table 2.

TABLE 2. SBIR INVESTMENTS ACROSS MILITARY CAPABILITIES

Joint Capability Area	Number of Investments	Percent Successful
Force Support. The ability to establish, develop, and maintain a mission-ready Joint Force and build relationships with foreign and domestic partners.	9	22%
Battlespace Awareness. The ability to understand dispositions and intentions as well as the characteristics and conditions of the operational environment that bear on national and military decision making by leveraging all sources of information, including intelligence, surveillance, reconnaissance, meteorological, and oceanographic.	74	12%
Force Application. The ability to integrate maneuver and kinetic, electromagnetic, and informational fires to gain a position of advantage and/or create lethal or nonlethal effects on designated targets.	82	7%
Logistics. The ability to project and sustain the Joint Force.	78	4%
Command and Control. The ability to exercise authority and direction by a properly designated commander or decision maker over assigned and attached forces and resources in the accomplishment of the mission.	7	0%
Communication and Computers. The ability to exercise authority and direction by a properly designated commander or decision maker over assigned and attached forces and resources in the accomplishment of the mission.	73	8%
Protection. The ability to preserve the effectiveness and survivability of military and nonmilitary personnel, equipment, facilities, and infrastructure by preventing, mitigating, and ensuring recovery from attacks, chemical, biological, radiological and nuclear (CBRN) incidents, and other hazards.	19	10%
Corporate Management and Support. The ability to provide strategic senior-level, enterprise-wide leadership, direction, coordination, and oversight through a chief management officer function.	90	11%

Factors Considered

In addition to a project's commercialization (our dependent variable), we sought factors that are known in advance of investment. Analysis of *ex ante* factors may reveal trends that can enable prediction and inform investment strategies. Three of these factors were considered: (a) military capability area pursued (control variable), (b) historical firm engagement with the government (independent variable), and (c) firm size (independent variable). These areas were chosen due to data availability, qualitative observations of the data set, and theories from innovation research.

Our unit of analysis is individual SBIR topics. An SBIR topic is a description of need that is released to prospective innovators for their subsequent bids. The topics spanned technologies from novel anticorrosion coatings to global satellite command and control systems. Due to this diversity, a means to segment the portfolio for analysis was sought. Segmentation allows for cross-portfolio and within-segment analysis.

With increased organizational size, "effectiveness of internal knowledge flows dramatically diminishes and degree of intra-organizational knowledge sharing decreases" (Serenko et al., 2007, p. 614).

Previous research of this data set categorized each SBIR project based on the military capability area it satisfied (Rask, 2019). The Joint Staff's Joint Capability Area listing was used for this purpose (Joint Chiefs of Staff, 2018). This choice of an existing, defense-related taxonomy facilitates analysis focused on specific areas of military need.

The choice of capability-based segmentation blends two factors—technology and market segment for application. Certain capabilities rely on a limited set of technologies. Further, patterns of success and failure could be due to the maturity or market associated with a capability area. Where the force application capability area is uniquely military, communications and computers has a wide range of applications and could potentially represent a thriving commercial innovation base.

Our next two factors, incumbency and size, shift our attention from the technology being sought to characteristics of the firms completing the work. Incumbency is a measure of historic interaction with the government. We operationalize incumbency as the number of government contracts held by a firm. Contracting with the government introduces complexities for small firms (Schilling et al., 2017). We hypothesize that increased experience working with the government reduces these challenges; through iteration, a firm learns government processes and needs. As an extension, we assume that experience with the government should improve the probability of commercialization.

The size of a firm can have multiple effects on performance. Literature on innovation with the government points to administrative burdens that do not favor smaller firms (Schilling et al., 2017). However, innovation literature has observed higher performance in smaller and flatter organizations (Quinn, 1985). The larger an organization becomes, the more likely it is to develop a hierarchical structure that may reduce innovation performance (Kirsner, 2018). Further, with increased organizational size, "effectiveness of internal knowledge flow dramatically diminishes and degree of intra-organizational knowledge sharing decreases" (Serenko et al., 2007, p. 614). We hypothesize that smaller companies will perform better than larger companies, yet what small and large represent is not certain.

Methodology

The objective of this research is to understand factors that are correlated to SBIR project success with the aim of improved investments. The data set we used was the SBIR Phase II program data set, which contains information on 433 SBIR topics with closed contracts reported during DoD FYs 2015 to 2018.

Analysis

Two methods were used to analyze this data set: Logistic regression and hypothesis testing associated with population comparisons. The first method, logistic regression, was selected due to the binary characteristic of the dependent variable (e.g., whether or not a project transition occurred). This analysis technique can provide a probability of success as a function of independent variables (company size and recidivism). Military capability areas were included as control variables. These military capabilities were assigned as part of previous research in which a panel of raters categorized each project into one of eight joint capability areas (Rask, 2019).

We did not find a statistically significant relationship between transition success and the independent variables. Using an open-source development environment for statistical analysis, R Studio, the probability of commercialization was estimated by fitting a logistic regression model. A summary of the results from this model is reported in Table 3. *P*-values of 0.05 or less indicate significant results, which were not found in the set.

TABLE 3. LOGISTIC REGRESSION MODEL RESULTS

Variable	Coefficient	*P* Value	Average Marginal Effect
Number_Employees	-0.000714	0.760	-0.0001
Total_Awards	-0.004566	0.326	-0.0004
JCA_1	1.055896	0.247	0.0823
JCA_2	0.101916	0.836	0.0079
JCA_3	-0.383365	0.483	-0.0299
JCA_4	-0.871345	0.206	-0.0679
JCA_5	-14.250346	0.987	-1.1101
JCA_6	-0.299243	0.584	-0.0233
JCA_7	-0.063236	0.939	-0.0049

Note. JCA = Joint Capability Area.

TABLE 4. RECIDIVISM

Quartile	# Awards	# Commercialized	Success Rate	Quartile Size
1	≤4	8	7.2%	111
2	5–14	14	13.2%	106
3	15–35	8	7.3%	109
4	36–419	8	7.5%	106
Half	**# Awards**	**# Commercialized**	**Success Rate**	**Half Size**
1	≤14	22	10.1%	217
2	15–419	16	7.4%	215

This lack of correlation may be due to a lack of an effect. However, it may also be due to the variation within the data set even following segmentation. As mentioned earlier, the capability-based segmentation has at least two factors within it—technology and market. The set may still be too noisy with too many effects to discern a relationship.

Our second analysis method, hypothesis testing using population comparison, is a coarser analysis, allowing for a binary result. Are commercialization rates of populations the same or different, and if different, to what extent? For example, in Table 4, commercialization rates (success rates) of quartiles are not the same. This technique is more resilient to noise in the data; however, it does not provide a relationship between the variables.

We have made comparisons of subpopulations within the set determining whether commercialization in those populations is significantly different. Two separate analyses were completed with the data based on the independent variables of recidivism and company size. In both analyses, the performance of the upper and lower quartiles as well as the upper and lower halves of the sets were compared to determine whether a difference existed.

The data included companies with no previous government interaction, up to companies with over 400 SBIR contracts awarded. The set was broken into nearly even quartiles, and hypothesis testing was accomplished to compare the upper and lower quartiles (new entrants to experienced firms). This hypothesis testing was repeated with the set broken into two nearly even halves. The average number of contracts awarded was 39.

Table 4 provides the quartiles and halves and success rates for the variable. The lower quartile ranged from one to four awards (111 firms), while the upper quartile ranged from 36 to 419 awards (106 firms). The average success rates were 7.2% for the lower quartile and 7.5% for the upper quartile. No significant difference exists between new entrants and incumbent firms ($p = 0.10$). The lower half ranged from one to 14 awards (217 firms), while the upper half ranges from 15 to 419 awards (215 firms). The average success rates were 10.1% for the lower half and 7.4% for the upper half. Statistically significant difference does exist between new entrants and incumbent firms ($p = 0.10$). We expected that experienced companies would outperform new entrants. However, it appears that no clear learning or improved performance occurs as companies repeatedly interact with the SBIR program. Surprisingly, new entrants appear to have improved performance.

Of interest, a bump in the data appears when comparing the success rate of the second quartile to other quartiles. The second quartile ranged from five to 14 awards (106 firms) with a success rate of 13.2%. This is a statistically significant result when compared to all other quartiles ($p = 0.09$). It appears that newer entrants with some experience perform higher than either new entrants or incumbents with more extensive experience. The increase from the first to second quartile may be due to learning; however, what dynamics explain the drop in performance?

TABLE 5. COMPANY SIZE

Quartile	# Employees	# Commercialized	Success Rate	Quartile Size
1	≤14	11	9.4%	117
2	15–31	11	11.0%	100
3	32–95	7	6.5%	108
4	96–499	9	8.4%	107
Half	**# Employees**	**# Commercialized**	**Success Rate**	**Half Size**
1	≤31	22	10.1%	217
2	32–499	16	7.4%	215

Next, the population of projects was segmented based on size, where the lower quartile (companies with one to 14 employees) was compared to the upper quartile (from 96 to 500). The small companies did not have a statistically significant difference in performance from the larger companies. The lower half (companies with one to 31 employees) was compared to the upper half (32 to 499 employees). The success rates for both quartiles and halves are found in Table 5. The small companies had a commercialization rate of 10.1% whereas the larger companies had a rate of 7.4%. This difference was statistically significant ($p = 0.10$). Consistent with the literature, we find that smaller companies perform better than larger companies.

For both independent variables, we then considered performance within large portfolio categories. Comparisons between quartiles were accomplished (Tables 6–9); however, there were not enough data points to yield a statistically significant result. We are able to draw conclusions only based on the entire population and not the segments.

TABLE 6. BATTLESPACE AWARENESS				
Quartile	# Awards	# Commercialized	Success Rate	Quartile Size
1	≤5	3	15.8%	19
2	6–16	3	15.8%	19
3	17–31	2	11.1%	18
4	32–419	1	5.6%	18
Quartile	# Employees	# Commercialized	Success Rate	Quartile Size
1	≤15	3	15.8%	19
2	16–33	3	16.7%	18
3	34–78	2	10.5%	19
4	79–334	1	5.6%	18

TABLE 7. FORCE APPLICATION				
Quartile	# Awards	# Commercialized	Success Rate	Quartile Size
1	≤5	3	13.0%	23
2	6–13	2	11.1%	18
3	14–28	1	4.5%	22
4	29–419	0	0.0%	19
Quartile	# Employees	# Commercialized	Success Rate	Quartile Size
1	≤14	3	15.0%	20
2	15–25	2	9.5%	21
3	26–69	1	4.8%	21
4	70–482	0	0.0%	20

TABLE 8. COMMUNICATION AND COMPUTERS				
Quartile	# Awards	# Commercialized	Success Rate	Quartile Size
1	≤5	2	10.0%	20
2	6–14	1	5.6%	18
3	15–47	1	5.9%	17
4	48–419	2	11.1%	18
Quartile	# Employees	# Commercialized	Success Rate	Quartile Size
1	≤15	3	14.3%	21
2	16–30	1	6.3%	16
3	31–110	1	5.3%	19
4	111–334	1	5.9%	17

TABLE 9. CORPORATE MANAGEMENT AND SUPPORT

Quartile	# Awards	# Commercialized	Success Rate	Quartile Size
1	≤3	2	10.0%	20
2	4-6	2	13.0%	23
3	7-31	4	12.0%	25
4	32-151	2	9.1%	22
Quartile	**# Employees**	**# Commercialized**	**Success Rate**	**Quartile Size**
1	≤11	0	0.0%	23
2	12-34	6	27.3%	22
3	35-85	1	4.3%	23
4	86-494	3	13.6%	22

Finally, we examined the intersection of the two independent variables—recidivism and company size. The average company size of each recidivism quartile was determined (Table 10). Additionally, we determined the average number of awards for each company size quartile. It appears that newer entrants are also, on average, smaller companies. Alternatively, it appears that larger companies are, on average, the incumbent.

TABLE 10. COMPANY RECIDIVISM AND SIZE

Quartile	# Awards	Average Company Size	Success Rate	Quartile Size
1	≤4	32	7.2 %	111
2	5-14	43	13.2 %	106
3	15-35	73	7.3 %	109
4	36-419	125	7.5 %	106
Quartile	**# Employees**	**Average # Awards**	**Success Rate**	**Quartile Size**
1	≤14	6	9.4 %	117
2	15-31	17	11.0 %	100
3	32-95	41	6.5 %	108
4	96-499	100	8.4 %	107

Discussion of Results

Our results focus on patterns with the two independent variables—recidivism and company size. Overall, we found that new entrants outperformed incumbents and small companies have an advantage over larger companies. We will consider our findings, relative to these variables in turn. The findings have complementary ties to existing literature and merit either further experimentation, policy change, or some combination thereof.

Our initial hypothesis was that small business commercialization rates will improve as firms gain experience working with the government. Our results did not support that hypothesis; rather, they revealed a more nuanced behavior. In considering just the upper and lower quartiles of our set, new entrants to SBIR (fewer than four contracts, median three) had statistically indistinguishable performance from incumbents (36–419 contracts, median 102). We hypothesized that commercialization performance would improve as companies gained experience; however, performance of the most experienced companies (median of 102 contracts) was indistinguishable from those with the least (median of three contracts).

> **Consistent with the literature, we find that smaller companies perform better than larger companies.**

In expanding our analysis to compare the upper and lower halves of our population, we found that our initial hypothesis is reversed: the new entrants (fewer than 14 contracts) outperform the incumbents (15 to 419 contracts) by 2.6%. This difference in performance is driven entirely by companies in the second quartile (five to 14 contracts). These companies outperform all other quartiles by 6%. If we limit our hypothesis test to a comparison between the first quartile (one to four contracts) and second (five to 14 contracts), we see evidence of a learning effect—a 6% increase in performance. However, commercialization performance drops by 5.9% in the next quartile and stays at that level into the fourth quartile. This spike in performance in the second quartile warrants further consideration. While learning may explain the increased performance witnessed in the transition from the first to the second quartile, what dynamics are driving the 5.9% drop in performance in companies with more than 15 contracts?

This spike in performance in the second quartile possibly represents a convolution of effects: on one side, the expected benefits from learning; on the other, a separate dynamic. The literature provides a possible explanation for the subsequent drop in performance, the "SBIR mill" phenomenon (Lerner, 2000; Link & Scott, 2009). SBIR mills exploit the public policy underlying the SBIR program. They are firms that exist, at least in part, for the purpose of securing SBIR awards with no intent to commercialize (rent-seeking). These firms may be less innovative and less likely to commercialize than other firms (Link & Scott, 2009). They are alternately known as "frequent winners," a class of firms that underperforms yet accounts for a disproportionate rate of awards (*Federal Research,* 1999). The rent-seeking behavior of SBIR mills would account for a class of firms with high recidivism and low performance—a dynamic that may underlie the drop in performance beyond the second quartile.

The goal of the SBIR program is to encourage high-tech innovation in the United States. The DoD invests in those areas of interest to national defense. The scope of this article is limited to 433 Air Force SBIR projects from 2015 to 2018; other Services and organizations may incentivize adoption differently. Analysis indicates the average SBIR company in this data set had 39 contracts. This represents $6.7 million to $39 million in SBIR funding and 19.5–78 years in periods of performance. If no benefit is derived from recidivism, or worse, if firms have less than earnest intents, a limit to recidivism should be considered. Reducing recidivism or setting limits on recidivism is in line with the intent of the SBIR program. Awards of over 100 contracts (or more than 400) to a single firm provide repeated stimulus for a single firm versus an industrial base. Since the objective of the SBIR program is the stimulation of an economic base, a policy that limits participation to companies with fewer than 100 historic government contracts (or perhaps fewer) merits consideration.

Our first independent variable was recidivism—our second was firm size. Consistent with the innovation literature, we found that smaller firms outperform larger firms. Further, and perhaps a confounding of positive effects, new entrants (low recidivism) are on average, smaller companies.

Businesses with fewer than 31 employees (the lower half of our data) have a commercialization rate that is 2.6% higher than larger businesses (32 to 499 employees). Further experimentation and research are merited to determine effects based on company size; the overall low rate of success limited our ability to draw statistically significant conclusions for finer gradations (i.e., lower than quartiles) based on company size.

Since the objective of the SBIR program is the stimulation of an economic base, a policy that limits participation to companies with fewer than 100 historic government contracts (or perhaps fewer) merits consideration.

In considering our two independent variables, we find improved performance among new entrants (one to 14 contracts) and smaller firms (one to 30 employees). The improvement from favoring either new entrants or smaller firms is 2.6%. On the surface, this improvement appears modest. However, the global commercialization performance of this set was 8.8%; relative to that baseline, 2.6% is significant. To give some scale to this number, this data set represented 433 individual capability-development efforts; 2.6% translates to 11 novel capabilities. Further, considering the DoD investments ($1.8 billion in FY 2019), 2.6% represents roughly $47 million in investment. Small percentage gains from policy shifts can have real effects in the development of needed capabilities and in the efficacy of our investments.

Recommendations

Our analysis considered commercialization performance within Air Force SBIR investments. An external calibration or comparison to other similar programs is warranted. Comparison of commercialization rates of Air Force SBIR programs should be made to other SBIR programs as well as innovation programs in the commercial market. The approximately 8.8% rate of commercialization for Air Force SBIR programs may or may not be comparable to the innovation rates of the broader market. Such a comparison would help determine the relative success of the SBIR program and other opportunities to improve. This would inform value provided to the Warfighter. This future research could be furthered by comparing areas of innovation of SBIR programs to similar commercial endeavors.

Further research should be accomplished, specifically experimentation with policy to deliberately target new entrants or limit the number of previous awards allowed. This form of policy experimentation is in line with the objectives of the SBIR program. SBIR works to stimulate high-tech innovation in the United States while targeting specific research and development needs of the government versus enriching individual firms (SBIR | STTR, n.d.). The program does not meet its goal by repeatedly funding the same small businesses with no increased commercialization rate. Program eligibility and selection criteria could consider the number of previous SBIR awards. An investigation into the bump in commercialization rates in the second quartile would complement this research as well. A better understanding of the key dynamics that result in both the increase and subsequent decrease in performance could better inform limits to recidivism as well as other policy choices. This could be explored through analysis of learning effect for businesses.

Experimentation could also take place to further evaluate performance of "small." Again, limitation through program eligibility requirements or evaluation criteria of select programs could assist in confirming findings. Additionally, research should refine "small" company size. More gradation between a small company of one employee and a small company of 500 employees is needed. With a larger data set, those break points could be determined.

Further research should take place to determine the value associated with the Air Force SBIR programs. This should be conducted in two parts:

- First, by examining the overall value for money of the approximately 8.8% of programs that were commercialized. The commercialized Air Force SBIR programs could possibly represent a substantial return on investment.
- Second, by examining the value to the Warfighter. Advancements in capability or value provided to the Warfighter may be procured that are not represented strictly by commercialization.

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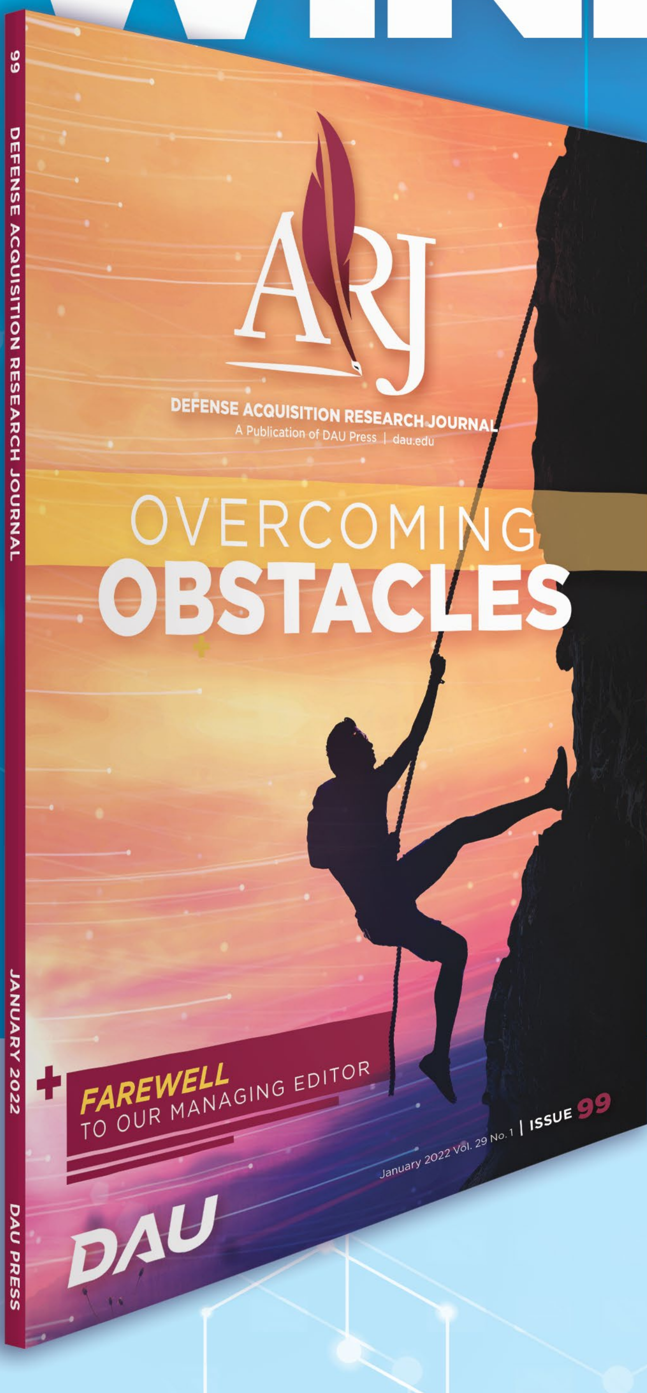

Nina Austin, Emily Beliles, Nicole Brate, and Christopher McGowan

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Fort Belvoir, VA

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ASSESSING Policy Changes ON THE COST OF HUSBANDING SERVICES for Navy Ships

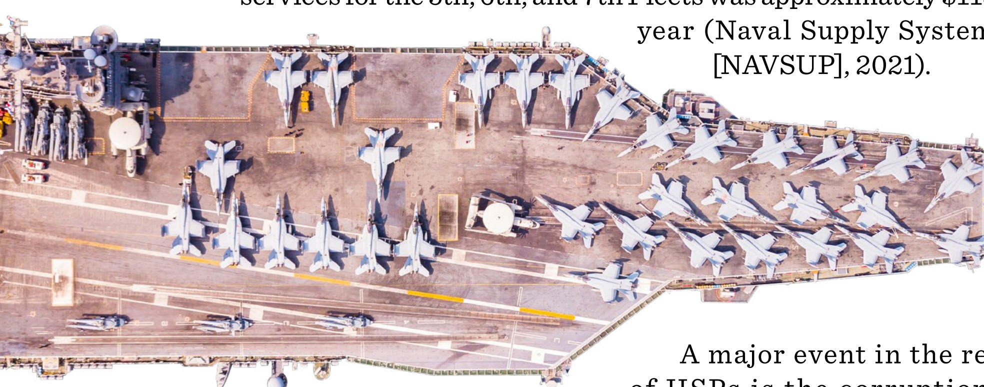
Margaret Hauser, Geraldo Ferrer, and COL Robert F. Mortlock, USA (Ret.)

In the wake of a major corruption conspiracy, the U.S. Navy reformed husbanding service procedures to increase competition, auditability, and accountability with the goal of reducing expenditures. The first policy change, Off-Ship Bill Pay (OSBP), formalized a process for procuring, rendering, and paying for husbanding services to increase oversight. The second policy change increased the use of multiple award contracts (MACs), in which multiple vendors are awarded a contract over a region, increasing competition for individual port visits. The purpose of this article is to analyze the effects of these policy changes on the cost of husbanding services. Multiple regression was used to account for port visit characteristics that affect cost such as ship type and the number of days in port. MACs demonstrated a reduction effect on the cost of port visits. Further, OSBP appears to have a negligible effect on port visit cost after the initial learning curve for both Navy personnel and vendors.

DOI: https://doi.org/10.22594/dau.21-884.29.04

Keywords: *Husbanding Services, Cost Modeling, Off-Ship Bill Pay (OSBP), Multiple Award Contract (MAC), Single Award Contract (SAC), Single Visit Contract (SVC)*

U.S. Navy vessels routinely make visits in non-U.S. ports for numerous reasons including resupply efforts, multinational exercises, and liberty, where husbanding services must be contracted from a commercial vendor, referred to as a husbanding service provider (HSP). Husbanding services include tugboats to guide vessels into and out of port; transportation services; waste removal and disposal; fuel, food, and water; and force protection equipment and services. HSPs provide essential services to Navy vessels that are "often rendered in remote locations where competition is limited, and where barriers, such as language and cultural differences, exist" (Whiteley et al., 2017, p. 1). From Fiscal Year (FY) 2010 to 2019, the dataset used in this study indicates that average spending on husbanding services for the 5th, 6th, and 7th Fleets was approximately $115 million each year (Naval Supply Systems Command [NAVSUP], 2021).

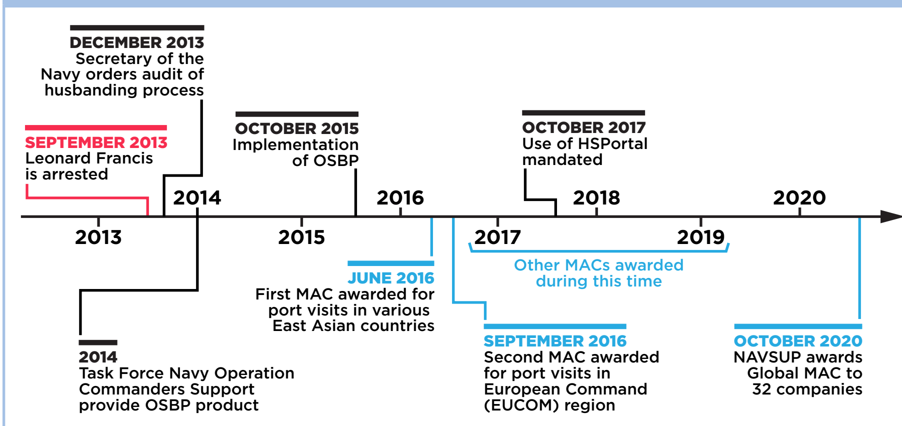


A major event in the recent history of HSPs is the corruption conspiracy known as the "Fat Leonard Scandal." Several U.S. Government officials, including Navy officers, began conspiring with Leonard Glenn Francis, the president and owner of the HSP Glenn Defense Marine Asia (GDMA), in early 2006 (Standifer, 2017). In exchange for extravagant meals, lavish hotel stays, and other expensive goods and services, Navy officials provided Francis with classified material about the movements of U.S. vessels, confidential contracting information, and additional contracting opportunities. This arrangement gave GDMA undue negotiating advantage, in addition to information about ongoing investigations into GDMA (Whiteley et al., 2017). GDMA held a monopoly on fuel and supplies in several Asian ports, making the U.S. Navy dependent on them for services despite overinflated prices (Whitlock, 2016). Allegedly, other vendors also committed bribery, fraud, price gouging, or bilking against the U.S. Government for profit to lesser degrees than Francis (Hyde, 2018).

Francis was arrested in September 2013, and the scandal motivated then-Secretary of the Navy Ray Mabus to order an audit of the current husbanding process. The Naval Audit Service (2014) noted that the Navy's model lacked internal controls.

> Acquiring husbanding and port services [did] not have sufficient internal controls in place to detect or deter fraud and abuse within all areas of the process...[such as] funding and scheduling of port visits...[and] the invoice review and payment process. (p. 2)

FIGURE 1. EVENT TIMELINE FOR HUSBANDING SERVICE POLICY AFTER THE ARREST OF LEONARD FRANCIS



Note. Events related to the adoption of MACs are highlighted in blue. HSPortal = Husbanding Services Portal; MAC = Multiple Award Contract; NAVSUP = Naval Supply Systems Command; OSBP = Off-Ship Bill Pay.

In response to the 2014 Naval Audit Service audit report, the Navy reformed its husbanding processes by implementing Off-Ship Bill Pay (OSBP). In addition to the OSBP policy, acquisition also underwent reform in the wake of the "Fat Leonard Scandal," shifting to multiple award contracts (MACs) in lieu of single award contracts (SACs). The purpose of the analysis in this article is to identify the effect, if any, of contracting policy changes (specifically the initiation of OSBP and the use of MACs) on the cost of husbanding services. Figure 1 depicts an overview of the specific husbanding service policy changes; a timeline of events pertinent to this analysis is also provided in Figure 1.

Contracting Changes

Prior to 2016, the U.S. Navy used SACs or single visit contracts (SVCs) for husbanding services. In 2016, the U.S. Navy began shifting towards the use of MACs. MACs and SACs have some similarities. Both have a base contract awarded by the Fleet Logistics Center (FLC, formerly the Fleet Industrial Supply Center [FISC]), which performs like a catalog for services.

HSP base contracts are usually of the indefinite-delivery, indefinite-quantity (IDIQ) type in which the U.S. Navy guarantees a minimum payment but does not have to specify the timing or quantity of port visits and services at the time of award. A task order is issued when a port visit is executed against the base contract. Traditionally, husbanding services have been awarded as a SAC in which a single HSP has control over specified ports in a region for a given time period. Vendors bid on the IDIQ base contract, and a single vendor is awarded the contract; prices of services are negotiated at the time of contract award. When requirements for a port visit are identified by the ship, the HSP is notified and returns a port cost estimate; any prices for services outside of the base contract are negotiated, and then a task order is issued for the visit. "Under this contract vehicle… ships were required to pay all invoices and payments via U.S. Treasury checks with limited oversight," as the unit's type commander (TYCOM) provided the operating funds but the ship's supply officer (SUPPO) was responsible for payment (Gage et al., 2021, p. 6). If a port is not covered by an existing IDIQ contract, then an SVC could be used to obtain husbanding services for the one-time visit.

HSP base contracts are usually of the indefinite-delivery, indefinite-quantity (IDIQ) type in which the U.S. Navy guarantees a minimum payment but does not have to specify the timing or quantity of port visits and services at the time of award.

MACs specify multiple vendors for a general region, and the base contract is awarded by the area's FLC. HSPs awarded the MAC bid on individual port visits (referred to as task orders, which are also awarded by the area's FLC). The purpose of MACs is to increase competition at the task-order level to drive down the cost of husbanding services. Not all port visits are made under a MAC, but the use of MACs over SACs and SVCs has been increasing; in October 2020 (FY 2021), NAVSUP awarded a global MAC to 32 companies (Dortch, 2020). "The decision to change from a SAC- to MAC-type IDIQ contract was independent from the implementation of the OSBP process and instead was predominantly influenced by the Navy-wide acquisition reform rather than auditability" (Kiengsiri et al., 2020, p. 7). It is hypothesized that the increased competition at the task-order level from MACs decreases total cost to the U.S. Navy for husbanding services. Competition has increasingly been shown to reduce prices for production contracts (Lyon, 2006).

Off-Ship Bill Pay (OSBP)

In FY 2016, the U.S. Navy instituted OSBP to increase auditability and accountability for husbanding services (Laron, 2015). OSBP constructs a specific timeline and sequence of events for a port visit. When a ship identifies the need for a port visit, the ship's SUPPO submits the logistics requirements (LOGREQ) to the contracting officer's representative (COR). LOGREQs include information pertinent to the ship's port visit such as how many tugboats are required, mooring line information, trash removal, etc. Prior to OSBP, the ship developed their own LOGREQ. LOGREQs have undergone a process of standardization at varying levels within a fleet by ship class, and in some cases, port-specific requirements are added. The LOGREQ submission is stipulated to occur at least 30 days prior to port arrival; however, some visits occur on shorter notice for various reasons. After the LOGREQ is approved by the FLC, the FLC issues a task order to the HSP (in the instance of a SAC) or a request for task-order proposal, and bids are solicited from HSPs in a MAC (followed by task-order award by the FLC). After the port visit, a port visit checklist, daily reconciliations, and other documentation are compared by the COR to confirm agreement on services rendered and price (Gage et al., 2021). Once the COR confirms consistency in the documentation, the TYCOM certifies and submits the package to Defense Finance and Accounting Service for payment to the HSP.

OSBP increases the auditability and accountability in the acquisition, rendering, and payment of husbanding services. Since OSBP increases oversight, inflated costs due to corruption should be decreased; but, other than auditability, OSBP was not intended to provide cost-reducing effects. OSBP is included in this analysis because it is a major policy change that may impact husbanding service costs. However, OSBP has been criticized for its lengthy, bureaucratic process.

Husbanding Service Cost-Modeling Methodology

In what follows, regression analyses are performed on a historical dataset of port visits to identify the effect on cost, if any, of husbanding service policy changes (i.e., OSBP and the use of MACs). The behavior of the residuals using ordinary least squares regression indicates the need for robust regression. Weighted least squares (WLS) regression is selected (specifically, two-stage least squares) due to the violation of the constant residual variance assumption (i.e., heteroscedasticity). Least absolute deviation was also considered but resulted in multiple solutions, and was therefore not selected.

The natural log transformation of total cost is used as the response variable in the regression models. In other words, *the regression models provide a base value for the total cost of a port visit* and the explanatory variables are multipliers to the base cost. The explanatory variables that showed a significant effect on the total cost are exhibit line item number (ELIN) count, type of mooring (pier-side or anchorage), ship type, days in port, time, and contract type (SAC, SVC, or MAC). Other factors, such as the number of antiterrorism protections (ATPs) and the number of deviations from the standard LOGREQ, were considered, but are only recorded for port visits made after FY 2015 so they are not included in the model. Different measurements of time as a continuous function (including various transformations) were also considered; however, the use of FY as a categorical variable led to better models to describe the dynamic effect on the cost of port visits over time.

Two regression analyses are performed on the dataset assuming fixed effects. The first analysis (referred to as the "global cost model") evaluates the entire dataset in a single model using WLS regression. The global cost model assumes a fixed factor effect over the time horizon. To test this assumption, the second analysis explores a unique WLS regression model for each FY; these cost models are referred to as "FY cost models."

Data on the Cost of Husbanding Services

Data on port visits were obtained from the Husbanding Support Portal (HSPortal) with arrivals beginning on October 1, 2009 (FY 2010), and the last port visit arriving in June 2020 (NAVSUP, 2021). Each of the 14,724 entries represents a port visit and includes details such as the dates (e.g., arrival, departure), ship type, the number of ATPs, ELIN count, and cost (given in total and daily values). The HSPortal records port visit information to support future planning and serves "as an audit trail and oversight function, allowing a high degree of visibility down to the individual vessel or port location" (Gage et al., 2021, p. 8). In FY 2018, NAVSUP mandated entry of port visit information; port visit entries in HSPortal for FY 2018 onward typically have more complete details (i.e., fewer instances of missing information [Gage et al., 2021]).

The use of FY as a categorical variable led to better models to describe the dynamic effect on the cost of port visits over time.

Not all port visits in the HSPortal provide accurate data on the cost of husbanding services. For example, some port visits had been cancelled, resulting in either a $0 total cost or a cancellation fee specific to the circumstances. The dataset is filtered for the following: a status of "Cancelled" (although some cancelled visits have a status of "Complete" or "Closed Out"); a total cost of $0; and comments/remarks/reasons that indicate the visit was cancelled. Removed from the dataset are 1,100 port visits due to evidence of cancellation, resulting in 13,624 observations. The purpose of this article is to analyze the costs of husbanding services for normal port visits. Port visits for diplomatic events, brief stops for fuel (BSFs) or personnel (BSPs), ammunition on-load/off-load, transits/canal navigation, and extended maintenance/dry dock are not considered normal port visits. These non-normal visits would not use typical husbanding services, and therefore pollute the dataset. Removed from the dataset are 366 port visits that fall into the previously mentioned categories. Additionally, typical port visits last 4 to 5 days. Single-day port visits or extended visits (i.e., visits longer than 10 days) are assumed to be indicative of an atypical port visit (such as maintenance or a BSF). Also removed from the dataset are 3,024 port visits for a single day or extended visit. After these filters, the dataset contains 10,204 observations of port visits.

The analyses use ship type as a cost factor. Ship types that do not have a port visit before and after October 1, 2015, are removed. For example, the Frigate was sun-downed before FY 2016 whereas the first MK VI patrol boats deployed in FY 2016. Filtering by ship type removed 420 entries for Expeditionary Mobile Base, MK VI, Frigate, and Navy Expeditionary Combat Command, resulting in a dataset with 9,784 observations.

Finally, the dataset is filtered to focus on frequently visited ports and frequently used ship types to improve the statistical strength of the model. The dataset is filtered to include a minimum of 15 visits per port and a minimum of 15 visits per ship type. This filter innately removes several SVC instances since SVCs are most often used where a husbanding contract is nonexistent; typically, this occurs at ports not commonly visited. The last filter removes 15 instances of SVCs. The final dataset contains 8,727 observations.

Supplemental Data

In the HSPortal, visits made under the OSBP policy are not clearly identified; therefore, it was assumed that any port visits made in FY 2016 onward use OSBP. Test cases of OSBP were used in early 2015, but these test cases are disregarded since the authors are unable to identify such visits. Additionally, the identification of a MAC, SAC, or SVC is not evident in each entry. The contract numbers were manually searched on GovTribe database (GovTribe, 2021) to ascertain the contract type. The contract type was added to the dataset.

To supplement the port visit data, the historical crude oil prices (nominal) are retrieved from Federal Reserve Bank of St. Louis (Federal Reserve Economic Data, 2021). The prevailing hypothesis is that the cost of port services such as tugboats (to shepherd the vessel in and out of port) depends on crude oil prices and affects the overall cost of the port visit. The crude oil price corresponding to the date the port visit was planned is also added to the dataset.

TABLE 1. DISTRIBUTION OF CONTINUOUS VARIABLES IN FINAL DATASET

Variable	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
Total Cost	$50	$21,226	$46,197	$88,394	$88,937	$2,700,918
Days in Port	2	3	4	4.543	6	10
ELIN Count	1	15	22	22.89	30	115
Price of Oil[a]	-$36.98	$50.61	$71.93	$72.19	$93.84	$113.39

Note. ELIN = Exhibit Line Item Number.
[a] Price of oil is given as dollars per barrel ($/bbl).

TABLE 2. NUMBER OF PORT VISITS BY CONTRACT TYPE AND MOORING OVER TIME

		Contract Type			Mooring	
FY	*N*	MAC	SAC	SVC	Anchorage	Pier-side
2010	674	0	671	3	62	612
2011	806	0	806	0	94	712
2012	903	0	903	0	70	833
2013	817	0	816	1	59	758
2014	972	0	942	30	114	858
2015	1,025	0	1,025	0	100	925
2016	977	10	967	0	113	864
2017	980	306	674	0	115	865
2018	612	402	210	0	100	512
2019	680	469	211	0	91	589
2020	281	193	88	0	37	244
Total	8,727	1,380	7,313	34	955	7,772

Note. *N* indicates the number of observations or dataset size. FY = Fiscal Year; MAC = Multiple Award Contract; SAC = Single Award Contract; SVC = Single Visit Contract.

Husbanding Service Cost Analysis

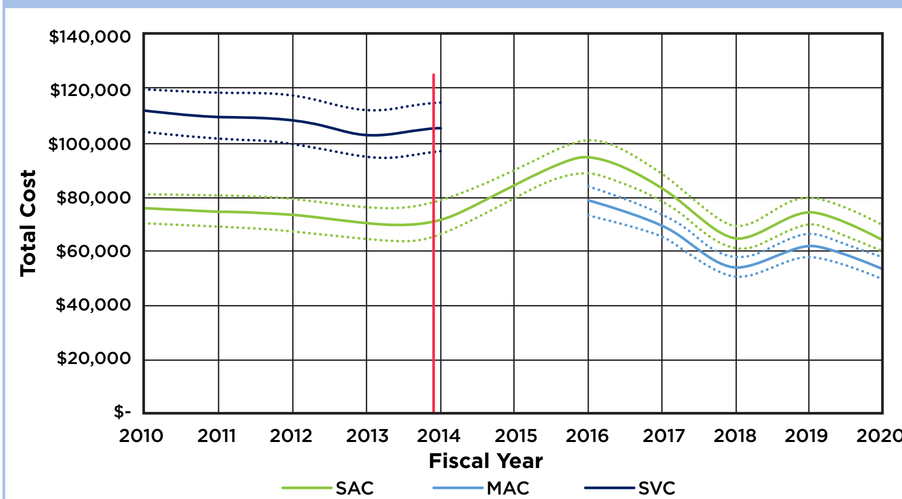
Table 1 shows the distribution of the continuous variables in the final dataset. The port visit total cost is skewed to the right (the median is less than the mean total cost). The number of days in port variable is limited to visits of at least 2 days and at most 10 days. The price of oil has a single negative value caused by the COVID-19 pandemic; at one point during the pandemic, oil producers paid buyers to take surplus oil because demand was so low and inventory capacity was limited. The data represent an unbalanced panel meaning that not every variable instance occurs in each FY.

The number of port visits by contract type or mooring for each FY is shown in Table 2. The full dataset has 8,727 visits. The number of port visits in FY 2020 is particularly low for two reasons: first, the full FY is not included in this analysis—the last port visit is made in June; second, the Covid-19 pandemic may have reduced the number of port visits for safety reasons. Port visits under MACs did not begin until FY 2016 and increased in utilization relative to SACs. The SVCs had a peak usage of 30 port visits in FY 2014. This is likely due to the lack of HSP support when the U.S. Government discontinued business with GDMA after September 2013. Pier-side mooring is used in the overwhelming majority of port visits made.

> **The price of oil has a single negative value caused by the COVID-19 pandemic; at one point during the pandemic, oil producers paid buyers to take surplus oil because demand was so low and inventory capacity was limited.**

The global cost model analysis is described first, followed by the FY cost models to evaluate the assumption of fixed explanatory variable effects.

FIGURE 2. COST OF A 5-DAY PORT VISIT FOR A DDG OVER TIME AND BY CONTRACT TYPE



Note. The red vertical line indicates the timing of Leonard Francis's arrest. The dotted lines indicate the 95% confidence intervals on the cost estimate. DDG = Guided Missile Destroyer; MAC = Multiple Award Contract; SAC = Single Award Contract; SVC = Single Visit Contract.

Global Cost Model Analysis

The global cost model demonstrates a dynamic effect over the time horizon (i.e., not constant increasing or decreasing) and a cost-reducing effect due to the use of MACs. Figure 2 (derived from the global cost model) plots the total cost using a 5-day port visit for a Guided Missile Destroyer (DDG) as the benchmark port visit. The DDG is the reference category for ship type because of the high volume of visits and near average cost over all ship types. The model plotted in Figure 2 assumes the average port multiplier and pier-side mooring as well as the dataset average for ELIN count (23) and average price of oil ($72.02/bbl). A "multiplier" is the value by which the base cost is adjusted; this value is derived by the natural exponential of the corresponding regression coefficient (where applicable).

TABLE 3. EFFECT OF SELECT FACTORS ON TOTAL COST FROM THE GLOBAL COST MODEL

Factor	Level	Multiplier	Significance
Contract Type	MAC	0.831	< 0.001
Contract Type	SVC	1.464	< 0.001
Mooring	Anchorage	1.315	< 0.001

Note. The multiplier value describes the adjustment (i.e., multiplier) to the corresponding single award contract (SAC) cost. MAC = Multiple Award Contract; SVC = Single Visit Contract.

SVCs were used only up to FY 2014 in the final dataset. SVCs led to an increase in cost of a port visit of approximately 46% (multipliers are provided in Table 3). Further, the use of MACs provided a statistically significant reduction in total cost. The trend of total cost over time fluctuates. From FY 2010 to FY 2014, Figure 2 shows relatively constant cost (with a mild decrease). The lowest cost in this period—occurring in FY 2013—is only $2,000–$3,000 less than surrounding FYs. This decrease may be attributed to increased scrutiny of husbanding invoices and targeted cost-reduction efforts by Navy officials.

After Francis's arrest in September 2013 (marked with a vertical red line in Figure 2), the cost of husbanding services continues to increase to a peak in FY 2016. Francis's company, GDMA, was the HSP for more than 25% of the port visits made prior to FY 2014. This is influential because after Francis's arrest, the U.S. Government no longer did business with GDMA, removing the HSP that provided services for a quarter of their port visits from the pool of possible vendors, thereby reducing competition. Additionally, it was known that GDMA had a monopoly on services in certain ports, which made those ports no longer accessible to Navy vessels. The prohibition of business with GDMA and the restriction on ports likely contributed to the increase in total port visit cost beginning in FY 2014 to FY 2016.

The peak of total cost occurs in FY 2016, the year that OSBP was implemented and port visits began to be executed using MACs. As shown in Table 2, only 10 port visits in the final dataset were made under a MAC in FY 2016 (accounting for only 1% of the port visits that FY). Further, the OSBP process can be complex, especially for the uninitiated. Although training was required, the OSBP process likely incurred a learning curve for both Navy personnel and HSPs. The use of LOGREQs, standardized by ship class, may have contributed to the ordering of unneeded services, leading to increased prices as well (Naval Audit Service, 2019). Ship classes are broad, and the standardized LOGREQs did not account for port-specific requirements or available services. Deviations from the standardized LOGREQ are made by the ship's SUPPO; however, the officer may not be familiar with special requirements for a specific port.

After FY 2016, the total cost of a DDG port visit decreases (as shown in Figure 2). The percentage of port visits made using a MAC increases to 31% in FY 2017 and for FY 2018 onward, holds relatively constant at approximately 68%. The use of port visits under a MAC decreases the price relative to use of a SAC. The total cost of a port visit under a SAC also decreases from FY 2016 onward. This may be an indirect effect of the increasing use of MAC contracts; HSPs operating under a SAC may have tried to provide more competitive prices to secure the continuation of their SAC. A SAC guarantees control over certain ports; but, as part of a MAC, an HSP has to compete and will most likely not be awarded all task orders for that area.

The use of anchorage mooring leads to a cost increase of more than 30% compared to pier-side mooring. Each of these factors had a statistically significant effect.

The multiplier on the base cost of a port visit for the contract types and anchorage mooring is shown in Table 3. The base cost assumes the port visit is executed using a SAC and pier-side mooring. As shown in Figure 2, the use of a MAC reduces the total cost by 16.9%, while the use of an SVC increases the cost by 46.4%. The use of anchorage mooring leads to a cost increase of more than 30% compared to pier-side mooring. Each of these factors had a statistically significant effect.

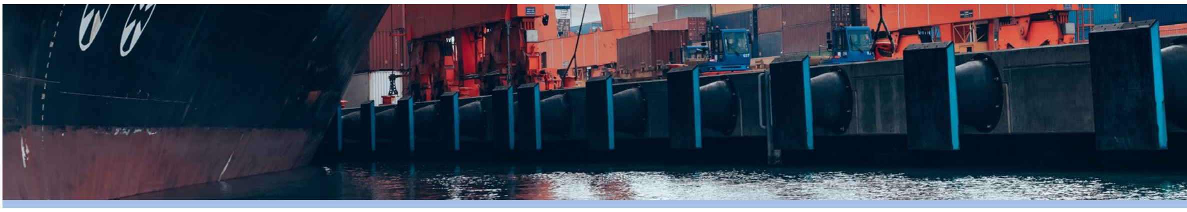


FIGURE 3A. REGRESSION MULTIPLIER VALUES FROM THE GLOBAL COST MODEL OVER THE RANGE OF THE CONTINUOUS EXPLANATORY VARIABLES FOR DAYS IN PORT

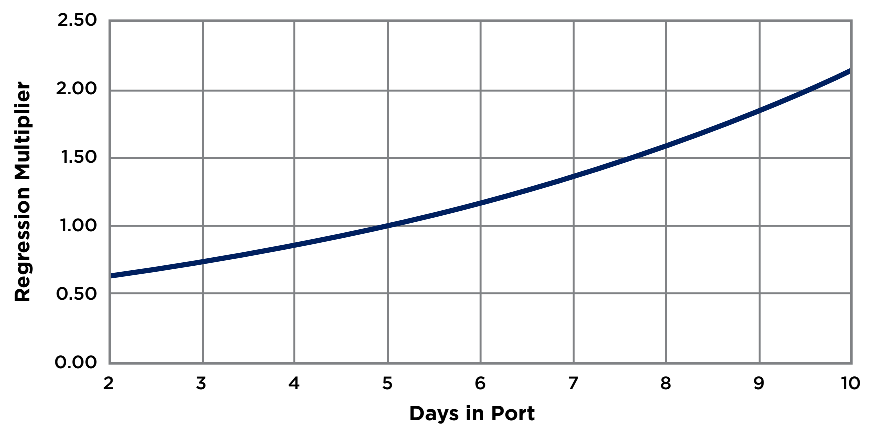
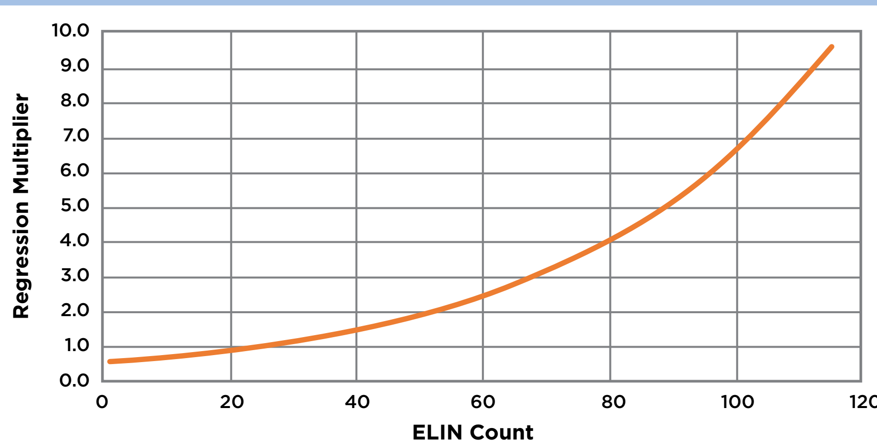
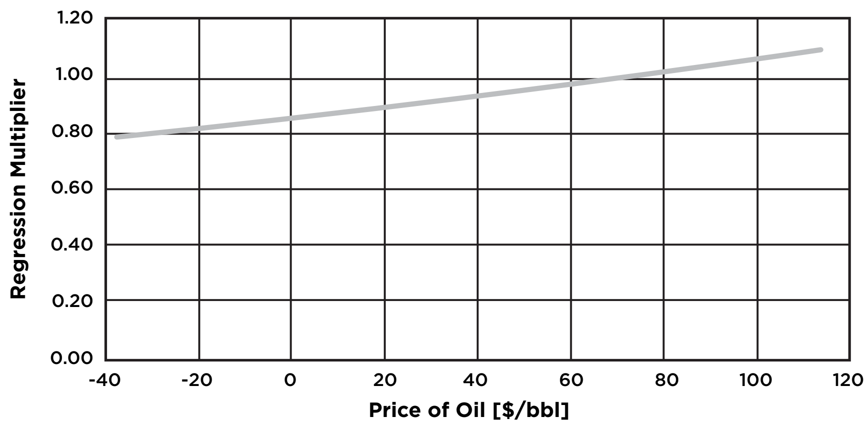


FIGURE 3B. REGRESSION MULTIPLIER VALUES FROM THE GLOBAL COST MODEL OVER THE RANGE OF THE CONTINUOUS EXPLANATORY VARIABLES FOR ELIN COUNT



Note. ELIN = Exhibit Line Item Number.

FIGURE 3C. REGRESSION MULTIPLIER VALUES FROM THE GLOBAL COST MODEL OVER THE RANGE OF THE CONTINUOUS EXPLANATORY VARIABLES FOR THE PRICE OF OIL



Note. The price of oil is given in dollars per barrel ($/bbl). For a brief moment in 2020, the price of oil was negative; this is reflected in the graph. ELIN = Exhibit Line Item Number.

The regression multipliers in the global cost model are plotted in Figures 3a, 3b, and 3c over the range of continuous variables; for continuous variables, regression multipliers are derived by taking the natural exponential of the quantity: regression coefficient multiplied by the variable value. All explanatory variable effects are statistically significant to a level of at least 0.01. Figure 3a shows the effect on days in port from the minimum number of days (i.e., 2) to the maximum value of 10 days and centered around the average 5 days in port. Spending 2 days in port adjusts the base cost to approximately 60% of its original value, and the effect increases total cost 115% by spending 10 days in port as opposed to 5.

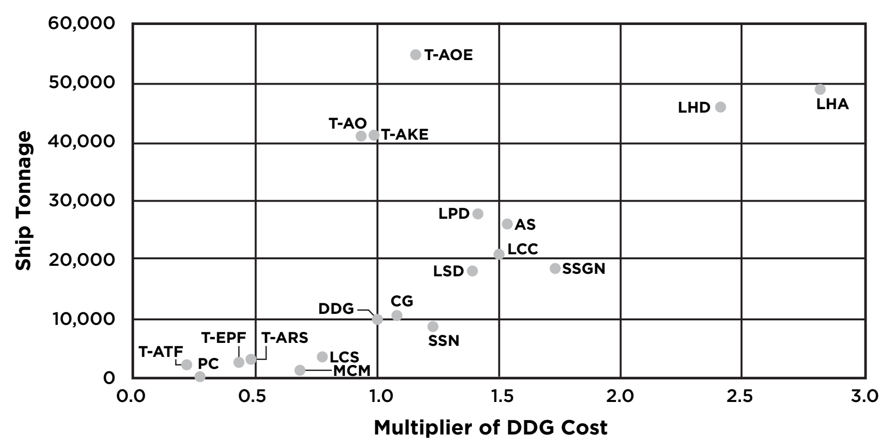
Figure 3b shows a massive increase in the total cost for high ELIN counts. For example, an ELIN count of 70 approximately triples the cost of the port visit; an ELIN count of 100 increases the port visit total cost nearly 570%. The higher the ELIN count, the more likely it is that costly ELINs are included. The data on specific ELINs for each port visit were not available.

Figure 3c shows the effect of the price of oil on the total cost of port visits. Although the effect of the price of oil is statistically significant, it does not have a large magnitude like the days in port and ELIN count effects. For a range of $150/bbl, the regression multiplier increases only about 0.31 (from 0.79 to 1.10).

The ship type multipliers of the base value from a DDG are plotted against ship tonnage in Figure 4 except for Aircraft Carriers (CVNs). CVNs have a tonnage just under 100,000 and the multiplier of the DDG base cost for a

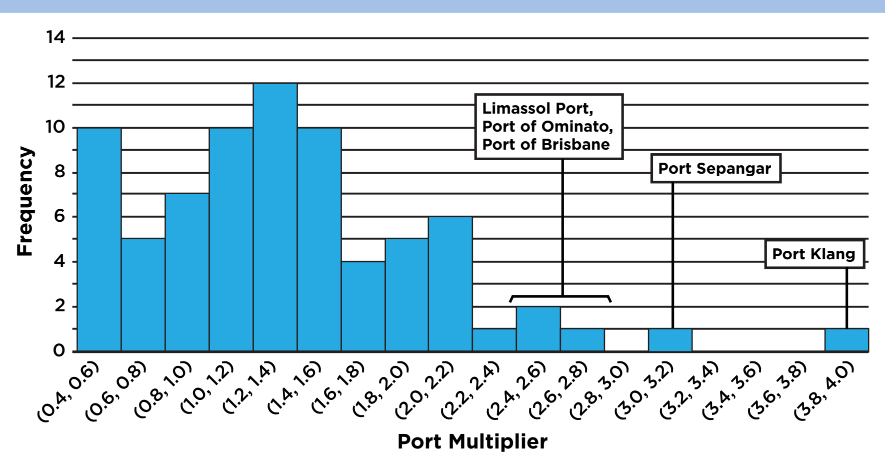
5-day port visit is 4.43. The multiplier value does appear to be correlated to tonnage for most ship types except for the Military Sealift Command (MSC) ships: Dry Cargo/Ammunition Ship (T-AKE), Underway Replenishment Oiler (T-AO), and Fast Combat Support Vessel (T-AOE).

FIGURE 4. SHIP TYPE MULTIPLIER FROM GLOBAL COST MODEL AND BY SHIP TONNAGE



Note. AS =Submarine Tender; CG = Guided Missile Cruiser; DDG = Guided Missile Destroyer; LCC = Command Ship; LCS = Littoral Combat Ship; LHA = Landing Helicopter Assault; LHD = Landing Helicopter Dock; LPD = Landing Platform Dock; LSD = Dock Landing Ship; MCM = Mine Countermeasure; PC = Coastal Patrol; SSGN = Guided Missile Submarine; SSN = Fast Attack Submarine; T-AKE = Dry Cargo/Ammunition Ship; T-AO = Underway Replenishment Oiler; T-AOE = Fast Combat Support Vessel; T-ARS = Rescue/Salvage Ship; T-ATF = Fleet Ocean Tug; T-EPF = Expeditionary Fast Transport Vessel.

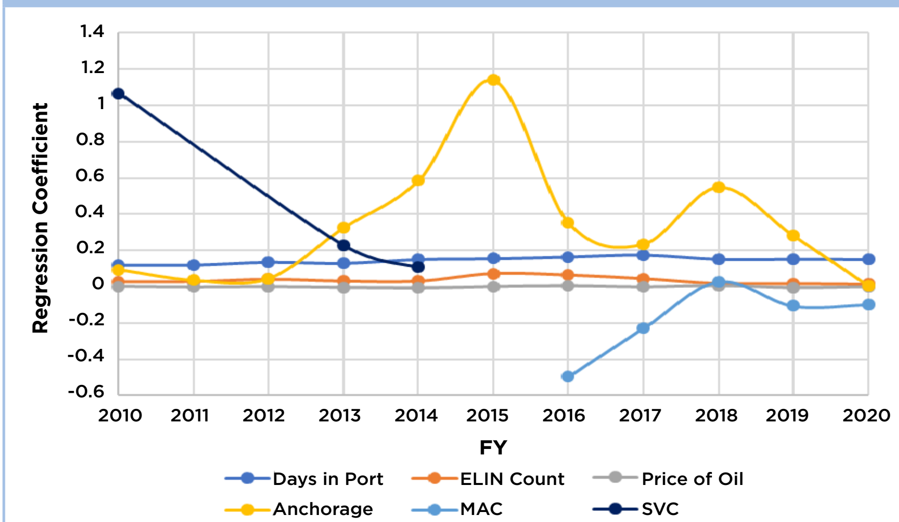
FIGURE 5. HISTOGRAM OF PORT MULTIPLIERS FROM GLOBAL COST MODEL



Note. The port multipliers provide the relation of cost to the reference port—Khalifa Bin Salman Port.

The 8,272 port visits were executed at 75 different ports. The reference port (i.e., the port at which the base cost is derived) is Khalifa Bin Salman Port. This port was chosen due to the high number of visits made at this port and the proximity of the average total cost at Khalifa Bin Salman Port to the overall dataset average. The histogram of port regression multipliers from the global cost model is shown in Figure 5. Port Klang, in Malaysia, has the highest regression coefficient leading to a quadrupled total port cost. The next most expensive port, Port Sepangar, triples the cost of a port visit and is also located in Malaysia. The exceptionally high cost of husbanding services at these ports may come from their connection with GDMA. Limassol Port, Port of Ominato, and Port of Brisbane are the next three most expensive ports (with multipliers greater than 2.2). Of these, only Brisbane utilized GDMA as the HSP; the connection occurs in FY 2012 and FY 2013.

FIGURE 6. REGRESSION COEFFICIENTS FROM FY COST MODELS



Note. The plot shows the regression coefficients from the FY cost models, *not* the regression multipliers since the multipliers would apply to different base values. FY = Fiscal Year; ELIN = Exhibit Line Item Number; MAC = Multiple Award Contract; SVC = Single Visit Contract.

FY Cost-Models Analysis

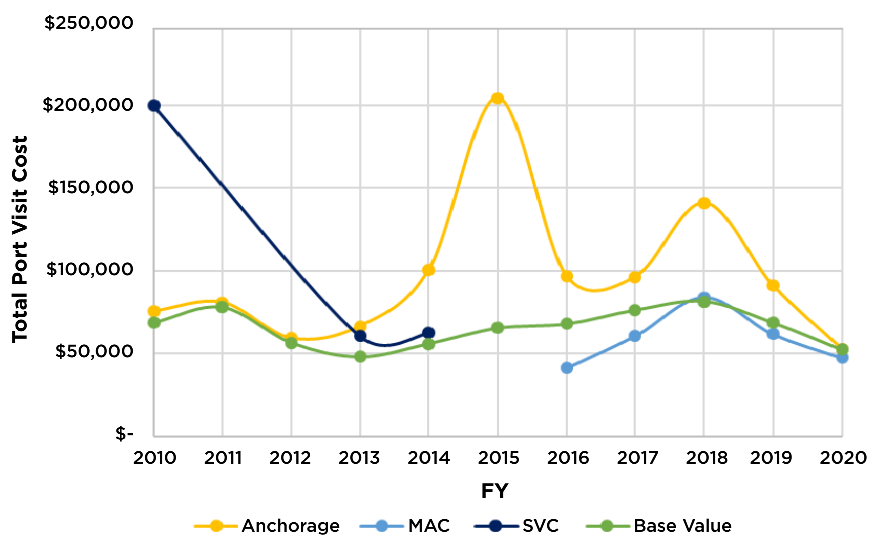
The purpose of the FY cost models is to test the assumption that explanatory variables (such as mooring, days in port, ship type, etc.) have constant effects over time. The regression coefficients of select factors are shown in Figure 6. The regression coefficient is plotted for each FY cost model instead of the multiplier of the base cost since the continuous variables (days in port, ELIN count, and price of oil) have a multiplier that is a function of the variable itself. Regression coefficients above zero lead to an increase in port visit total cost, a value of zero would lead to no effect, and negative values reduce the total cost. The factors of days in port, ELIN count, and price of oil have relatively constant effects over time.

Port visits under an SVC have a large change in regression coefficient (from 1.07 to 0.107, which translates to regression multiplier values of 2.9 and 1.1, respectively). The large multiplier in FY 2010 is caused by the three observations of an SVC in that FY. Two of the three visits had a port visit cost equivalent to 160–170% of the predicted port visit cost made under a SAC; the increase applies to both the global and FY cost models.

Similarly, the effect of anchorage mooring appears to have a dynamic effect over time. Figure 6 shows a near zero coefficient for FYs 2010–2012 and a spike to a value of 1.14 in FY 2015, followed by a trough and another spike before approaching zero again in FY 2020. The cause of this fluctuation is unknown.

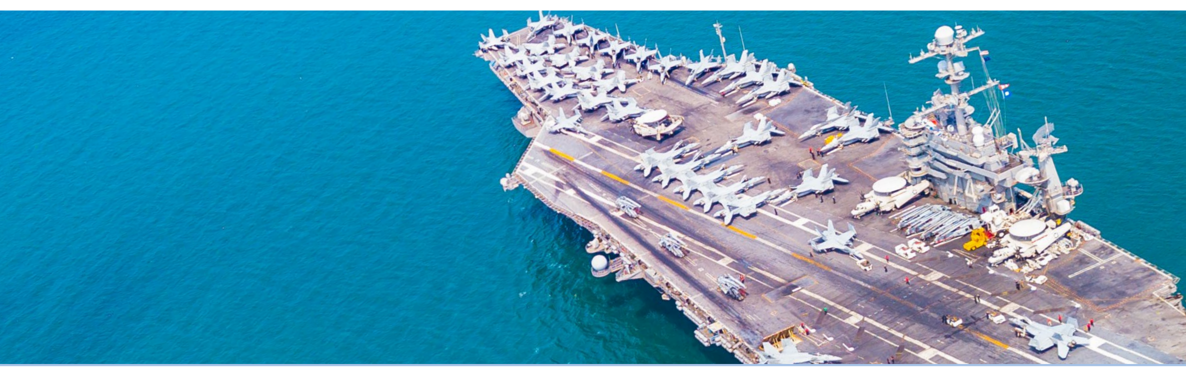
Lastly, the MAC effect is also dynamic over time. The MAC has a regression coefficient of -0.5 in FY 2016 (when there are only 10 observations), increasing to approximately 0 by FY 2018. In FYs 2019 and 2020, the regression coefficient levels out around -0.1. The decreasing cost-reduction power of the MAC may be due to HSPs with SAC trying to provide more competitive prices to maintain its contracts.

FIGURE 7. TOTAL COST FOR 5-DAY PORT VISIT WITH DDG BASED ON FY COST MODELS



Note. The base value refers to the cost of a port visit executed under a single award contract (SAC) using pier-side mooring. DDG = Guided Missile Destroyer; FY = Fiscal Year; MAC = Multiple Award Contract.

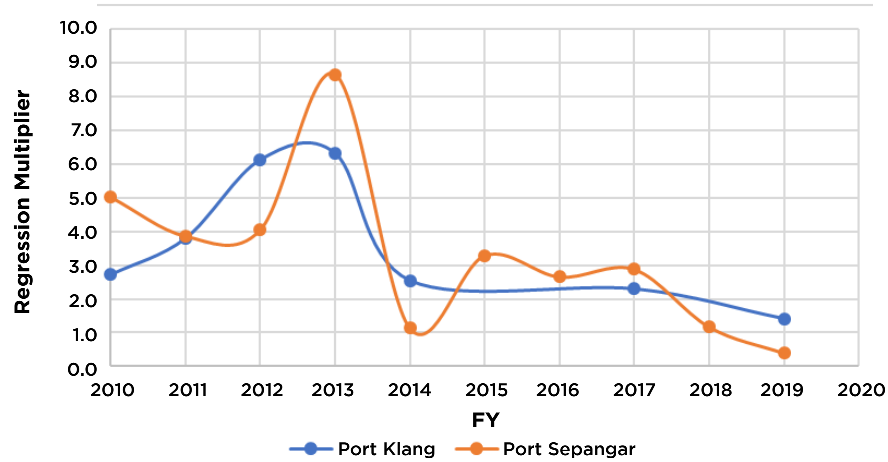
The regression coefficient does not provide a complete picture in the change of total cost over the FY cost models. The total cost for a 5-day port visit of a DDG is shown in Figure 7 for the base value (pier-side mooring and execution under a SAC), a visit made under an SVC, a visit made under a MAC, and a visit using anchorage mooring. Similar effects using the metric of total cost in Figure 7 are evident as shown in the regression coefficients in Figure 6. The MAC coefficient does not provide a statistically significant effect in FYs 2018, 2019, and 2020. The low costs of port visits made under MACs in FYs 2016 and 2017 induce the statistically significant effect of MACs in the global cost model. Similarly, outliers using SVC in FY 2010 and anchorage in FY 2015 likely influence the corresponding variable effect in the global cost model. Two-stage WLS regression does reduce the impact of outliers; however, the dynamic effect of these factors over time does violate the assumption in the global cost model.



The regression multipliers from the FY cost models for the most expensive ports—Port Klang and Port Sepangar—were analyzed (shown in Figure 8). Evidently, while GDMA was the HSP in these ports (FYs 2010–2013), the cost multiplier was significantly higher than when other HSPs provided husbanding services (FY 2014 onward). Although Brisbane Port also had a connection with GDMA, a dramatic dynamic effect is not present in its regression multiplier.

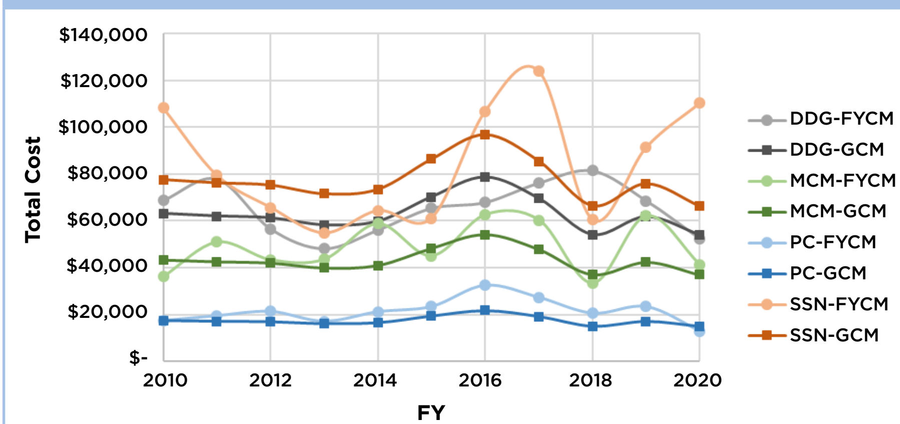
In some FYs, certain ship types had little to no observations in the dataset, reducing statistical significance of their cost estimates. For ship types with at least 15 observations in most FYs, the global cost model's predicted value is compared to the FY cost model. Figure 9 compares the predicted costs over time for DDGs, Mine Countermeasures (MCMs), Coastal Patrols (PCs), and Fast Attack Submarines (SSNs)—ship types with a sufficient number of observations. Figure 9 is a good representation of the differing variation between the two modeling approaches; the remaining cost comparisons are provided in Appendix A.

FIGURE 8. REGRESSION MULTIPLIER FOR PORT KLANG AND PORT SEPANGAR OVER TIME FROM FY COST MODELS



Note. FY = Fiscal Year.

FIGURE 9. COMPARISON OF THE PREDICTED TOTAL COST BY GLOBAL COST MODEL AND FY COST MODEL



Note. DDG = Guided Missile Destroyer; FY = Fiscal Year; FYCM = FY Cost Model; GCM = Global Cost Model; MCM = Mine Countermeasure; PC = Coastal Patrol; SSN = Fast Attack Submarine.

The dark version of each color in Figure 9 represents the global cost model. Since the ship type equates to a multiplier of the base value cost (of a DDG), the total costs are parallel. The FY cost model demonstrates that total costs do not follow the general trend of port visit costs over time. For example, the FY cost models for MCMs and SSNs show various fluctuations above and below the global cost model. Even the DDG FY cost model (the light grey line in Figure 9) shows an increasing cost from FY 2016 to FY 2018, where the global cost model predicts decreasing cost.

The changing fluctuation in the effect of ship types, in combination with other findings, would seem to indicate that port visits incur widely varying costs. Further, the variations cannot be completely described by using the explanatory variables in the models (days in port, ELIN count, price of oil, FY, mooring type, contract type, ship type, and port). Depending on the purpose of the analysis, useful insights can be derived from each cost model analysis. The global cost model has the advantage of aggregating the entire dataset to provide an average effect over time. In Figure 9, the aggregate effect is evidenced by the mild changes in predicted values of the global cost model. Although mooring, SVC, and MAC show dynamic effects over time, the global cost model shows the aggregated effect over time of each factor. The mooring effect in the FY cost models is by far the most curious with the massive increase in FY 2015 and relatively mild effects for all other FYs.

Conclusions

The U.S. Navy instituted policy changes in FY 2016 to improve husbanding service processes in terms of reducing cost and increasing oversight. The policies were enacted after the arrest of Leonard Glenn Francis; the elimination of GDMA as a possible HSP appears to have increased costs of husbanding services for years after his arrest. As a direct response to a Navy audit following the arrest, OSBP was instituted in FY 2016 to increase the auditability and accountability for husbanding services. The OSBP process has been criticized for the increased administrative requirements for port visits, both for Navy personnel and HSPs. OSBP may have increased port visit costs initially due to the learning curve, but in recent years has not demonstrated such an effect.

The cost of husbanding services has decreased since FY 2016, coinciding with increased utilization of MACs. The decreasing cost may not be directly caused by MACs (particularly in FY 2018); however, an indirect effect from MAC contracts has likely motivated HSPs operating under SACs with the Navy to provide more competitive prices in order to maintain the SAC in their designated markets. This is a promising indication since NAVSUP awarded a Global MAC on October 2, 2020 (Dortch, 2020). The Global MAC was awarded for a 5-year period with an option for another 5-year period. The MAC will essentially be the sole contract type for husbanding services until at least 2025 and possibly to 2030.

The findings show that OSBP increased cost initially (likely due to the learning curve), but has since not had a significant effect. The findings also demonstrate a cost-reducing effect with the use of MACs instead of SACs for selecting an HSP for port visits.

This study has a few limitations. The variation in the total cost of port visits is not completely captured by either model presented in this study; not included are characteristics or components of port visits that are unknown. In addition, port visits that were either cancelled or are non-normal port visits likely still remain in the dataset due to lack of identification; these observations pollute the model. Finally, the selection of model type depends on the desired perspective of the data. For an overall impression of the effect of certain factors, such as contract type or the number of days in port, the global cost model provides the best estimate since it is aggregated over the entire dataset. From this claim, the authors have drawn the conclusions of a decreasing effect on cost achieved by the OSBP as well as a cost-reducing effect from the MAC. The FY cost models have reduced statistical significance for certain variables due to the lack or small sample of observations. Though the FY cost models provide less complete information, the FY cost models expose a dynamic effect from certain variables, which provides insight into cost trends.

This study evaluated the effect of husbanding service policy changes. The findings show that OSBP increased cost initially (likely due to the learning curve), but has since not had a significant effect. The findings also demonstrate a cost-reducing effect with the use of MACs instead of SACs for selecting an HSP for port visits.

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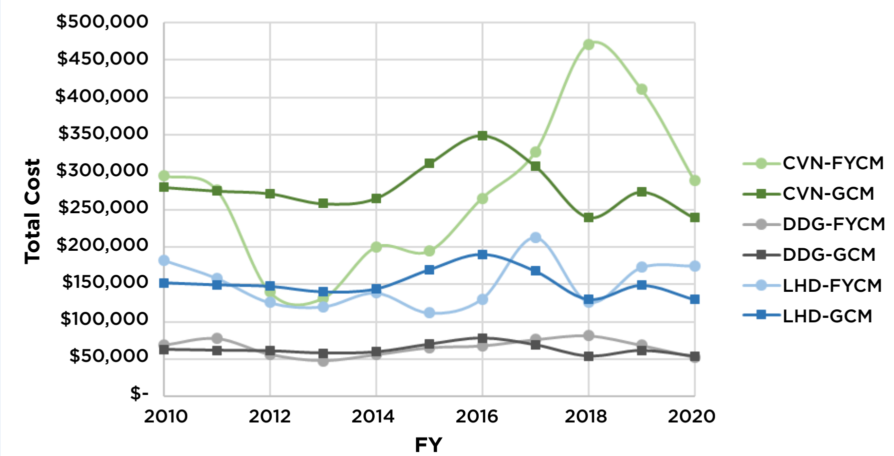
Appendix A
Comparison of Global Cost Model and FY Cost Models Over Time

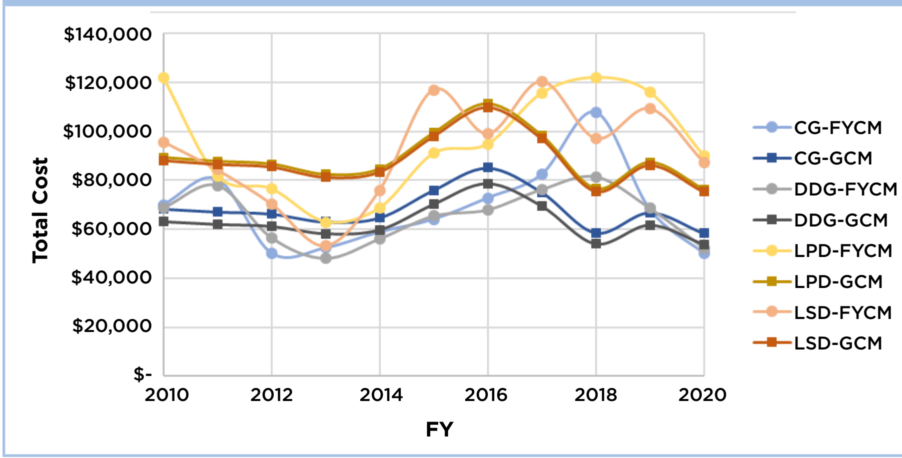
The figures below show the comparisons of predicted cost between the global cost model and FY cost models over time. The DDG predicted cost is included in each figure since it is the reference ship type. Figure A.1 shows the comparisons for large decks, Figure A.2 shows the comparison for amphibious assault vessels and combat vessels (crudes), and Figure A.3 shows the comparisons for Military Sealift Command ships. The charts are not on the same scale.

FIGURE A1. COMPARISON OF THE PREDICTED TOTAL COST BY GLOBAL COST MODEL AND FY COST MODEL—LARGE DECKS



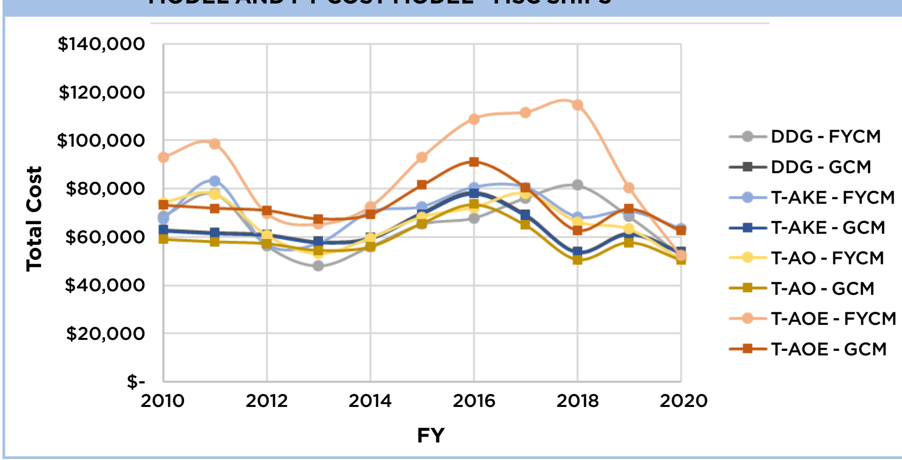
Note. A DDG is not a large deck; however, it is included for comparison since DDG is the reference ship type. CVN = Aircraft Carrier; FY = Fiscal Year; FYCM = FY Cost Model; GCM = Global Cost Model; LHD = Landing Helicopter Dock.

FIGURE A2. COMPARISON OF THE PREDICTED TOTAL COST BY GLOBAL COST MODEL AND FY COST MODEL—AMPHIBIOUS ASSAULT AND COMBAT VESSELS



Note. CG = Guided Missile Cruiser; DDG = Guided Missile Destroyer; FY = Fiscal Year; FYCM = FY Cost Model; GCM = Global Cost Model; LPD = Landing Platform Dock; LSD = Dock Landing Ship.

FIGURE A3. COMPARISON OF THE PREDICTED TOTAL COST BY GLOBAL COST MODEL AND FY COST MODEL—MSC SHIPS



Note. A DDG is not a Military Sealift Command ship; however, it is included for comparison since DDG is the reference ship type. DDG = Guided Missile Destroyer; FY = Fiscal Year; FYCM = FY Cost Model; GCM = Global Cost Model; MSC = Military Sealift Command; T-AKE = Dry Cargo/Ammunition Ship; T-AO = Underway Replenishment Oiler; T-AOE = Fast Combat Support Vessel.

Appendix B
List of Abbreviations & Acronyms

AS	Submarine Tender
ATP	anti-terrorism protection
bbl	barrel
BSF	brief stop for fuel
BSP	brief stop for personnel
CG	Guided Missile Cruiser
COR	contracting officer's representative
CVN	Aircraft Carrier
DDG	Guided Missile Destroyer
ELIN	exhibit line item number
FISC	Fleet Industrial Supply Center
FLC	Fleet Logistics Center
FY	fiscal year
FYCM	fiscal year cost model
GCM	global cost model
GDMA	Glenn Defense Marine Asia
HSP	husbanding service provider
HSPortal	Husbanding Support Portal
IDIQ	indefinite-delivery, indefinite-quantity
LCC	Command Ship
LCS	Littoral Command Ship
LHA	Landing Helicopter Assault
LHD	Landing Helicopter Dock
LOGREQ	logistics requirement
LPD	Landing Platform Dock
LSD	Dock Landing Ship
MAC	multiple award contract
MCM	Mine Countermeasure
MSC	Military Sealift Command
NAVSUP	Naval Supply Systems Command
OSBP	Off-Ship Bill Pay
PC	Coastal Patrol
SAC	single award contract
SSGN	Guided Missile Submarine
SSN	Fast Attack Submarine
SUPPO	Supply Officer
SVC	single visit contract
T-AKE	Dry Cargo/Ammunition Ship
T-AO	Underway Replenishment Oiler
T-AOE	Fast Combat Support Vessel
T-ARS	Rescue/Salvage Ship
T-ATF	Fleet Ocean Tug
T-EPF	Expeditionary Fast Transport Vessel
TYCOM	Type Commander
WLS	weighted least squares

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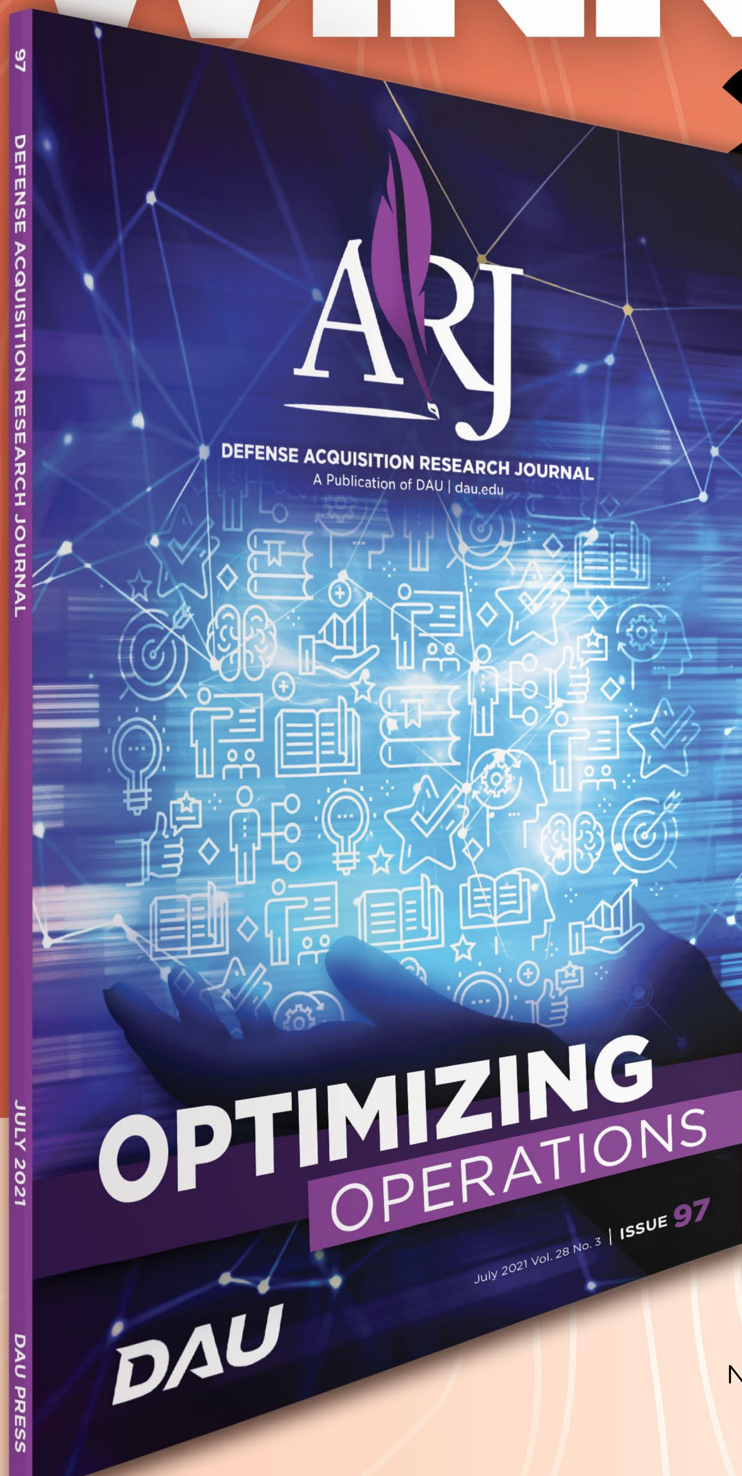


Norene Johnson, Emily Beliles, and Nicole Brate

DAU Press

Fort Belvoir, VA

PHASING RISK IN **Aircraft Development** PROGRAMS

Image designed by Nicole Brate

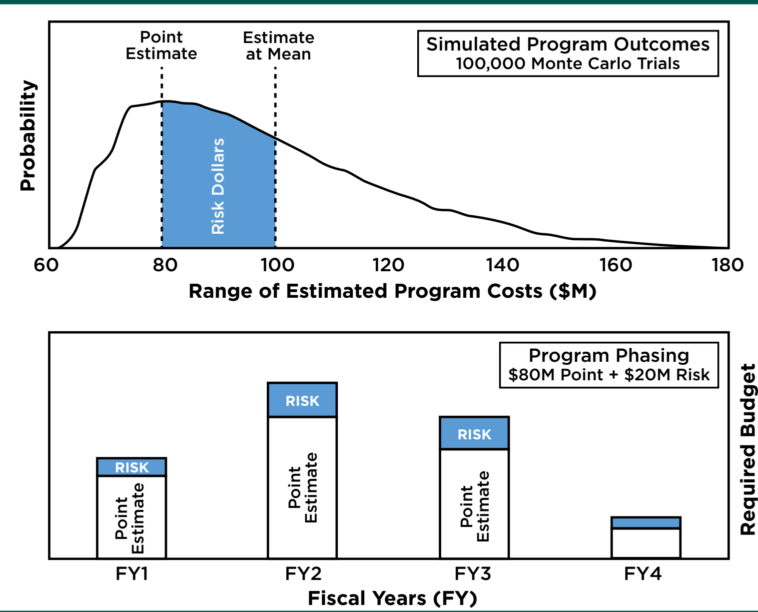
Gregory E. Brown

This article analyzes the timing of cumulative cost growth over the planned development schedule, with the goal of utilizing the pattern of historic cost growth to phase the risk dollars for new aircraft development programs. Using data from Selected Acquisition Reports for 21 completed programs, a polynomial regression model is fit to cost growth. The polynomial indicates that 85% of cost growth occurs in the second half of the planned development schedule, on average. These results suggest that risk dollars for new programs should be "backloaded," or phased later in the program schedule. Backloading risk dollars could improve early program execution and provide greater budget flexibility in the event of schedule delays or schedule growth.

DOI: https://doi.org/10.22594/dau.21-885.29.04
Keywords: *Risk, Cost Growth, Phasing, Aircraft Development*

The military acquisition community recognizes the need to capture the inherent uncertainty of new development programs. Despite a Future Years Defense Program (FYDP) process that focuses on budgeting a discrete dollar value, cost estimates for new programs are required by public law to assess uncertainty, producing a range of likely dollar values and an associated confidence level (Weapon Systems Acquisition Reform Act, 2009). An important result of the uncertainty modeling process is the "probability adjustment dollars," representing the aggregated cost impact that opportunities (favorable events) and risks (unfavorable events) are expected to have on the program. Probability adjustment dollars are commonly referred to as "risk dollars."

FIGURE 1. VISUAL DEPICTION OF RISK DOLLARS FOR 4 YEAR PROGRAM



As shown in Equation 1 and the left part of Figure 1, risk dollars are the difference between a program's cost estimate at the mean and the point estimate. The cost estimate at the mean represents the average cost outcome for a program after the impacts and probabilities of opportunities and risks are considered. A repeated sampling technique, such as a Monte Carlo or Latin hypercube simulation, is used to produce the probability distribution containing the possible program-cost outcomes. Conversely, the "point" cost estimate represents a cost for the program without consideration of opportunities and risks. Given that the impact of program risks generally outweighs the cost impact of program opportunities, risk dollars are typically positive and will increase the overall cost estimate. By increasing the estimate, risk dollars decrease the likelihood that the program will exceed its requested budget (Department of Defense [DoD], 2014).

$$\textit{Risk Dollars} = \textit{Estimate at the Mean} - \textit{Point Estimate} \qquad (1)$$

After calculating risk dollars, the cost or budget analyst must next decide how to phase or spread the risk dollars over the fiscal years of the program. Risk dollars are phased on top of the point estimate phasing, shown notionally for a 4-year program in the right side of Figure 1. The total of the point estimate and risk dollars for a given fiscal year typically becomes the required budget for that year. Determining how to phase risk dollars, however, can be problematic due to a lack of guidance on risk phasing. Despite extensive instruction on how to model uncertainty (and extensive instruction on phasing a point estimate), remarkably limited literature addresses the phasing of risk dollars. The primary guide to capturing cost-related risk, the *Joint Agency-Cost Schedule Risk and Uncertainty Handbook*, only allocates two of its 203 pages to risk phasing. While the JA-CSRUH does provide phasing strategies, such strategies are subjective in that they do not offer specific solutions based on data and are instead generalized approaches for phasing risk dollars (e.g., prorate consistent with the point estimate, backload, phase after a risky event). Applying these methods will typically require further subjective input from engineers and program managers before implementation (DoD, 2014). As a result, the analyst has limited objective guidance on phasing risk dollars. The analyst may miss an opportunity to phase risk dollars appropriately, leading to a mismatch between the planned budget and future requirements if program risks (e.g., schedule growth, requirements change, flight test extension) are realized.

To overcome this problem, the author sets forth in this article a proposal that analysts can use historical cost growth profiles, which identify where mismatches between the planned budget and required budget occur within the schedule, to phase

new programs. Unlike subjective input, a sample of historical cost growth profiles is expected to be statistically unbiased. When cost growth profiles are aggregated, knowledge may be gained from many programs, rather than from a single program or expert. The author therefore aims to provide a risk-phasing function derived from annualized cost growth of completed aircraft development programs. The author posits that risk phasing based on historical cost growth profiles will improve program execution by placing additional dollars where risks—and their associated cost growth—are most likely to occur.

Background

Phasing helps answer how dollars should be spread across a development program's fiscal years. Many prior research efforts have attempted to overcome subjective phasing methods by applying mathematical functions or probability distributions to historical program data. Although not an all-inclusive list, several significant works on phasing are summarized. The first use of a distribution for development phasing is Norden (1970), who suggests that the Rayleigh distribution be utilized for predicting person-hours over the life of an engineering project. Putnam (1978) applies Norden's approach to DoD data, applying a best-fit Rayleigh distribution to 50 U.S. Army Computer Systems Command contracts. Lee et al. (1997) use aircraft data, fitting a Rayleigh distribution to aircraft development programs, recommending that first flight be used to predict the shape of the Rayleigh distribution via the scale parameter. Unger et al. (2004) suggest the use of the more flexible Weibull distribution rather than the Rayleigh, but are unable to successfully predict the two distribution parameters using program data. Brown et al. (2002) resolve Unger's limitation, using an expanded data set from 128 development programs to determine that program length, Service (e.g., Navy, Air Force), and program type best predict the Weibull shape and scale. Burgess (2006) applies a similar approach to satellite development data, finding that the number of production units and percent of nonrecurring work are most predictive of Weibull shape. Brown et al. (2015) apply the Weibull to aircraft development data, solving for a Weibull that uses timing of first flight to predict the shape of phasing.

The analyst may miss an opportunity to phase risk dollars appropriately, leading to a mismatch between the planned budget and future requirements if program risks (e.g., schedule growth, requirements change, flight test extension) are realized.

In spite of this abundance of literature providing recommended solutions for the phasing of an overall program cost estimate, no literature provides a mathematical solution specific to the phasing of risk dollars. As introduced earlier, the JA-CSRUH, the premier guide to cost-related risk, offers only generalized recommendations that still require further judgment to implement. Several recent research papers address the timing of cost growth, although the efforts stop short of solving and providing a recommended mathematical function, especially one specific to aircraft development programs. As notable examples, Kozlak et al. (2017) and D'Amico et al. (2018) study how program cost estimates change over the major milestones of aircraft development programs. The author finds that most cost growth in programs occurs later in the schedule, typically between the program's first flight and the end of development testing. It should be stressed, however, that both papers focus on measuring growth of the total cost estimate, without regard to annual phasing (i.e., which individual fiscal years are driving the cost growth). Their findings therefore have limited direct applicability to a risk-phasing solution for a new program. As a more direct approach, Elworth et al. (2019) study the timing and shape of cumulative cost growth for 12 space programs and fit both linear and exponential functions to annual cost growth data. The authors observe that, on average, space programs encounter early program underspending with late program overspending. Elworth et al. (2019) also find that the exponential function offers a superior fit to the linear function for 11 of the 12 programs, but the authors do not attempt to fit an exponential function to a combined data set nor offer a recommended phasing solution. Tran (2021) repeats Elworth et al.'s methodology, but instead uses all program types, including aircraft, missile, and space programs. Tran observes early program underspending, and notes that most significant budget changes occur after the 70 to 80% schedule mark. Similar to Elworth et al., Tran does not attempt to combine his dataset for the purpose of defining a single best-fit function.

As a result of this literature review, the author concludes a long history of using mathematical function is available to predict phasing. Despite this long history, no one has yet attempted to fit a mathematical function to a cost growth dataset consisting of multiple programs for the purpose of informing risk phasing. To meet the author's goal of offering a function-based risk-phasing profile for aircraft development, three overarching research questions are outlined:

1. Where in the planned schedule does cost growth typically occur?
2. What regression equation best fits the observed cost growth data?
3. May the equation be simplified into annualized percentages for application to risk phasing by the program office?

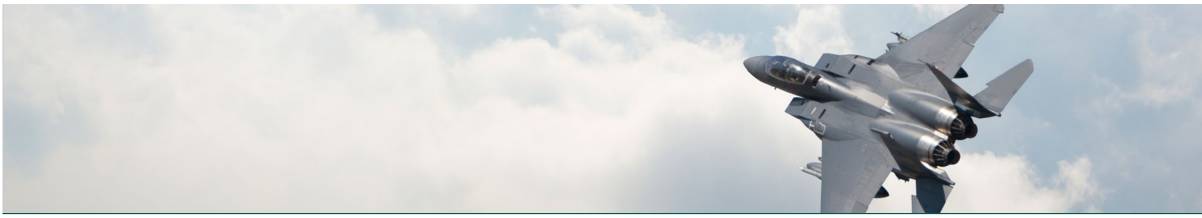
These questions will be examined using cost and schedule data taken from a Selected Acquisition Report (SAR) database.

Data Normalization

SARs are used for this study. They are more consistently published than the various contractor cost reports available for analysis. By law, SARs for individual acquisition programs are prepared annually in conjunction with the submission of the President's Budget. They include budgeted authority for future fiscal years and expenditures for prior fiscal years. SARs also offer the advantage of including schedule and performance data.

As a major disadvantage, SARs are reported only for Acquisition Category (ACAT) I programs, which potentially limits the applicability of this research to larger aircraft development programs and excludes ACAT IIs and ACAT IIIs. Additionally, SARs sometimes commingle funding from initial programs and their associated follow-on programs. For example, the F-15 SAR reports annual development funding from 1967 through

1997, encompassing funds for both the initial F-15A development program and subsequent F-15E Strike Eagle upgrade program. To avoid capturing follow-on program funding, the author captures only development funding from Milestone B—when a program officially becomes a “program of record” and enters engineering and manufacturing development—through the Initial Operational Capability (IOC). The IOC is the latest consistently reported milestone and the primary driver in a program’s development schedule (Department of the Air Force, 2007). Papers treating IOC as the development end point include those from RAND (e.g., Light et al., 2017), from the Institute for Defense Analyses (e.g., Tate, 2016), and from government researchers (e.g., Elworth et al., 2019; Tran, 2021).



SAR data were obtained from a local Microsoft Access SAR database hosted by the Air Force Life Cycle Management Center’s Cost & Economics Division. Initially, 96 aircraft development program “shells” are identified in the database. For inclusion in the study, aircraft development programs are required to have a published Milestone B, a published IOC, an initial/planned development budget dated within 24 months of their Milestone B, as well as a final/actual budget published at or after IOC. For consistency, programs that began development after Milestone B are excluded (e.g., HC/MC-130J Recapitalization). Lastly, programs are required to have positive cost growth to IOC to be included, and programs with negative cost growth to IOC are excluded (e.g., C-5 Reliability Enhancement and Re-engining Program). Of these criteria, the requirement for a budget within 2 years (24 months) of Milestone B and the requirement for positive cost growth at IOC are the most likely to be challenged; these two criteria are addressed in the following two paragraphs. The requirement for an initial budget within 2 years of Milestone B exists to ensure that early program spending is properly recorded. In particular, the author seeks to validate the early program underspending documented by Elworth et al. (2019) and Tran (2021). The criteria for an initial budget were initially set at 1 year from Milestone B in an earlier version of this manuscript, but expanding the criteria to 2 years allowed for the inclusion of four additional aircraft development programs. The requirement for positive cost growth to IOC exists because the author assumes that risk dollars applied to new programs will always be positive at the aggregate program level. In practice, analysts typically avoid applying negative risk dollars. This view is supported by DoD guidance, which suggests that the financial impact of unfavorable program risks generally outweighs the financial gains of favorable program opportunities (DoD, 2014, 2017). In more practical terms, the author discovered that including programs with negative cost growth prevents the fit of a statistically significant model. Although a clear pattern of cost growth emerges for those programs with positive cost growth, no clear pattern exists among the programs without cost growth. As a result, programs without cost growth would insert too much unexplained variation into the sample.

As summarized in Table 1, 14 programs are removed for beginning development post-Milestone B. Thirty-one programs are excluded because their first reported SAR budget occurred more than 24 months after Milestone B, and thus the SAR budget was not representative of an initial budget. Eighteen programs are removed because they were either cancelled or they have yet to reach IOC. As a final step, 12 programs are removed as they were under budget (i.e., negative cumulative cost growth) at the time they reached IOC. The full list of excluded programs is provided in Appendix A (Table A.1).

TABLE 1. CRITERIA FOR PROGRAM INCLUSION

Program Inclusion Criteria	Number of Programs
Aircraft Programs Listed in SAR Database	+ 96
Program Met Milestone B	- 14
SAR with Phased Budget Published within 2 Years of MS B	- 31
Program Achieved IOC	- 18
Positive Cost Growth at IOC (CGF > 1)	- 12
Total Programs Available	**21**

Note. CGF = Cost Growth Factor; IOC = Initial Operational Capability; MS B = Milestone B; SAR = Selected Acquisition Report.

TABLE 2. INCLUDED AIRCRAFT DEVELOPMENT PROGRAMS

AH-64 Apache	E-2D AHE	F-22
AV-8B	E-6A	F-35
C-17A	F-5E	H-1 Upgrade
CH-47F	F-14A	JSTARS
CMH-53E	F-15A	P-8A
CH-53K	F-16	T-45TS
EA-6B ICAP II	F-18A	V-22

Note. AHE = Advanced Hawk Eye; ICAP II = Installation Compliance Action Plan II; JSTARS = Joint Surveillance Target Attack Radar System; TS = Training System.

Each of the remaining 21 programs (Table 2) has a planned Milestone B budget and an actual, post-IOC budget representative of dollars actually expended. The planned budget represents the phased budget between the fiscal year containing Milestone B and fiscal year containing the planned IOC date, as reported on the Milestone B SAR. For programs that did not publish a planned IOC date, the last fiscal year of planned budget is treated as the IOC, as it is observed that the final year of planned budget generally overlaps with the planned IOC date. In contrast, the actual budget represents the phased budget between the fiscal year containing Milestone B and fiscal year containing the actual IOC date, as reported on the program's most recent SAR.

The requirement for positive cost growth to IOC exists because the author assumes that risk dollars applied to new programs will always be positive at the aggregate program level. In practice, analysts typically avoid applying negative risk dollars.

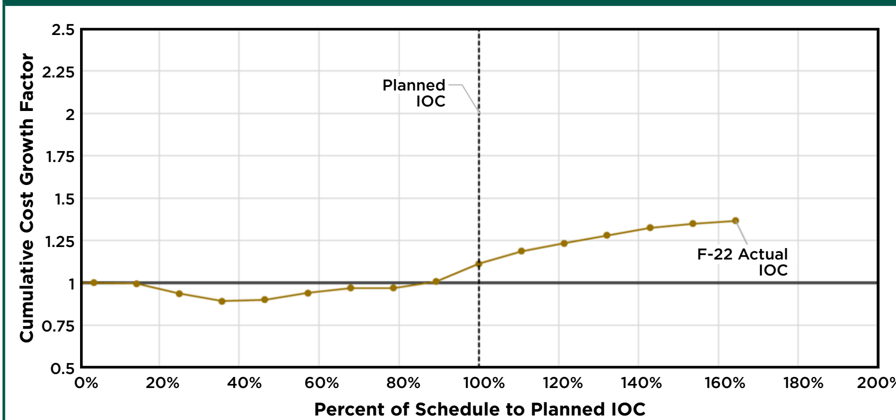
As the next step in data normalization, the planned budget profiles and actual budget profiles' costs are escalated from "Then Year" dollars to a constant price in 2021 dollars using the Producer Price Index 3364, Aerospace Products and Parts. This removes the effects of industry-specific inflation, allowing programs to be compared regardless of the length of development. In general, it is expected that longer programs are more influenced by inflation.

Having normalized for inflation, cost growth may be calculated. A cumulative planned budget and cumulative actual budget are summed for every fiscal year of the program, representative of the cumulative budget from the Milestone B fiscal year through that given fiscal year. No attempts are made to extrapolate partial years when Milestone B and IOC occurred mid-year. Finally, a comparison between the actual cumulative budget and planned cumulative budget is possible. The cumulative CGF—sometimes referred to as a cumulative CGF—is calculated for each fiscal year of the program beginning with Milestone B through actual IOC, by application of Equation 2, with FY_n representing a specific fiscal year (e.g., FY 1994) for a specific program (e.g., F-22). A CGF greater than 1 represents positive cost growth, while a CGF of less than 1 represents negative cost growth.

$$[(Cumulative\ \ Cost\ Growth\ Factor)]\_FY_n = [(Actual\ Cumulative\ \ Budget)]\_(FY_n)\ / \ [(Planned\ Cumulative\ Budget)]\_FY_n \quad (2)$$

An example of the CGF calculation is provided for the F-22 in Table 3. The final year of funding per the Milestone B SAR is FY 2000, and FY 2000 is therefore treated as the planned IOC. The actual IOC is declared by the Air Force in FY 2006. Data for the planned budget are taken from the December 31, 1991, SAR (published 7 months after Milestone B), while data for the actual budget are taken from the latest F-22 SAR available, published December 25, 2010. For reasons explained previously, budget data beyond the actual IOC are not captured. The result for the F-22 is plotted in Figure 2.

FIGURE 2. COST GROWTH BY PLANNED SCHEDULE, F 22



Note. IOC = Initial Operating Capability.

Data Analysis

Having normalized the data into percent cumulative schedule and CGF factor, data analysis may begin. The data analysis section follows the structure set forth by the research questions posed in the background section and is therefore broken into three sequential steps. The first step plots and assesses the data visually for trends. The second step finds a best-fit regression model to predict the shape of the cumulative CGF over the planned program schedule. The third step utilizes the final regression model to estimate incremental cost growth by program year.

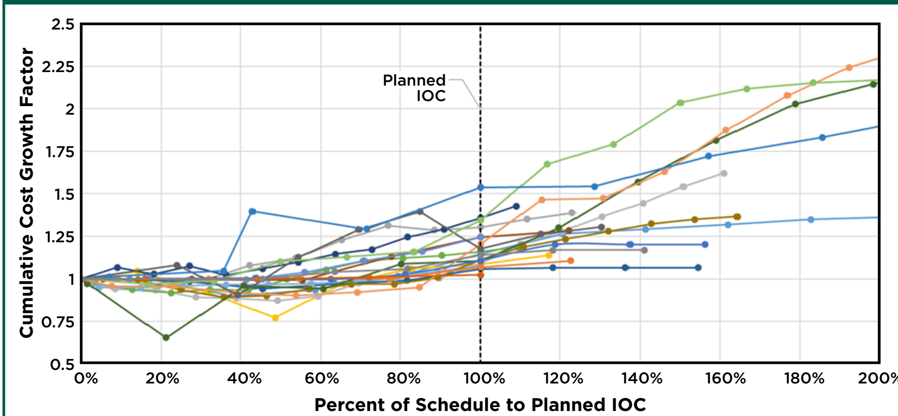
TABLE 3. CALCULATIONS FOR F 22 CUMULATIVE COST GROWTH BY PROGRAM YEAR

CONSTANT PRICE 2021 $M		
	MS B	IOC
Milestone Date	6/1/1991	12/1/2005
SAR Date	12/31/1991	12/25/2010
FY	**$**	**$**
1991	$1,895	$1,895
1992	$3,116	$3,089
1993	$4,160	$3,600
1994	$4,665	$3,761
1995	$4,395	$4,070
1996	$3,249	$3,770
1997	$2,597	$3,139
1998	$3,536	$3,457
1999	$1,602	$2,649
2000	$566	$3,678
2001	$—	$2,252
2002	$—	$1,366
2003	$—	$1,377
2004	$—	$1,335
2005	$—	$741
2006	$—	$536

CALCULATIONS					
Year	Date	Cum. Schedule	MS B Cum.	IOC Cum.	CGF
MS B	6/1/1991	0.0%	$—	$—	1.00
1991	9/30/1991	3.5%	$1,895	$1,895	1.00
1992	9/30/1992	14.3%	$5,011	$4,984	0.99
1993	9/30/1993	25.0%	$9,171	$8,584	0.94
1994	9/30/1994	35.7%	$13,836	$12,345	0.89
1995	9/30/1995	46.4%	$18,231	$16,415	0.90
1996	9/30/1996	57.1%	$21,480	$20,186	0.94
1997	9/30/1997	67.8%	$24,077	$23,325	0.97
1998	9/30/1998	78.6%	$27,614	$26,782	0.97
1999	9/30/1999	89.3%	$29,216	$29,432	1.01
2000	9/30/2000	100.0%	$29,782	$33,110	1.11
2001	9/30/2001	110.7%	$29,782	$35,362	1.19
2002	9/30/2002	121.4%	$29,782	$36,728	1.23
2003	9/30/2003	132.1%	$29,782	$38,105	1.28
2004	9/30/2004	142.9%	$29,782	$39,440	1.32
2005	9/30/2005	153.6%	$29,782	$40,181	1.35
2006	9/30/2006	164.3%	$29,782	$40,717	1.37

Note. CGF = Cost Growth Factor; IOC = Initial Operational Capability; MS B = Milestone B; SAR = Selected Acquisition Report.

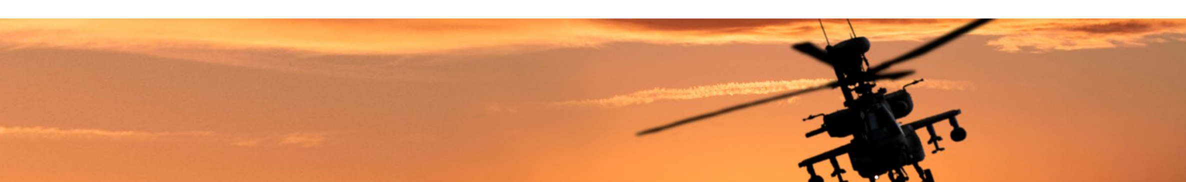
FIGURE 3. COST GROWTH BY PLANNED SCHEDULE, ALL PROGRAMS



Note. IOC = Initial Operating Capability.

Observed Cost Growth by Program

As the first step in the data analysis, the 21 development programs are plotted on a graph (Figure 3) with the *X*-axis representing the percent of planned schedule to IOC, and the *y*-axis representing the CGF factor. The graph is bound at 200% of planned schedule and 2.5 for the CGF for improved legibility. Although difficult to discern due to variability between the programs, it appears that most programs experience little or no cumulative cost growth in the first half of the schedule, with positive cumulative cost growth beginning as the program approaches the second half of the schedule. In terms of schedule, the majority of programs reach IOC between 100% and 170% of the planned schedule. No programs reach IOC early. Five programs (AH-64 Apache, CMH-53E, Joint Surveillance Target Attack Radar System [JSTARS], H-1 Upgrade, V-22) are observed with schedule lengths that more than double to IOC (i.e., > 200% schedule). Three of these programs (JSTARS, H-1 Upgrade, V-22) also experience a CGF greater than 2, indicating that costs more than doubled.



Fitted Model

As the second step in the data analysis, ordinary least squares (OLS) regression models are fit to the data. Due to the nonlinear nature of the data, a 2nd degree polynomial regression and an exponential regression are selected a priori. By applying transformations to the independent variable (polynomial model) and dependent variable (exponential model), the author can model nonlinear data while remaining within the OLS regression framework. A simple linear regression model without transformation is also considered as a baseline comparison. The equations for the regression models are provided in Table 4, with *X* representing the percent cumulative schedule and *y* representing the CGF. The Weibull and Beta distributions, although popular for phasing point estimates, are not considered. As the Weibull and Beta are probability distributions, their domain is bound between 0 and 1. In simple terms, the Weibull and Beta distributions are incapable of modeling schedule growth, as they do not allow the *X* variable (cumulative schedule) to exceed 100%. Applying a probability distribution to schedule growth data would require further normalization of the data, which would unnecessarily complicate the model's interpretation and results.

TABLE 4. OLS REGRESSION MODEL EQUATIONS

Simple Linear	Exponential	Polynomial
$y = B_0 + B_1X$	$\ln(y) = \ln(B_0) + B_1X$	$y = B_0 + B_1X + B_2X^2$

TABLE 5. INITIAL OLS REGRESSION OUTPUTS

	Simple Linear		Exponential		Polynomial	
***R*-Squared (R^2)**	0.759		0.780		0.871	
Adj. *R*-Squared	0.758		0.779		0.870	
Observations	245		245		245	
***F*-test *p* value**	(<0.01)		(<0.01)		(<0.01)	
Coefficients	**Estimate**	***p* value**	**Estimate**	***p* value**	**Estimate**	***p* value**
Intercept	0.768	(<0.01)	-0.132	(<0.01)	0.964	(<0.01)
X	0.574	(<0.01)	0.368	(<0.01)	0.015	(0.726)
X^2					0.234	(<0.01)

Note. Adj. = Adjusted.

The author provides initial results for the three regression models in Table 5. The polynomial offers the superior fit statistics, with an R^2 of 0.87 and a statistically significant *F*-test *p* value of < 0.01. Despite the impressive R^2 fit statistic, diagnostic issues are noted for the polynomial. The first observation is that the regression is heavily influenced by the five programs with extreme cost and schedule growth, and the removal of any one of the five programs significantly alters the polynomial solution. This is an indication that the polynomial may be overfitting the data points representing extreme cost and schedule growth. This concern is further investigated using a Cook's

Distance plot. Cook's Distance is a numerical measure of the influence that a single observation has on the regression model. As shown in Appendix B (Figure B.1), the Cook's Distance values (*y*-axis) are plotted against the percent of schedule to planned IOC (*X*-axis) for each observation. The plot reveals that observations beyond 100% of planned schedule tend to exert greater influence on the model than observations prior to 100% of planned schedule. This phenomenon likely occurs because the data points beyond 100% of planned schedule have greater dispersion. Additionally, programs with no or minimal schedule growth begin to "drop out" of the sample beyond 100% of planned schedule, leaving fewer remaining programs—and hence fewer observations—for which to fit the regression line. The second observation is that the polynomial model may violate several linear regression assumptions. The residual plot in Appendix B (Figure B.2) shows the "residual"—or error—between the actual and predicted CGF for each observation. The residuals appear to increase as one moves from left to right across the *X*-axis, indicating that the model does a worse job of predicting observations with larger CGFs. This trend points to nonconstant variance, violating the linear regression assumption of homoscedasticity. The model also fails a Shapiro-Wilks test for normality, with a p value of < 0.01, indicating that the model's residuals are not normally distributed—a violation of another linear regression assumption. When taken in aggregate, these diagnostic issues indicate that the model potentially needs revision.

Given the worsened goodness-of-fit performance for the exponential and linear models, the models are discarded, and the polynomial model is accepted as the best-performing model for the truncated data.

As a simple solution that resolves the influence of programs with extreme schedule growth, the author determines that the dataset should be truncated to avoid the extreme schedule growth data. The decision of where to truncate requires careful consideration. If the sample data are truncated too early (e.g., at 100% of planned schedule), then the equation cannot be utilized to phase risk dollars beyond the planned schedule without extrapolation. If the sample is truncated too late, it may not correct the diagnostic issues identified earlier, and programs with greater schedule growth will continue to exert greater influence on the model.

The cutoff for truncation ultimately selected is 130% of planned schedule, with cost growth data that occurred beyond 130% of the planned schedule truncated, or excluded. The author's own experience indicates that program office estimates at Milestone B do not phase risk dollars in the fiscal years beyond the planned development schedule. However, a senior leader in the cost analysis field explains that in some instances, higher level cost analysis organizations (e.g., the Air Force Cost Analysis Agency, the Office of Cost Assessment and Program Evaluation) may add 1 or 2 years of risk-related budget beyond the planned schedule. The senior leader has not observed more than 2 years of budget added beyond the planned schedule (L. K. Hawthorn, personal communication, December 10, 2021). Given that the median planned program length in the author's sample is 7 years, 130% of planned schedule is a logical data cutoff, as 130% of schedule is roughly equivalent to a 7-year program experiencing 2 years of unplanned schedule growth. The truncated data will allow the analyst to phase up to 2 years of additional risk beyond the planned schedule for programs of 7 years or longer and 1 year of additional risk for programs of 6 years or less without risk of extrapolating beyond the data set.

Using the truncated data set, the polynomial, exponential, and linear regression models are again fit, with updated results provided in Table 6. The polynomial model again offers the superior fit statistic, with an R^2 of 0.50, F-test p value of < 0.01, and p values of 0.15 and < 0.01 for the X and X^2 variables, respectively. While the polynomial's X^2 variable is statistically significant, the X variable is not, but is maintained in the model per the hierarchy principle.[1] In contrast to the polynomial, the exponential and linear models provide worsened R^2 fits of 0.43, with greater sum of squared residuals (SSR). SSR is used as an alternative goodness-of-fit metric as we are comparing across models with transformed variables. Given the worsened goodness-of-fit performance for the exponential and linear models, the models are discarded, and the polynomial model is accepted as the best-performing model for the truncated data.

TABLE 6. REVISED OLS REGRESSION OUTPUTS USING TRUNCATED DATA

	Simple Linear		Exponential		Polynomial	
***R*-Squared (R^2)**	0.429		0.432		0.502	
Adj. *R*-Squared	0.426		0.429		0.496	
Observations	196		196		196	
***F*-test *p* value**	(<0.01)		(<0.01)		(<0.01)	
Coefficients	**Estimate**	***p* value**	**Estimate**	***p* value**	**Estimate**	***p* value**
Intercept	0.928	(<0.01)	-0.066	(<0.01)	0.988	(<0.01)
X	0.268	(<0.01)	0.235	(<0.01)	-0.105	(0.152)
X^2					0.319	(<0.01)

Note. Adj. = Adjusted.

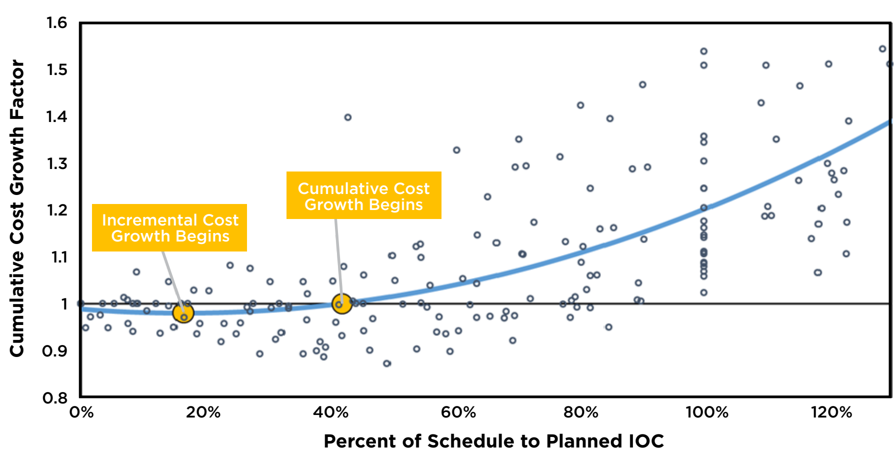
Turning to diagnostics for the polynomial model, the Cook's Distance plot in Appendix C (Figure C.1) shows fewer influential data points. Moreover, the influential data points that do exist are more evenly distributed across the *X*-axis of the plot, indicating that the truncation of the data set successfully controlled for the influence of observations with extreme cost and schedule growth. The residual plot in Appendix C (Figure C.2) displays improved homoscedasticity (i.e., constant variance) across the range of predicted values when compared to the polynomial fit to the entire dataset. Unfortunately, the model's residuals still fail to pass the Shapiro-Wilks test for normality (*p* value < 0.01), likely due to the model's residuals being positively skewed. This violation is accepted as an allowable model weakness. Given that the author does not strive to produce confidence or prediction intervals around the model's estimate, the lack of normality in the residuals is not expected to significantly bias the model's output. The polynomial model fitted to the truncated dataset is thus accepted as the final model.

The coefficients for the final model are interpreted and written as:

$$\begin{aligned} &\mathit{Cumulative\ \ Cost\ Growth\ Factor} \\ &= [(0.3187\,(\mathit{Cum.Schedule}))]^2 - 0.1055\,(\mathit{Cum.Schedule}) \\ &\quad + 0.9882,\ \mathit{when}\ 0 \le \mathit{Cum.Schedule} \le 1.3 \end{aligned} \tag{3}$$

When Equation 3 is plotted (Figure 4), it visually reinforces the observation that CGF is less than 1 early in the planned program schedule, indicating negative cumulative cost growth. To find the point at which incremental cost growth first becomes positive, the author takes the first derivative of the polynomial equation. After solving for *X*, it is shown that positive incremental cost growth will begin at 17% schedule, on average. In contrast, by setting the original equation equal to 1 and solving for *X*, the author discovers that cumulative cost growth becomes positive in the second half of the program's planned schedule at 42% schedule.

FIGURE 4. PLOTTED POLYNOMIAL REGRESSION COST GROWTH EQUATION



This raises the question: When phasing risk dollars, are we most interested in the point at which incremental cost growth begins or cumulative cost growth begins? As evidenced by the data in this study, programs do frequently lose total obligation authority (budget) within the early years of the program. It would therefore be unwise to begin phasing risk only after the point of cumulative cost growth, as doing so assumes that underexecuted development funds are always carried forward to fund effort in later years of the program. A more realistic assumption of underspent development funds is that between 0% and 17% of planned schedule are lost to the program, and incremental risk phasing should begin at 17% schedule to cover the lost funding. The author utilizes this assumption in the next section of this article to calculate a risk-phasing profile using the incremental cost growth within each year of the development program.

> **As evidenced by the data in this study, programs do frequently lose total obligation authority (budget) within the early years of the program. It would therefore be unwise to begin phasing risk only after the point of cumulative cost growth, as doing so assumes that underexecuted development funds are always carried forward to fund effort in later years of the program.**

Annualized Percentages

As the third step in the data analysis, the best-fit polynomial equation is used to estimate the percentage of cost growth by year. For purposes of demonstrating the calculations, a 4-year development program is imagined. The author does not desire to phase any additional years of risk dollars beyond the 4-year schedule in this example. Using the polynomial equation and cumulative schedule increments of 25, 50, 75, and 100%, the cumulative CGF at the end of each increment is calculated in row one of Table 7. In row two of Table 7, the cumulative CGF is converted into annualized cost growth by calculating the change in cost growth between each increment. Any year in which the incremental cost growth is negative is then rounded to zero to avoid the phasing of negative risk dollars. Lastly, the third row of Table 7 normalizes cost growth so that annualized cost growth sums to 100% across the program's years. This allows an analyst to use the table to easily phase the entirety of their calculated risk dollars without further normalization. These calculation steps are recompleted for programs ranging from 3 to 10 years, with assumptions for no schedule growth (Table 8), 1 year of schedule growth (Table 9), and 2 years of schedule growth (Table 10). Risk percentages phased beyond the planned schedule are signified by shading. When assuming 2 years of schedule growth and applying Table 10, consider referencing the article's endnote to ensure a smooth, downward sloping budget tail.[2]

TABLE 7. ANNUALIZED COST GROWTH CALCULATIONS

	A	B	C	D	E
1		Schedule Treatments			
2		25%	50%	75%	100%
3	**Cumulative Cost Growth Factor**	0.982	1.015	1.088	1.201
4	**Incremental Cost Growth**	0%	3.3%	7.3%	11.3%
5	**Increm. Cost Growth (Normalized)**	0%	15%	33%	52%

Sample Calculations for Column D
D3 = 0.317 x 0.75^2 - 0.1055 x 0.75 + 0.9882
D4 = 1.088 - 1.015
D5 = 0.073 / (0.033 + 0.073 + 0.113)

Note. Increm. = Incremental.

TABLE 8. ANNUALIZED COST GROWTH – NO SCHEDULE GROWTH

# Years of Funding from MS B to EMD Completion	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
3	0%	33%	67%							
4	0%	15%	33%	52%						
5	0%	8%	19%	31%	42%					
6	0%	2%	12%	20%	28%	38%				
7	0%	2%	8%	14%	20%	25%	31%			
8	0%	1%	5%	10%	14%	19%	23%	28%		
9	0%	0%	4%	7%	11%	14%	18%	21%	25%	
10	0%	0%	2%	5%	8%	11%	14%	17%	20%	23%

Note. EMD = Engineering and Manufacturing Development; MS B = Milestone B.

TABLE 9. ANNUALIZED COST GROWTH — 1 YEAR SCHEDULE GROWTH

# Years of Funding from MS B to EMD Completion	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
3	0%	33%	67%	*							
4	0%	9%	20%	30%	41%						
5	0%	5%	13%	20%	27%	35%					
6	0%	2%	8%	14%	19%	25%	32%				
7	0%	1%	6%	10%	14%	19%	23%	27%			
8	0%	1%	4%	7%	11%	14%	18%	21%	24%		
9	0%	0%	3%	6%	8%	11%	14%	17%	19%	22%	
10	0%	0%	2%	4%	7%	9%	11%	13%	16%	18%	20%

**Indicates that value could not be provided without extrapolating beyond truncated sample data*
Note. EMD = Engineering and Manufacturing Development; MS B = Milestone B.

TABLE 10. ANNUALIZED COST GROWTH — 2 YEAR SCHEDULE GROWTH

# Years of Funding from MS B to EMD Completion	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
3	0%	33%	67%	*	*							
4	0%	9%	20%	30%	41%	*						
5	0%	5%	13%	20%	27%	35%	*					
6	0%	2%	8%	14%	19%	25%	32%	*				
7	0%	1%	4%	8%	11%	14%	17%	21%	24%			
8	0%	0%	3%	6%	8%	11%	14%	16%	19%	23%		
9	0%	0%	2%	4%	7%	9%	11%	13%	16%	18%	20%	
10	0%	0%	2%	3%	5%	7%	9%	11%	13%	15%	17%	18%

**Indicates that value could not be provided without extrapolating beyond truncated sample data*
Note. EMD = Engineering and Manufacturing Development; MS = Milestone B.

Interpretation of Results

The historical cost growth data in this study indicate that, on average, underspending yearly is typical in the planned program schedule, with the majority of positive incremental cost growth occurring in the second half of the planned schedule. These results support prior studies from Kozlak et al. (2017), D'Amico et al. (2018), Elworth et al. (2019), and Tran (2021). This study goes one step further, however, by determining the specific cost growth percentages within each program increment. As observed in Table 8, if cost growth beyond the planned IOC is ignored, approximately 15% of incremental cost growth occurs in the first half of the program's planned schedule, with the remaining 85% of incremental cost growth occurring in the second half of the planned schedule. Moreover, Tables 9 and 10 show that as additional years of risk are added to the program's base schedule, an even greater proportion of cost growth occurs beyond the 50% schedule mark.

If these percentages are used to phase risk dollars for a new program, the resulting phasing profile would be described as “backloading” or “backloaded.” What are some possible explanations for why cost growth is historically backloaded? Articles address many causes for cost growth. Among the most frequently cited causes, several could feasibly lead to a backloaded cost growth profile. While it is not the author’s intent to identify all possible causes of backloaded cost growth, four common causes are explained below, with the goal of assisting the real-world practitioner in better understanding and justifying to decision makers why a backloaded risk-phasing profile may be warranted for a new program.

- **Schedule Optimism**. Many programs pursue aggressive schedules despite historical evidence that indicates significantly longer cycle times. RAND finds that ACAT I programs have average schedule growth of 39% to achieve IOC (Light et al., 2017). This statistic is equivalent to a planned 5-year program taking almost 7 years to reach IOC. A cost estimate phased across an unrealistically short schedule will result in a surplus of funds early in the schedule and cost growth later in the schedule, regardless of the accuracy of the cost estimate.
- **Schedule Delays**. Conley et al. (2014) research the execution of development budgets, finding that budget execution for development programs is an ongoing problem area, with less than half of development budget lines meeting execution goals. Simply put, programs cannot spend money on development activity as quickly as planned. Identified causes for poor budget execution include delayed contract awards, delayed source selections, and lack of personnel availability, among other reasons (Tremaine & Seligman, 2013). Many of these causes are most pronounced early in the planned development schedule, causing the program’s remaining effort and risk to be pushed ‘to the right’ of the planned schedule.
- **Complex Integration**. Another potential contributor to late schedule cost growth is high complexity system integration, found to be a major contributor to extreme cost growth

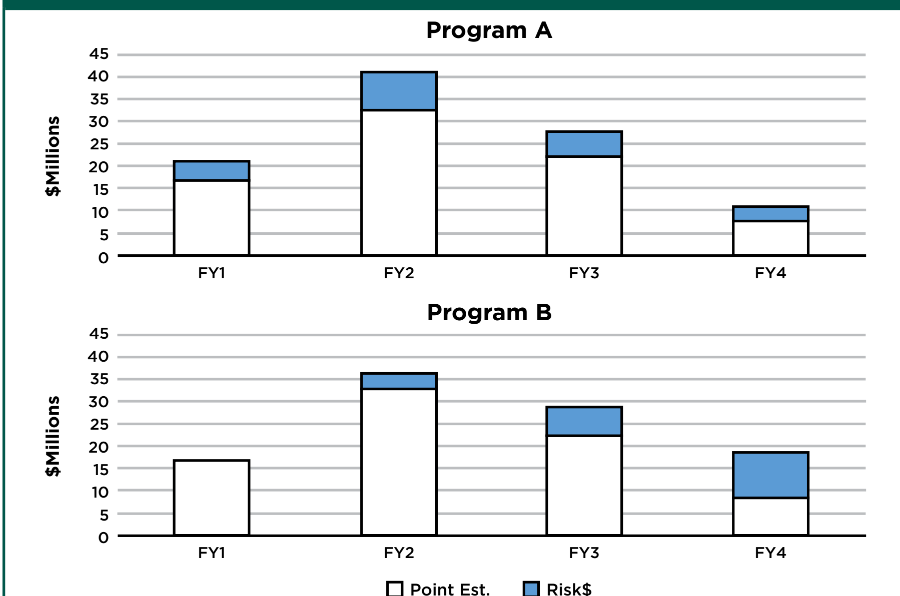
(Lorell et al. 2017). Integration issues often appear later in the program schedule, such as during developmental or operational flight testing. This leads to testing extensions and unplanned redesigns—and therefore cost growth—late in the program schedule. Fixing design defects during integration testing is ten times costlier than during the initial design phase (Briski et al., 2008).

- **Requirement Change**. This is an alteration in system requirements driven by an "undisciplined definition [or] uncontrolled growth in system requirements" (DoD, 2003, p. 2). Requirement change is analogous to engineering change orders (ECOs), which 46% of aircraft development contracts experience. Research shows that, typically, a major uptick in ECOs occurs late in the program schedule, which in turn would drive backloaded cost growth (Valentine, 2016, 2017).

Integration issues often appear later in the program schedule, such as during developmental or operational flight testing. This leads to testing extensions and unplanned redesigns—and therefore cost growth—late in the program schedule.

One notable example that ties these four common causes together is the F-22 development program. From the start, the F-22 was judged to have had an optimistic schedule estimate. The Government Accounting Office (GAO—now the Government Accountability Office) identified the F-22 development schedule as risky due to the strategy of initiating production prior to the testing of an aircraft with a fully integrated avionics suite (GAO, 1988). Once development began, unexpected schedule delays occurred. The prime contractor struggled with manufacturing the advanced composites required for the airframe, slowing the delivery of the test aircraft. This led to first flight and flight testing occurring 2 years later than planned. Integration proved troublesome for the F-22, particularly for the avionics suite and software. The avionics for the F-22 were the most advanced ever designed, and subsequently used as a central processor rather than federated (i.e., modularized) avionic components. Integration of these components was further complicated by the avionics development work being shared over three major contractors—Lockheed Martin, Northrop Grumman, and Boeing. Per RAND analysis, avionics drove a significant portion of the redesign, flight testing, and cost growth late in the program (Younossi et al., 2005). Lastly, the F-22 encountered unforeseen ECOs late in the program. Although specific data on the causes of the F-22 ECOs are not available, a GAO report released in the second half of development states that "Air Force and Lockheed officials attribute recent cost growth to…the need to incorporate more engineering changes than planned" (GAO, 2001, p. 19). Taken in aggregate, this potentially explains the F-22's concave cost growth pattern shown previously in Figure 2. The F-22 experienced early program underspending—driven by schedule optimism and schedule delay, and late program cost growth—driven in part by integration difficulties, flight test extensions, and ECOs.

FIGURE 5. NOTIONAL COMPARISON OF RISK PHASING APPROACHES



So, what is the practical implication of backloading risk in future acquisition programs? Intentionally backloading risk will place fewer dollars at the front of the program schedule and more dollars later in the program schedule. As a notional example, Program A in Figure 5 shows a 5-year program where both the point estimate ($80 million) and risk dollars ($20 million) are phased using a traditional 60/40 Weibull—60% of budget in the first half of the program, 40% in the second half. These figures represent a common distribution for phasing aircraft development. Most of the risk is placed in the first half of the planned schedule. In contrast, Program B does not utilize the same phasing for the point estimate and risk dollars. A traditional 60/40 Weibull phases the $80 million point estimate only, with the $20 million in risk dollars phased using the backloaded profile recommended in this article. As a result, Program B's funding is better positioned to handle the schedule delay typical of development programs. This allows Program B to improve early budget execution while also allowing for greater funding later in the program schedule.

Conclusion

Current uncertainty and risk analysis literature only offer subjective strategies for the phasing of risk dollars. By leveraging the historical cost growth profiles of completed aircraft development programs, the acquisition community may begin to understand where risk-driven cost growth is typically realized within the development schedule. This knowledge may then be used to phase risk dollars for future aircraft development programs. With that goal in mind, three specific research questions are proposed and answered:

1. **Where in the planned schedule does aircraft development cost growth occur?** Cost growth is historically backloaded, with underspending (i.e., underexecution or lost funding) early in the program schedule and overspending (i.e., cost growth or budget growth) later in the program schedule. The author theorizes that schedule optimism, schedule delays, highly complex systems integration, and requirements change are all drivers of backloaded cost growth.

2. **What equation best fits the observed cost growth data?** Cost growth may be defined by the polynomial provided in Equation 3 and plotted visually in Figure 4. The polynomial reveals that,

on average, early cost growth is negative. Positive incremental cost growth begins at 17% of planned schedule and continues to increase through the end of development.

3. **May the equation be simplified into annualized percentages for application to aircraft development risk phasing by the program office?** Simplifying the polynomial output for a 4-year program shows that 15% of total cost growth occurs in the second year, 33% of total cost growth occurs in the third year, and 52% of total cost growth occurs in the fourth year of the planned schedule. Negligible cost growth occurs in the first year of the planned schedule (rounds to 0%), as programs historically underspend during the early schedule. Annualized percentages are provided for programs of other lengths in Table 8. Additionally, Table 9 and Table 10 provide solutions for the phasing of risk beyond the planned schedule.

> **By leveraging the historical cost growth profiles of completed aircraft development programs, the acquisition community may begin to understand where risk-driven cost growth is typically realized within the development schedule. This knowledge may then be used to phase risk dollars for future aircraft development programs.**

As a caveat to these results, several limitations in the data and methodology herein are noted. These caveats are directly tied to suggestions for follow-on research. First, this research focuses only on DoD aircraft programs, and it is therefore not applicable to other types of DoD programs. The author suggests that the research methodology could be extended to other types of DoD programs—ships, space, missiles, land vehicles, and software. Similarly, this research focuses only on development, and cost growth within other stages of the acquisition life cycle (e.g., production or sustainment) could also be modeled using OLS regression. As a second limitation, due to this study's sample being limited to 21 observations, is that no attempt is made to explain the differences in cost growth behavior between individual programs. Opening up the sample to additional program types would allow for a greater number of sample observations, which in turn would permit the introduction of additional independent variables to predict variations in the shape of cost growth. Statisticians generally recommend ten observations for every independent variable, thereby limiting the independent variables in this research to two or less (Harrell et al., 1996). The timing of Critical Design Review (CDR), test and evaluation, length of development, and percent of development completed prior to Milestone B are potential predictors of cost growth behavior (D'Amico et al., 2018; Kozlak et al., 2017). A third limitation is that this research only utilizes SAR data. A drawback of the SAR data used in this research is that it reports only total program costs, without delineating major contractor cost categories such as the nonrecurring engineering, test and evaluation, or systems engineering and program management. SARs also do not differentiate between contractor cost and government costs. The author therefore suggests that this research be repeated using a database of annual program office estimates (POEs), which would allow for such delineations. Based on anecdotal experience, the author posits that differences exist in the timing of cost growth for the various cost elements within a development program. POEs could easily validate whether these differences exist. A fourth and final limitation of this article is that the methodology assumes that sufficient risk dollars are available for phasing. Without sufficient risk dollars to phase, budget shortfalls will still occur, particularly within the later years of the development schedule. Analysts should look beyond the findings in this article when determining an appropriate amount of overall risk, due to the author's intentional exclusion of programs without positive cost growth. Recent research indicates that development programs experience about 70% cost growth to IOC, with fixed-wing aircraft exhibiting less growth and helicopter programs exhibiting more growth, on average (Light et al., 2017).

In closing, the author stresses that the results of this article are not a one-size-fits-all solution. Some programs will not experience any of the identified drivers of backloaded cost growth. Other programs will have reasons for expecting program risks to occur earlier within the planned schedule (e.g., a design review resulting in change). For this minority of programs, a risk-phasing profile—different than the profile recommended by this article—may be optimal. However, for the majority of program/project managers, especially those lacking a clear understanding of when risks may occur, the results of this article will be helpful in objectively phasing and defending a more backloaded risk-phasing profile.

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Endnotes

[1] When performing polynomial regression, it is suggested that the lower order term (i.e., X) should not be eliminated from the model if the higher order term (i.e., X^2) is statistically significant. This is sometimes referred to as the hierarchy principle. The lower order term provides basic information about the shape of the response, while the higher order term provides refinements about the shape of the response. (See Faraway [2005, pp. 114–116]; Griepentrog et al. [1982]; or Kutner et al., [2005, pp. 298–299] for a more in-depth discussion.)

[2] When referencing the 2-year schedule growth table, note that the table recommends phasing a greater percentage of risk dollars in the second year of schedule growth than in the first year of schedule growth. The analyst may find it helpful either to transpose these two percentages or else manually adjust the percentages if a smoother budget "tail" is desired.

Acknowledgement

Special thanks to Shawn Valentine, Air Force Life Cycle Management Center, Cost & Economics Division, for his feedback throughout multiple iterations of this research project.

Appendix A
List of Excluded Aircraft Programs

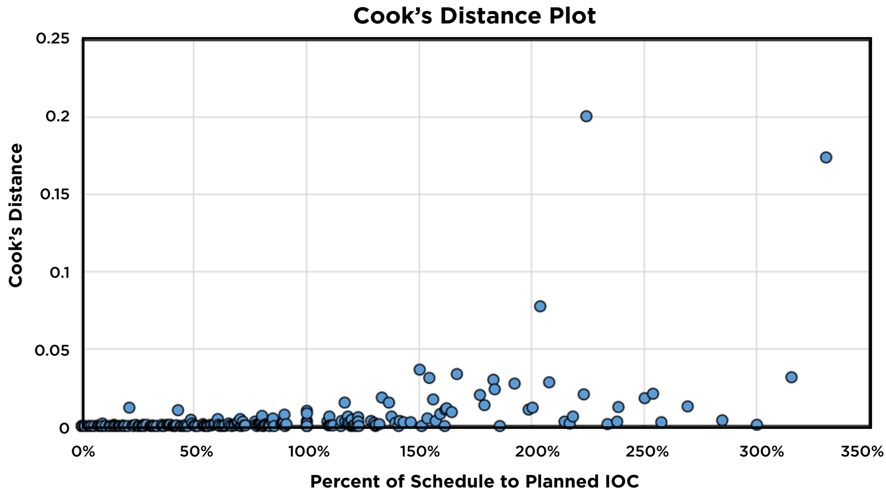
TABLE A.1. PROGRAMS REMOVED FOR BEGINNING DEVELOPMENT POST MILESTONE B

No Milestone B	No Milestone B Budget	Canceled or Missing IOC Budget	Ongoing	Negative Cost Growth at IOC
AH-64E New Build	A-7D	AFX	Adv. Pilot Trainer	A-10
AH-64E Remanufacture	A-7E	Airborne Laser	B-2 BDM	B-1 CMUP Comp. Upgrade
C-130J	ATIRCM/CMWS	Armed Recon. Helicopter	MH-139A	B-2 EHF Inc 1
C-27J	AV-8B Remanufacture	B-1 CMUP DSUP	MQ-25	B-2 RMP
E-4	AWACS Block 40-45	C-130 AMP	VC-25B	C-5 RERP
F-14 Block 1 Upgrade	AWACS RSIP	Comanche	VH-92A	EA-18G
F-5E	B-1 CMUP-JDAM	CV Helo		F-14D
FB-111A	B-2A	EA-6B		F-18EF
HC/MC-130J Recap	B-52 OAS-CMI	HHD-60 Night Hawk		F-22 3.2B
KC-10A	Blackhawk UH-60A	P-7A LRAACA		HH-60W
KC-130J	C-5 AMP	T-46		JPATS
Medium Lift Replacement	E-3A	VH-71		KC-46A
P-3C Avionics IV Upgrade	EF-111A			
UH-72 LUH	F-111A			
	F-14A			
	F-18A			
	F-4E			
	KC-135R			
	Kiowa Warrior			
	Longbow Apache			
	MH-60R			
	MH-60S			
	MQ-1B			
	MQ-1C			
	MQ-4C			
	MQ-8			
	MQ-9			
	RQ-4A Block 5			
	S-3A			
	SH-60B LAMPS MKIII			
	UH-60M Blackhawk			

Appendix B

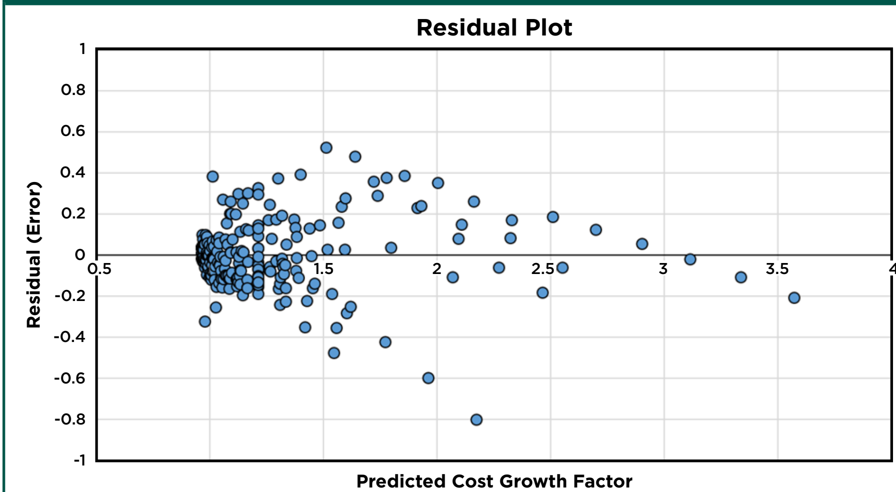
Polynomial Regression Model Residual Plot—Full Dataset

FIGURE B.1. COOK S DISTANCE PLOT FOR POLYNOMIAL MODEL



Note. IOC = Initial Operational Capability.

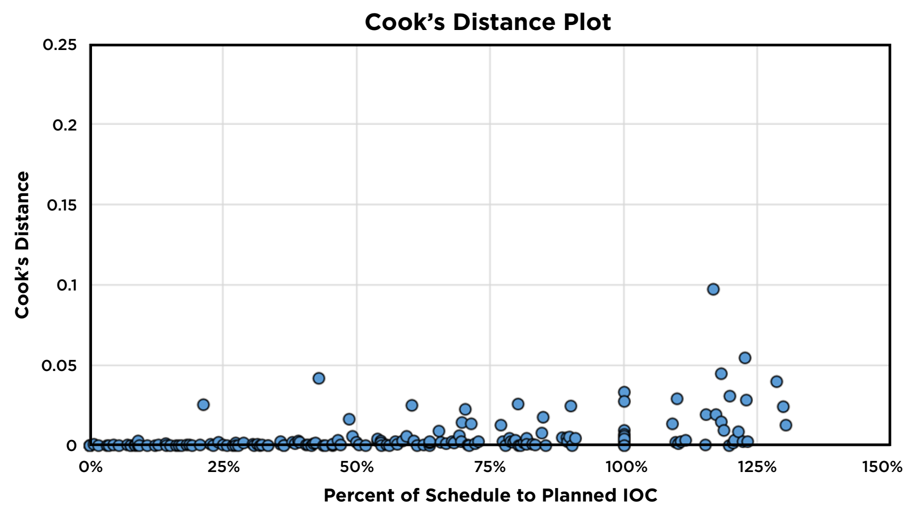
FIGURE B.2. RESIDUAL PLOT FOR POLYNOMIAL MODEL



Appendix C

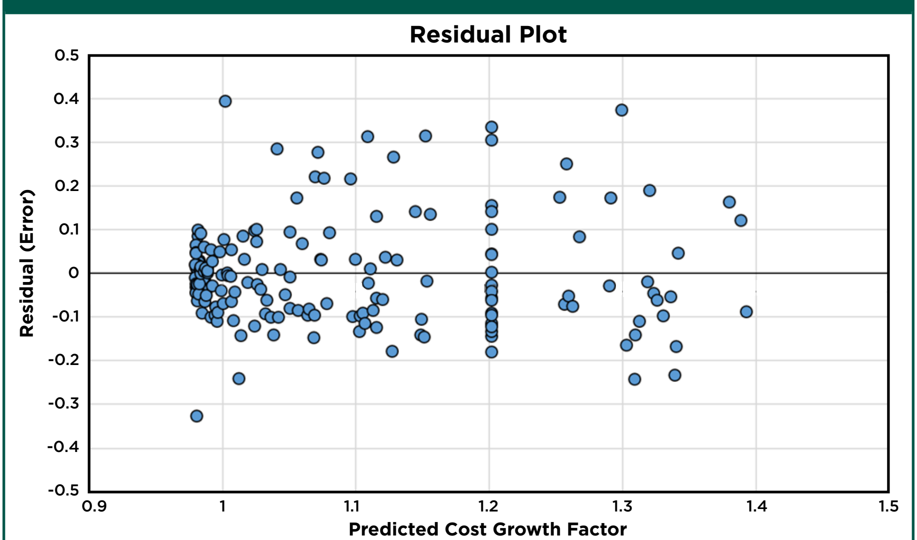
Polynomial Regression Model Residual Plot— Truncated Dataset

FIGURE C.1. COOK S DISTANCE PLOT FOR POLYNOMIAL MODEL TRUNCATED DATA



Note. IOC = Initial Operational Capability.

FIGURE C.2. RESIDUAL PLOT FOR POLYNOMIAL MODEL TRUNCATED DATA



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PROFESSIONAL READING LIST

The Defense Acquisition Professional Reading List is intended to enrich the knowledge and understanding of the civilian, military, contractor, and industrial workforce who participate in the entire defense acquisition enterprise. These book recommendations are designed to complement the education and training vital to developing essential competencies and skills of the acquisition workforce. Each issue of the *Defense Acquisition Research Journal* will include one or more reviews of suggested books, with more available on our website: http://dau.edu/library.

We encourage our readers to submit book reviews they believe should be required reading for the defense acquisition professional. The books themselves should be in print or generally available to a wide audience; address subjects and themes that have broad applicability to defense acquisition professionals; and provide context for the reader, not prescriptive practices. Book reviews should be 450 words or fewer, describe the book and its major ideas, and explain its relevance to defense acquisition. Please send your reviews to the managing editor, *Defense Acquisition Research Journal* at DefenseARJ@dau.edu.

Featured Book

A History of Government Contracting (2nd ed)

Author: James F. Nagle

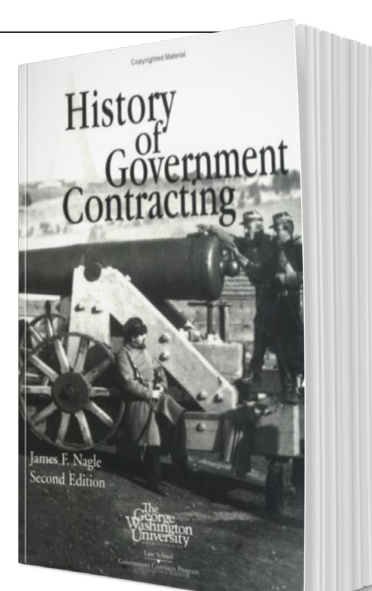
Publisher: The George Washington University

Copyright Date: 1999

Hard/Softcover/Digital: Softcover, 605 Pages

ISBN-13: 9780935165692

Reviewed by: John Krieger, Professor of Contract Management, DAU, Defense Systems Management College



Review:

A History of Government Contracting is a history of the United States viewed through the filter of Federal Government acquisition contracting. In this history of the United States, Nagle has provided an eminently readable survey. As a review and analysis of government acquisition and contracting, it is enlightening and invaluable. For those of you who are not familiar with the history of government contracting, it often seems like tides coming and going. If you just wait 7 to 10 years, you'll see the flip-flops of acquisition reform. For example, fixed-price development contracts for major systems were in vogue in the 1970s, banned in the 1980s, and made a comeback in this century.

Many of us in government acquisition have a tendency to think about acquisition contracting through the filter of our own careers in the business. As a result, we tend to think of things we hadn't heard about before as being new. But as Nagle shows us, "Nothing is new under the sun!" (Ecclesiastes 1:9). For example, you may think contractors on the battlefield is something new, invented as a result of our need for critical support services in Afghanistan and Iraq. Not so. As Nagle points out, it is something that has been with us since before the beginning of our nation, during the French and Indian War Campaign of 1755-1756. Some other examples:

1792—First Congressional investigation focusing on contracting

1794—Cost overruns on the six frigates (i.e., Chesapeake, Constitution, President, United States, Congress, and Constellation) require reducing the quantity to three

1799—Government Furnished Property (GFP) in the form of cloth to provide clothing for the military

1861—One of the first examples of a weapons system (i.e., the Monitor or "cheese board on a raft")

1917—Cost-plus-incentive-fee contract—in the original it came to be known as "cost-plus with sliding fee and fixed maximum fee"

1935—Cost growth on Navy and Army Air Corps aircraft

1938—Competitive prototypes

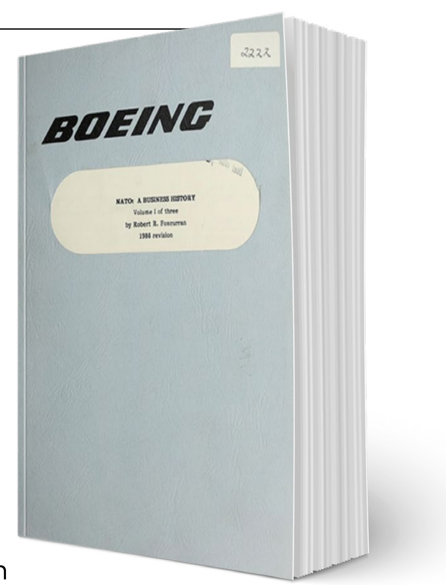
1961—Oral presentations in formal source selections

For those who might like to delve deeper into some topics, the book has extensive endnotes for cited material, includes a bibliographical essay of all the books and articles that Nagle consulted in the development of the work, (e.g., Revolution, Constitutional Period, Start of the Arms Industry Civil War to 1880, Aircraft, Shipbuilding, Modern Era), and a Name Index of people mentioned in the book.

When I was first asked to write a review of *A History of Government Contracting*, I emailed Jim Nagle and asked whether he had a snappy quotation that he might like included. His response was, "I don't think I have any snappy quotes but I think it's important for people to recognize that our procurement system didn't just come into existence of [*sic*] the day the FAR became affective [*sic*]. It's a product of over 240 years of trial, error, scandals and triumphs often in the most stressful circumstances the nation has encountered." That's snappy enough for me.

Note: The most recent edition of *A History of Government Contracting* is the third edition, published in two volumes (ISBN 978-1-937246-38-9).

Featured Book



NATO: A Business History

Author: Robert Foxcurran

Publisher: Boeing

Copyright Date: 1986

Hard/Softcover/Digital: EPUB, 2,300 pages

OCLC Number: 1049892862

Reviewed by: Dr. Paul Spitzer,
Former Boeing Corporate Historian

Review:

NATO: A Business History by Robert Foxcurran covers interallied collaboration in weapon systems acquisition. It has now been republished online by the Smithsonian Institution as Volumes I–III, available here: https://archive.org/search.php?query=creator%3A%22Foxcurran%2C+Robert+R%22

These three encyclopedic volumes (2,300 pages) were originally published by Boeing in 1986 and should be of considerable interest to program, contract, and procurement managers in both government and industry. The volumes describe collaborative activities within NATO that encompass infrastructure and logistics, as well as case studies with the associated lessons learned from dozens of weapon systems projects. These projects range from joint design and development of systems among a variable mix of nations, to the transfer of technical data packages to second sources for purposes of work redistribution. The origins and diffusion of the technology involved are also major factors. The term utilized in the study for each type of cooperative venture is "Mode of Industrial Collaboration."

Volume I comprises five chapters covering the first 36 years of institutional development in joint acquisition efforts at the alliance level. Volumes II and III (the latter published in two parts) are organized into chapters containing case studies of transnational projects, each grouped within one of eight different Modes of Industrial Collaboration. Intergovernmental teaming arrangements are also summarized for these projects.

The Modes of Industrial Collaboration provide a framework for comparing similar interallied projects. An example of the continuing value of this reference work was provided by Foxcurran in an article published in 2013 by the National Contract Management Association's *Journal of Contract Management* entitled, "The Harrier AV-8B and the U.S. Roland Programs: A Comparative View of Technology Transfer to the U.S. of European Designed Systems." For this article, two updated case studies were extracted from the chapter covering Mode #4 of Industrial Collaboration wherein the U.S. adopted European systems through a second source production arrangement.

The context within which this history project was launched is worth noting. The research began in 1977 under the sponsorship of Boeing's Vice President Contract Planning and Administration Frank Shrontz. He had just returned from a stint as Assistant Secretary of Defense, where he had overseen the launch of the joint F-16 program with four European allies. Once back in Seattle, he saw that Boeing's interallied programs were experiencing considerable turbulence. The aim of the research was to capture and review management experience at the company, along with input from DoD participants and other defense contractors. This was intended to improve the understanding of the complexity of such projects, and the options available going forward.

These volumes take us into the final years of the Cold War. The enduring usefulness of these three volumes should not be overlooked as a model to again document collective memory and institutional development. *NATO: A Business History* is detailed and encyclopedic, providing a solid base upon which follow-on research can be pursued. It is time to build upon the tangible results achieved and practical know-how acquired that was laid out in the 1986 volumes.

Current Research Resources in DEFENSE ACQUISITION

Great Power Competition

Each issue of the *Defense Acquisition Research Journal* will bring to the attention of the defense acquisition community a topic of current research, which has been undertaken by the DAU Virtual Research Library team in collaboration with DAU's Director of Research. Both government civilian and military Defense Acquisition Workforce readers will be able to access papers publicly and from licensed resources on the DAU Virtual Research Library Website: https://dau.libguides.com/daukr.

Nongovernment Defense Acquisition Workforce readers should be able to use their local knowledge management centers/libraries to download, borrow, or obtain copies. We regret that DAU cannot furnish downloads or copies.

Defense Acquisition Research Journal readers are encouraged to submit proposed topics for future research by the DAU Virtual Research Library team. Please send your suggestion with a short write-up (less than 100 words) explaining the topic's relevance to current defense acquisition to: Managing Editor, *Defense Acquisition Research Journal*, DefenseARJ@dau.edu.

Competition and Cooperation: Sino-Russian Interactions in Asia in the Era of Great Power Competition

Ivan R. Georgiev

Summary:

In the era of Great Power Competition, the United States finds itself challenged by two main adversaries: Russia and China. This is especially evident in Asia, where both rival powers seek to retain and expand their traditional political, economic, and military spheres of influence while attempting to put limits on U.S. involvement. This thesis explores the dynamics of competition and cooperation between Russia and China to ascertain which are stronger. Toward that end, the thesis examined Sino-Russian interactions in three specific cases: Central Asia, North Korea, and Mongolia.

APA Citation:

Georgiev, I. R. (2022). *Competition and cooperation: Sino-Russian interactions in Asia in the era of Great Power Competition* [Master's thesis, Naval Postgraduate School]. The NPS Institutional Archive. http://hdl.handle.net/10945/69644

Global Development in an Era of Great Power Competition

Conor M. Savoy and Janina Staguhn

Summary:

This Center for Strategic and International Studies brief highlights three issues: (a) The U.S finds itself in an era of renewed Great Power Competition with a rising People's Republic of China (PRC) and a revisionist Russia. The PRC presents a unique challenge given its expansive military, economic, and development power. Competition with the PRC will rely far more on economic tools, especially development finance (including foreign aid), trade and investment, and digital technologies; (b) the U.S. has long relied on foreign assistance to effect geopolitical outcomes; in confronting the PRC, it should draw on past lessons. History shows that good development policy must be at the core of U.S. assistance in strategic environments; and (c) in contrast to the PRC, the U.S. offers a compelling development model that is built on a transformational rather than transactional approach. This will require a prioritization of sectors where the U.S. can either offer a better approach or a clear comparative advantage over what the PRC offers.

APA Citation:

Savoy, C. M., & Staguhn, J. (2022). *Global development in an era of Great Power Competition*. Center for Strategic and International Studies. https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/220324_Savoy_Great_Power_Competition.pdf?hz8CzYrMY5o_HQx2K_cGZ5gY7CA3HSpP

U.S. Strategic Competition with Russia: A RAND Research Primer

Stephanie Pezard

Summary:

A central theme of the 2017 U.S. National Security Strategy is the "growing political, economic, and military competitions" with which the United States is now challenged, including with Russia. Russia's annexation of Crimea made it clear how far Moscow would go to advance its interests, including redrawing internationally recognized borders. This perspective presents key aspects from past RAND Corporation research on this competition between Russia and the United States.

APA Citation:

Pezard, S. (2022). *U.S. strategic competition with Russia: A RAND research primer*. RAND. https://doi.org/10.7249/PEA290-2

Renewed Great Power Competition: Implications for Defense—Issues for Congress

Ronald O'Rourke

Summary:

This report provides a brief overview of implications for U.S. defense in the emergence of an era of Great Power Competition with China and Russia. The issue for Congress is how U.S. defense planning should respond to the renewal of an era of Great Power Competition, and whether to approve, reject, or modify the Biden Administration's proposed defense funding levels, strategy, plans, and programs for addressing Great Power Competition.

APA Citation:

O'Rourke. R. (2022). *Renewed Great Power Competition: Implications for defense—issues for Congress*. Congressional Research Service. https://crsreports.congress.gov/product/pdf/R/R43838

Beyond Biological Defense: Biotech in U.S. National Security and Great Power Competition

Robert Carlson, Chad Sbragia, and Katherine Sixt

Summary:

The U.S. Government has historically viewed biotechnology as a civilian and economic pursuit. In contrast, China is sensitive to biotechnology's central role in its military and security. In this paper, the authors describe the current state and trajectory of biotechnology in both the United States and China. They also provide recommendations to the U.S. Government on securing the biotechnology industry and maintain dominance in this foundational technology.

APA Citation:

Carlson, R., Sbragia, C., & Sixt, K. (2021). *Beyond biological defense: Biotech in U.S. national security and Great Power Competition*. Institute for Defense Analyses. https://www.ida.org/-/media/feature/publications/b/be/beyond-biological-defense-biotech-in-us-national-security-and-great-power-competition/p-22700.ashx

U.S. Strategic Competition with China: A RAND Research Primer

Timothy R. Heath

Summary:

A rapid unraveling of the U.S.-China relationship has unsettled global politics. Although both capitals appear committed to peacefully resolving their differences, the intensifying acrimony and distrust have raised fears among many observers that the two countries could be headed toward confrontation. In this examination the author discusses various issues pertaining to the competition, including China's strategic goals and priorities, the policies and measures through which China attempts to fulfill these goals, how China's actions affect U.S. strategic interests, and what additional steps might further protect U.S. interests.

APA Citation:

Heath, T. R. (2021). *U.S. strategic competition with China: A RAND research primer*. RAND. https://doi.org/10.7249/PE-A290-3

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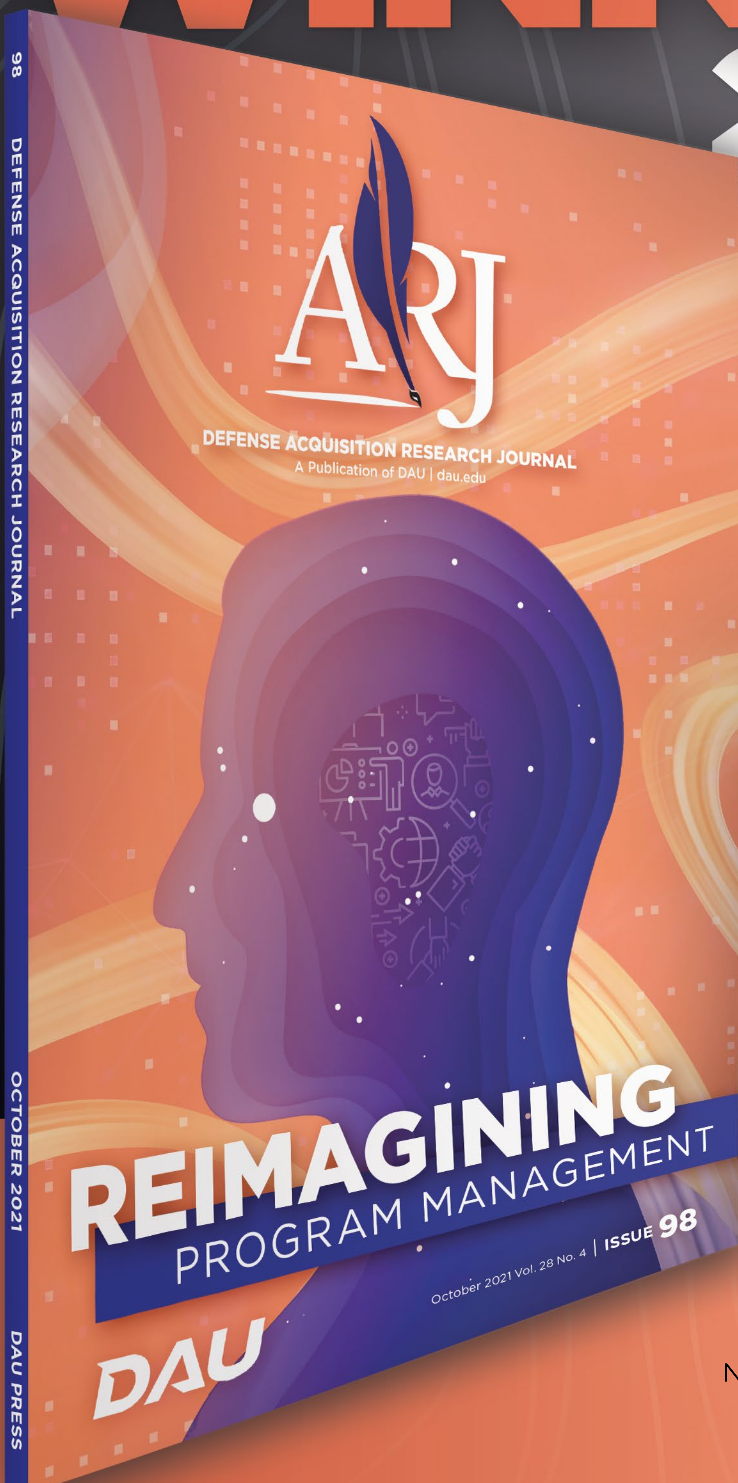

Norene Johnson, Emily Beliles, and Nicole Brate

DAU Press

Fort Belvoir, VA

Defense ARJ Guidelines FOR CONTRIBUTORS

The *Defense Acquisition Research Journal (ARJ)* is a scholarly peer-reviewed journal published by DAU. All submissions receive a double-blind review to ensure impartial evaluation.

IN GENERAL

We welcome submissions describing original research or case histories from anyone involved in the defense acquisition process. Defense acquisition is broadly defined as any actions, processes, or techniques relevant to as the conceptualization, initiation, design, development, testing, contracting, production, deployment, logistics support, modification, and disposal of weapons and other systems, supplies, or services needed for a nation's defense and security, or intended for use to support military missions.

Research involves the creation of new knowledge. This generally requires either original analysis of material from primary sources, including program documents, policy papers, memoranda, surveys, interviews, etc.; or analysis of new data collected by the researcher. Articles are characterized by a systematic inquiry into a subject to establish facts or test theories that have implications for the development of acquisition policy and/or process.

The *Defense ARJ* also welcomes case history submissions from anyone involved in the defense acquisition process. Case histories differ from case studies, which are primarily intended for classroom and pedagogical use. Case histories must be based on defense acquisition programs or efforts. Cases from all acquisition career fields and/or phases of the acquisition life cycle will be considered. They may be decision-based, descriptive, or explanatory in nature. Cases must be sufficiently focused and complete (i.e., not open-ended like classroom case studies) with relevant analysis and conclusions. All cases must be factual and authentic. Fictional cases will not be considered.

We encourage prospective writers to coauthor, adding depth to manuscripts. We recommend that junior researchers select a mentor who has been

previously published or has expertise in the manuscript's subject. Authors should be familiar with the style and format of previous *Defense ARJs* and adhere to the use of endnotes versus footnotes, formatting of reference lists, and the use of designated style guides. It is also the responsibility of the corresponding author to furnish any required government agency/employer clearances with each submission.

MANUSCRIPTS

Manuscripts should reflect research of empirically supported experience in one or more of the areas of acquisition discussed above. The *Defense ARJ* is a scholarly research journal and as such does not publish position papers, essays, or other writings not supported by research firmly based in empirical data. Authors should clearly state in their submission whether they are submitting a research article or a case history. The requirements for each are outlined below.

Research Articles

Empirical research findings are based on acquired knowledge and experience versus results founded on theory and belief. Critical characteristics of empirical research articles:

- clearly state the question,
- define the research methodology,
- describe the research instruments (e.g., program documentation, surveys, interviews),
- describe the limitations of the research (e.g., access to data, sample size),
- summarize protocols to protect human subjects (e.g., in surveys and interviews), if applicable,

- ensure results are clearly described, both quantitatively and qualitatively,
- determine if results are generalizable to the defense acquisition community
- determine if the study can be replicated, and
- discuss suggestions for future research (if applicable).

Research articles may be published either in print and online, or as a Web-only version. Articles that are 5,000 words or fewer (excluding abstracts, references, and endnotes) will be considered for print as well as Web publication. Articles between 5,000 and 10,000 words will be considered for Web only publication, with a two sentence summary included in the print version of the *Defense ARJ*. In no case should article submissions exceed 10,000 words.

Case Histories

Care should be taken not to disclose any personally identifiable information regarding research participants or organizations involved unless written consent has been obtained. If names of the involved organization and participants are changed for confidentiality, this should be highlighted in an endnote. Authors are required to state in writing that they have complied with APA ethical standards. A copy of the APA Ethical Principles may be obtained at http://www.apa.org/ethics/.

All case histories, if accepted, will receive a double-blind review as do all manuscripts submitted to the *Defense ARJ*.

Each case history should contain the following components:

- Introduction
- Background
- Characters
- Situation/problem
- Analysis
- Conclusions
- References

Book Reviews

Defense ARJ readers are encouraged to submit book reviews they believe should be required reading for the defense acquisition professional. The reviews should be 500 words or fewer describing the book and its major ideas, and explaining why it is relevant to defense acquisition. In general, book reviews should reflect specific in-depth knowledge and understanding that is uniquely applicable to the acquisition and life cycle of large complex defense systems and services. Please include the title, ISBN number, and all necessary identifying information for the book that you are reviewing as well as your current title or position for the byline.

Audience and Writing Style

The readers of the *Defense ARJ* are primarily practitioners within the defense acquisition community. Authors should therefore strive to demonstrate, clearly and concisely, how their work affects this community. At the same time, do not take an overly scholarly approach in either content or language.

Format

Please submit your manuscript according to the submissions guidelines below, with references in APA format (author date-page number form of citation) as outlined in the latest edition of the *Publication Manual of the American Psychological Association.* References should include Digital Object Identifier (DOI) numbers when available. The author(s) should not use automatic reference/bibliography fields in text or references as they can be error-prone. Any fields should be converted to static text before submission, and the document should be stripped of any outline formatting. All headings should conform to APA style. For all other style questions, please refer to the latest edition of the *Chicago Manual of Style.*

Contributors are encouraged to seek the advice of a reference librarian in completing citation of government documents because standard formulas of citations may provide incomplete information in reference to government works. Helpful guidance is also available in *The Complete Guide to Citing Government Information Resources: A Manual for Writers and Librarians* (Garner & Smith, 1993), Bethesda, MD: Congressional Information Service.

The author (or corresponding author in cases of multiple authors) should attach a cover letter to the manuscript that provides all of the authors' names, mailing and e-mail addresses, as well as telephone numbers. The letter should verify that (1) the submission is an original product of the author(s); (2) all the named authors materially contributed to the research and writing of the paper; (3) the submission has not been previously published in another journal (monographs and conference proceedings serve as exceptions to this policy and are eligible for consideration for publication in the *Defense ARJ*); (4) it is not under consideration by another journal for publication. If the manuscript is a case history, the author must state that they have complied with APA ethical standards in conducting their work. A copy of the APA Ethical Principles may be obtained at http://www.apa.

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We reserve the right to decline any article that fails to meet the following copyright requirements:

- The author cannot obtain permission to use previously copyrighted material (e.g., graphs or illustrations) in the article.
- The author will not allow DAU to post the article in our *Defense ARJ* issue on our Internet homepage.
- The author requires that the usual copyright notices be posted with the article.
- To publish the article requires copyright payment by the DAU Press.

SUBMISSION

All manuscript submissions should include the following:

- Completed submission checklist

- Completed copyright release form
- Cover letter containing the complete mailing address, e-mail address, and telephone number for each author
- Biographical sketch for each author (70 words or fewer)
- Headshot for each author saved as a 300 dpi (dots per inch) high resolution JPEG or Tiff file no smaller than 5x7 inches with a plain background in business dress for men (shirt, tie, and jacket) and business appropriate attire for women. All active duty military should submit headshots in Class A uniforms. Please note: low-resolution images from Web, PowerPoint, or Word will not be accepted due to low image quality.
- One copy of the typed manuscript, including:
  - Title (12 words or fewer)
  - Abstract (150 to 250 words)
  - Two sentence summary
  - Keywords (5 words or fewer—please include descriptive words that do not appear in the manuscript title, to make the article easier to find)
- Figures and tables saved as separate individual files and appropriately labeled
- Links to any supporting videos, lectures, interviews, or presentations to be shared in our digital publication.

The manuscript should be submitted in Microsoft Word (please do not send PDFs), double-spaced Times New Roman, 12-point font size (5,000 words or fewer for the printed edition and 10,000 words or fewer for online-only content excluding abstracts, figures, tables, and references).

Figures or tables should not be inserted or embedded into the text, but submitted as separate files in the original software format in which they were created. For additional information on the preparation of figures or tables, refer to the Scientific Illustration Committee, 1988, Illustrating Science: Standards for Publication, Bethesda, MD: Council of Biology Editors, Inc. Restructure briefing charts and slides to look similar to those in previous issues of the *Defense ARJ*.

All forms are available at our website: www.dau.edu/library/arj. Submissions should be sent electronically, as appropriately labeled files, to the *Defense ARJ* managing editor at: DefenseARJ@dau.edu.

Defense ARJ
PRINT SCHEDULE

The *Defense ARJ* is published in quarterly theme editions.

All submissions are due by the first day of the month.
See print schedule below.

Author Deadline	Issue
July	January
October	April
January	July
April	October

In most cases, the author will be notified that the submission has been received within 48 hours of its arrival. Following an initial review, submissions will be referred to peer reviewers and for subsequent consideration by the Executive Editor, *Defense ARJ*.

Contributors may direct their questions to the Managing Editor, *Defense ARJ*, at the address shown below, or by calling 703-805-4655, or via email at DefenseARJ@dau.edu.

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We welcome submissions describing original research or case histories from anyone involved with or interested in the defense acquisition process—the conceptualization, innovation, initiation, design, testing, contracting, production, deployment, logistics support, modification, and disposal of weapons and other systems, supplies, or services (including construction) needed by the DoD or intended for use to support military missions.

After initial review, all manuscript submissions are peer reviewed. Articles of 5,000 words or fewer appear in both our print and digital publications. Articles of 5,000 to 10,000 words will be considered for digital publication only.

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