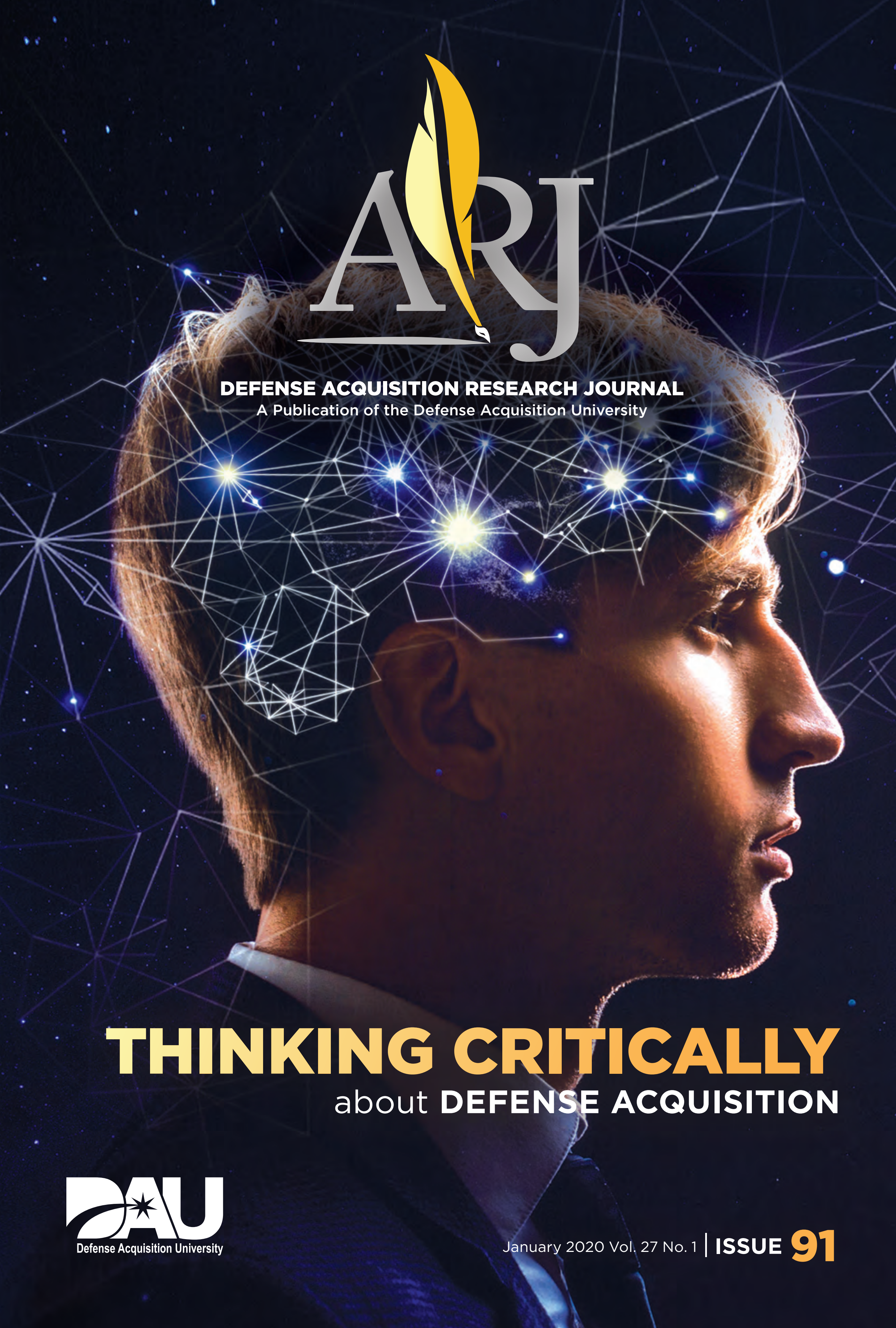


# ARJ

DEFENSE ACQUISITION RESEARCH JOURNAL
A Publication of the Defense Acquisition University

# THINKING CRITICALLY
## about DEFENSE ACQUISITION

DAU
Defense Acquisition University

January 2020 Vol. 27 No. 1 | ISSUE 91

*Critical Thinking for the Federal Auditor*

**Gabrielle G. McClure-Nelson**

*Complexity in an Unexpected Place: Quantities in Selected Acquisition Reports*

**Gregory A. Davis and David M. Tate**

*Risk-Based ROI, Capital Budgeting, and Portfolio Optimization in the Department of Defense*

**Johnathan Mun**

# ARTICLE LIST

# ARJ EXTRA

**The Defense Acquisition Professional Reading List**

*Perspectives on Defense Systems Analysis: The What, the Why, and the Who, but Mostly the How of Broad Defense Systems Analysis*

**Written by William P. Delaney, with Robert G. Atkins, Alan D. Bernard, Don M. Boroson, David J. Ebel, Aryeh Feder, Jack G. Fleischman, Michael P. Shatz, Robert Stein, and Stephen D. Weiner**

**Reviewed by Kevin Garrison**

# DEFENSE ACQUISITION RESEARCH JOURNAL

A Publication of the Defense Acquisition University

**ISSN 2156-8391 (print) ISSN 2156-8405 (online)**
**DOI: https://doi.org/10.22594/dau.012020-91.27.01**

The *Defense Acquisition Research Journal*, formerly the *Defense Acquisition Review Journal*, is published quarterly by the Defense Acquisition University (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.

**DEFENSE ACQUISITION RESEARCH JOURNAL**
A Publication of the Defense Acquisition University

# CONTENTS | Featured Research

60

## Risk-Based ROI, Capital Budgeting, and Portfolio Optimization in the Department of Defense

*Johnathan Mun*

This research illustrates and recommends approaches of modeling methodology and development of military value metrics, and how to combine them into a defensible, reusable, extensible, and practical approach within portfolios of programs. The author showcases how the methodologies can be applied to develop a comprehensive and analytically robust case study that senior leadership at the DoD might utilize to make optimal decisions.

# CONTENTS | Featured Research

# FROM THE CHAIRMAN AND EXECUTIVE EDITOR

Dr. Larrie D. Ferreiro

The theme of this edition of the *Defense Acquisition Research Journal* is "Thinking Critically about Defense Acquisition." In order to open the aperture for critical thinking, the *Defense Acquisition Research Journal* has updated its guidelines for contributors to now include submissions for case histories based on defense acquisition programs or efforts. Case histories differ from case studies in that case histories (like research papers) draw specific conclusions based on analysis as opposed to case studies, which are primarily intended for classroom and pedagogical use, and generally terminate with a jumping-off point for the student or class to come to decisions. We invite potential authors to consider submitting case history manuscripts. 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. [Please note that we do not accept fictional cases.]

The first research article in this issue, "Critical Thinking for the Federal Auditor" by Gabrielle G. McClure-Nelson, identifies to what extent critical thinking skills are considered an important competency for federal auditors, given the often tightly constrained and rules-focused nature of auditing government contractors.

The second article, authored by Gregory A. Davis and David M. Tate and titled, "Complexity in an Unexpected Place: Quantities in Selected Acquisition Reports," notes that the definition of unit quantities in acquisition programs is not consistent (for example, the units produced at the end of a long production run are substantially different from the early ones). The authors offer explanations as to why this is the case, and possible methods for improving the reporting requirement. The third article, "Risk-based ROI, Capital Budgeting, and Portfolio Optimization in the Department of Defense" by Johnathan Mun, describes an analytical modeling process to help the U.S. Department of Defense (DoD) senior leadership with making decisions about risk-based capital budgeting and optimizing acquisition and program portfolios.

This issue's Current Research Resources in Defense Acquisition focuses on the use of Other Transaction Authority (OTA) in government contracting. It contains descriptions of several key resources, along with links to the DAU Knowledge Repository sites.

The featured reading in this issue's Defense Acquisition Professional Reading List is *Perspectives on Defense Systems Analysis: The What, the Why, and the Who, but Mostly the How of Broad Defense Systems Analysis* by William P. Delaney, with Robert G. Atkins, Alan D. Bernard, Don M. Boroson, David J. Ebel, Aryeh Feder, Jack G. Fleischman, Michael P. Shatz, Robert Stein, and Stephen D. Weiner, reviewed by Kevin Garrison.

Dr. Michael J. Pryce has departed the Defense ARJ Editorial Board. We thank him for his service and wish him well. We welcome Mr. John McCormack to the Editorial Board.

Please note at the end of this journal the re-issued Call for Papers for the 2020 DAU Alumni Association Edward Hirsch Acquisition and Writing Competition. Due date is March 15, 2020.

**Dr. Larrie D. Ferreiro**
*Chairman and Executive Editor*
*Defense ARJ*

## From the Art Director

*Michael Bubar-Krukowski*

As we start a new decade, so does the *Defense Acquisition Research Journal (ARJ)*—and with some big changes. Like most publications, the *Defense ARJ* tries to keep up with the latest design trends and push the standards for design in the research journal world. We pride ourselves on this at the *Defense ARJ* and are always trying to keep the journal fresh and accessible to everyone.

One of the big changes you will notice is the updated logo. Like most great brands, the *Defense ARJ* logo should evolve over the years while still keeping aspects that make it recognizable. The *Defense ARJ* has been long overdue for an update. Our new logo still pays homage to the previous version that everyone knows, but the updated version has been cleaned up to be more on trend. The signature quill exhibits the most drastic change, becoming cleaner while also creating more opportunities to add color. Also the chosen typeface is a slight update from the previous version that adds a cleaner feel, allowing the quill to shine and creating a timeless look.

Other changes have been made to the design of the journal that should hopefully revitalize the aesthetic and keep the *Defense ARJ* at the top of its class. You will notice a redesigned table of contents, new ads, and more! For several years now the *Defense ARJ* has been winning awards for design. Going forward, we strive to keep up the same standards of excellence while also becoming more competitive in the world of design and publication.

# DAU CENTER FOR DEFENSE ACQUISITION

## RESEARCH AGENDA 2020

This Research Agenda is intended to make researchers aware of the topics that are, or should be, of particular concern to the broader defense acquisition community within the federal government, academia, and defense industrial sectors. The center compiles the agenda annually, using inputs from subject matter experts across those sectors. Topics are periodically vetted and updated by the DAU Center's Research Advisory Board 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. Most of these research topics were selected to support the DoD's Better Buying Power Initiative (see http://bbp.dau.edu). 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. They are also encouraged to contact the listed Points of Contact (POC), who may be able to provide general guidance as to current areas of interest, potential sources of information, etc.

### Competition POCs

- John Cannaday, DAU: john.cannaday@dau.edu
- Salvatore Cianci, DAU: salvatore.cianci@dau.edu
- Frank Kenlon (global market outreach), DAU: frank.kenlon@dau.edu

### Measuring the Effects of Competition

- What means are there (or can be developed) to measure the effect on defense acquisition costs of maintaining the defense industrial base in various sectors?
- What means are there (or can be developed) to measure the effect of utilizing defense industrial infrastructure for commercial manufacture, and in particular, 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 vs. 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, is there evidence that sole source can result in lower overall administrative costs at both the government and industry levels, to the effect of lowering total costs?
- What are the long-term historical trends for competition guidance and practice in defense acquisition policies and practices?

- To what extent are contracts being awarded noncompetitively by congressional mandate for policy interest reasons? What is the effect on contract price and performance?

- What means are there (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 simple head-count of providers?

- Has change in the defense industrial base resulted in actual change in 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, schedule, and 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 benefited from global technology development?
- How/why have militaries missed the largest technological advances?
- What are the key areas that require the DoD's focus and attention in the coming years to maintain or enhance the technological advantage of its weapon systems and equipment?
- What types of efforts should the DoD consider pursuing to increase the breadth and depth of technology push efforts in DoD acquisition programs?
- How effectively are the DoD's global science and technology investments transitioned into DoD acquisition programs?
- Are the DoD's applied research and development (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 the DoD take to improve its performance in these two areas?
- What are the strengths and weaknesses of the DoD's global defense technology investment approach as compared to the approaches used by other nations?
- What are the strengths and weaknesses of the 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 the 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 the 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. Technology Security and Foreign Disclosure (TSFD) decision-making policies and processes be improved to help the 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. Export Control System decision-making policies and processes be improved to help the 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 between the DoD and complex, custom-built commercial products (e.g., offshore oil platforms).
- Compare program cost performance in various market sectors: highly competitive (multiple offerors), limited (two or three offerors), 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.


APEX® AWARD FOR PUBLICATION EXCELLENCE
WINNER
2019
ARJ
Defense Acquisition Research Journal
A Publication of the Defense Acquisition University
2019
APEX®
AWARDS FOR PUBLICATION EXCELLENCE
One-of-a-Kind Publications
Government
DEFENSE ACQUISITION RESEARCH JOURNAL
25TH
1994–2019
ANNIVERSARY
SPECIAL ANNIVERSARY EDITION
January 2019 Vol. 26 No. 1 | ISSUE 87
DAU
Defense Acquisition University
87
DEFENSE ACQUISITION RESEARCH JOURNAL
Defense Acquisition University
JANUARY 2019
DAU PRESS
Norene Johnson, Emily Beliles, and Michael Bubar Krukowski
Defense Acquisition University Press
Fort Belvoir, VA
WINNER
2016
APEX®
AWARDS FOR PUBLICATION EXCELLENCE
WINNER
2017
APEX®
AWARDS FOR PUBLICATION EXCELLENCE
WINNER
APEX®
1988 30 YEARS 2018
AWARDS FOR PUBLICATION EXCELLENCE

We're on the Web at:
http://www.dau.edu/library/arj

ISSUE **91**
JANUARY 2020
VOL. 27 NO. 1

# CRITICAL THINKING for the FEDERAL AUDITOR

*Gabrielle G. McClure-Nelson*

In the overly constrained space of the federal audit environment, to what extent can critical thinking skills be applied in a profession characterized by arduous public trust expectations, controlling auditing standards, prescriptive federal acquisition policies, frequently changing guidance, continual peer oversight, and the slow implementation of audit findings? Promoting the increased use of private sector auditors may suggest that federal auditors perceive competencies differently. However, a recent survey administered to 645 auditors of a federal audit agency region indicated that the majority of the core competencies identified by the American Institute of Certified Public Accountants are perceived as relevant in auditing government contractors. However, of concern, the data were mixed in support of critical thinking as an important competency. Given employer preference for skills in this area, the author attempts to identify applications to increase auditor critical thinking skills and to offer suggestions for increasing the relevance of the federal audit.

**DOI:** *https://doi.org/10.22594/dau.19  830.27.01*
**Keywords:** *Generally Accepted Government Auditing Standards (GAGAS), Yellow Book, American Institute of Certified Public Accountants (AICPA), Core Competencies, Section 809 Panel*

Image designed by Michael Krukowski

The ability to succeed in an over-constrained space was recently identified as an important leadership attribute by Microsoft Chief Executive Officer Satya Nadella (Jones, 2019). But, in the overly constrained space of the federal audit environment, what does success look like for the federal auditor who aspires to exercise leadership skills? To what extent can critical thinking skills necessary for leadership be applied in a profession characterized by arduous public trust expectations, controlling auditing standards, prescriptive federal acquisition policies, frequently changing guidance, continual peer oversight, and the slow implementation of audit findings?

## Importance of the Federal Auditor in Acquisition

Federal auditors play a vital role in the acquisition process. In 2018, federal spending was subject to evaluation by about 11,000 auditors primarily employed by the Departments of Defense (DoD) and Health and Human Services (DHHS) (Office of Personnel Management, 2018). The Section 809 Panel, established by Congress in the Fiscal Year 2016 National Defense Authorization Act (National Defense Authorization Act [NDAA], 2016), describes defense auditors as "essential components of the Department of Defense's system of contracting internal controls" (Section 809 Panel, 2018a, p. 54).

## Impediments to Auditor Critical Thinking

Several factors can inhibit the federal auditor's exercise of critical thinking and leadership skills, among them: untimely response to audit findings, auditing standards oversight, changing mission guidance, and threats to job stability.

### Untimely Response to Audit Findings

Inaction to audit findings can erode federal auditor morale and compromise auditor commitment to success. Annually, the DHHS publishes the top *un*implemented recommendations from its Office of Inspector General audits and evaluations (DHHS, 2018). The Department of Defense Inspector General (DoDIG) distributed a similar 2018 compendium describing about $2 billion of potential monetary benefits from *open* recommendations (DoDIG, 2018a). Unsustained audit findings on contractor business systems, federal cost accounting standards, and millions of dollars of audit exceptions reported by other DoD agencies were disclosed by the DoDIG for the years 2016 through 2019 (DoDIG, 2016, 2017a, 2018b, 2019).

> **In 2018, federal spending was subject to evaluation by about 11,000 auditors primarily employed by the Departments of Defense (DoD) and Health and Human Services (DHHS).**

### Auditing Standards Oversight

During this same period, federal auditors were cited for insufficient adherence to auditing standards. In 2017, the DoDIG reported the Army failed its 2017 quality control system review (DoDIG, 2017b); and in that same year, the U.S. Government Accountability Office (GAO) identified untimely audits as a reason for delinquent contract close-outs at the Departments of Defense, State, Transportation, and the National Aeronautics and Space Administration (GAO, 2017b).

### Changing Mission Guidance

Rapidly changing mission guidance can trigger auditor fatigue. The customer identity confusion at the Defense Contract Audit Agency (DCAA) is a significant example. The Section 809 Panel (2019, p. 25) reports that about 10 years ago, in response to critical audit independence findings, DCAA identified the "taxpayer" customer in its mission statement. The GAO promptly challenged this action by noting DCAA's primary role is to advise contracting officers. The Section 809 Panel, in turn, bested GAO's challenge by recommending DCAA not only advise contracting officers, but provide "education and training"—a recommendation that appears eligible for unintended independence abuse (Section 809 Panel, 2018a, pp. 64–65, 67).

Contradictory guidance not only promotes auditor weariness, but wariness, regarding management trustworthiness. In spite of its best intentions to recognize contracting officer needs, the Section 809 Panel recommendations appear redundant in that DCAA's current mission statement (available on its external website) already acknowledges both the acquisition team (of which the contracting officer is part) and the taxpayer (DCAA, n.d., *Mission*). Likewise, the DoDIG describes its audit function as including actionable recommendations, that is, actions that improve DoD programs and operations (DoDIG, n.d.). Finally, providing advice to the contracting officer is already compatible with government auditing standards that require the auditor to assist oversight officials by "making recommendations for corrective action" (GAO, 2018c, para. 7.50, p. 139).

## Threats to Job Stability

Lastly, the federal auditor deals with the continual threat of job encroachment by private sector auditors. Both the National Defense Industrial Association (Thomas, 2017) and the Section 809 Panel recently recommended the hire of "independent professional auditors" (Section 809 Panel, 2019, p. 25). However, the promotion of commercial auditors as a remedy for federal audit failings appears an easy suggestion that may warrant further deliberation in light of the millions of dollars recently paid for audit failure by the most prestigious accounting firms: a $335 million Price Waterhouse professional negligence settlement in 2019 (Johnson & Schroeder, 2019), a $12 million Ernst & Young failed-audits settlement in 2016 (Securities & Exchange Commission, 2016), and a recent consideration by General Electric to fire KPMG after a 109-year relationship due to significant undisclosed liabilities and other accounting issues (Gryta & Lublin, 2018, pp. B.3, 3). In fact, some government acquisition officials have already expressed concern that public accounting firms may lack "sufficient understanding" of federal contractor business systems (GAO, 2019a, p. 29).

Commercial auditors may not be prepared for the complexity of subject matter with which the federal auditor deals. In March 2019, a GAO review identified more than $3.4 billion in subcontract costs incurred over a 10-year period that had not been audited due, in part, to complex ownership relationships among contractors and subcontractors (GAO, 2019b). Likewise, in November 2018, in connection with its audit of the Internal Revenue Service (IRS) 2017–2018 financial statements, the GAO noted that the complex statistical process the IRS uses to estimate the amounts of taxes receivable contributed to material weakness in internal control over unpaid assessments (GAO, 2018b). Private sector auditors may be less familiar with these complexities than their federal counterparts.

## Auditor Competencies Research

Promoting the use of nonfederal auditors may suggest that federal auditors perceive the importance of competencies differently than their private sector colleagues. However, recent research conducted by the author finds federal auditors agree with the professional core skills identified by the American Institute of Certified Public Accountants (McClure-Nelson, 2013).

The American Institute of Certified Public Accountants (AICPA) publishes a listing of core competencies needed to enter the accounting profession—a listing that hasn't significantly changed since the AICPA 2011 "Horizons 2025" report, or AICPA 1999 competency listing (AICPA, 2018a). For the federal auditor, many of whom are certified public accountants (CPAs), the AICPA competencies are largely compatible with the proficiencies identified by the GAO generally accepted government auditing standards (GAGAS) in its Yellow Book. (See Table 1 for a crosswalk of the majority of these competencies.)

**TABLE 1. PARTIAL CROSSWALK OF AICPA COMPETENCIES TO GAO YELLOW BOOK AUDITOR PROFICIENCIES**

| Partial Crosswalk of AICPA Competencies to GAO Government Auditing Standards | | | |
|---|---|---|---|
| **AICPA 2018 Precertification Core Competency Framework** | | **GAO 2018 Yellow Book** | |
| **Pillar** | **Competency** | **¶** | **Competency** |
| Accounting | Risk assessment, analysis | 3.116 | An auditor's consideration of the **risk** level of each engagement … |
| Accounting | System and process management | 1.19 | The subject matter of an attestation engagement may take many forms, including the following: e. **systems and processes …** |
| Accounting | Reporting | 1.06 | GAGAS contains requirements and guidance dealing with …. **reporting.** |
| Accounting | Research | 5.30 | Consultation uses appropriate **research** resources …. |
| Accounting | Technology and tools | 4.24 | Subject matter that directly enhances auditors' professional expertise to conduct engagements may include … h. **information technology** |
| Business | Strategic perspective | 1.04 | Those charged with governance refers to the individuals responsible for overseeing the **strategic** direction of the entity …. |
| Business | Global and industry perspectives | 5.26 | The audit organization's policies and procedures may address consistency in the quality of engagement performance. This is often accomplished through …. **industry-specific** or subject matter-specific guidance materials. |
| Business | Resource management | 1.24 | Examples of internal control audit objectives include determining whether b. **resources** are used in compliance with laws, regulations … |
| Business | Governance perspective - Legal and regulatory | 5.26 | … Matters addressed may include the following: j. … applicable **legal and regulatory requirements.** |

| | | | |
|---|---|---|---|
| Business | Customer perspective | 7.04 | Auditors often conduct GAGAS engagements under a contract with a party other than the officials of the audited entity or **pursuant to a third party request.** |
| Professional | Ethical conduct | 4.24 | Subject matter that directly enhances auditors' professional expertise to conduct engagements may include … b. **general ethics** and independence … |
| Professional | Decision-making | 1.26 | Examples of prospective analysis objectives include providing conclusions … b. program or policy **alternatives** … |
| | Objectively identify ….alternative courses of action | | |
| Professional | Collaboration | 5.38 | Appropriate **teamwork** and training help less experienced members of the engagement team to clearly understand the objectives of the assigned work. |
| Professional | Leadership | 4.24 | Subject matter that directly enhances auditors' professional expertise to conduct engagements may include … f. **leadership** … |
| Professional | Communication | 4.24 | Subject matter that directly enhances auditors' professional expertise to conduct engagements may include … d. **communicating** clearly and effectively, both orally and in writing … |
| Professional | Project management | 4.24 | Subject matter that directly enhances auditors' professional expertise to conduct engagements may include … e. **managing time and resources …** |

Since the opinions of federal auditors have been inadequately solicited regarding competencies required for success, a recent study was undertaken by the author to assess the relative importance of the AICPA core competency framework to the federal auditor of government contractors (McClure-Nelson, 2013). The study was based on the 1999 AICPA competency framework that categorized skills as either functional, broad business, or personal (presently referred to by the AICPA as accounting, business, and professional categories). A survey was administered to 645 auditors of a federal audit agency region requesting opinions of the importance of AICPA-defined competencies.

## Research Questions

The main research question of the study was whether the categorized AICPA core competencies adequately describe the skills and attributes required in a federal auditing environment. (See Table 2 for a complete listing of the skills included in these categories.) Questions and hypotheses included:

- **Research Question 1:** To what extent are the AICPA core competencies relevant in auditing federal contractors? Auditors were expected to find that the majority of AICPA core competencies were relevant and that risk analysis would be identified as an important competency.
- **Research Question 2:** To what extent are some AICPA core competencies more important than others to auditors of federal contractors? Auditors were expected to rank the functional accounting skills as well as the personal skills as more important than the business skills. Of the business skills, auditors were expected to identify strategic critical thinking as the most important of these competencies.
- **Research Question 3:** To what extent are opinions different regarding the relevance and ranking of the AICPA core competencies given increased job experience of the auditor of federal contractors? The more experienced federal auditors were expected to demonstrate greater appreciation for the business competencies than their junior counterparts.
- **Research Question 4:** To what extent are other competencies, not identified by the AICPA, important to the work of auditors of federal contractors? Senior auditors were expected to identify maintaining independence as an additional required competency.

| TABLE 2. LISTING OF CORE COMPETENCY CATEGORIES AND COMPETENCIES | | |
|---|---|---|
| CATEGORIES AND COMPETENCIES | | |
| **Functional** | **Personal** | **Broad Business** |
| Decision Modeling | Communication | International Global |
| Measurement | Interaction | Industry Sector |
| Risk Analysis | Leadership | Legal Regulatory |
| Research | Professional Demeanor | Marketing Client Focus |
| Reporting | Project Management | Resource Management |
| | Problem Solving | Strategic Critical Thinking |
| Leverage Technology—applicable to all categories | | |

## Protocols to Protect Human Subjects

Protection of Human Subjects (2019) protocols were based on the requirements set forth in 21 C.F.R. Pts. 50, 56 and 45 C.F.R. Pt. 46. The research was reviewed and approved by the Wilmington University Human Subject Review Committee. Procedures for obtaining informed consent included notifying participants that participation would contribute to academic research regarding the best preparation for a career in federal auditing, communicating that the study did not involve payments or incentives, and finally, that participation was voluntary and anonymous.

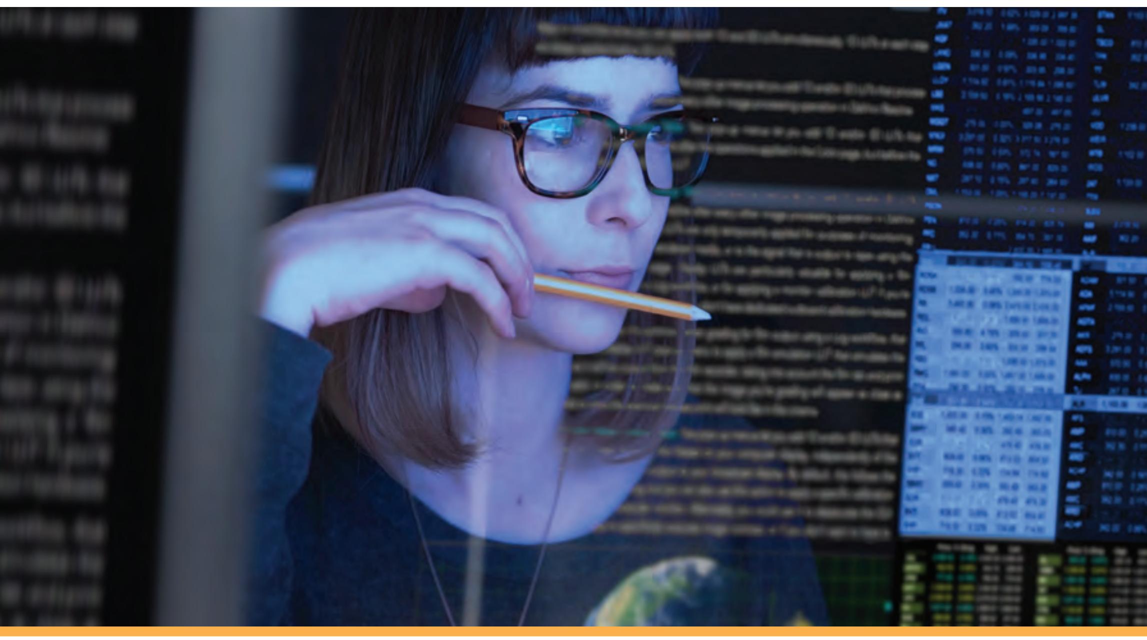
## Limitations of the Research

The study is limited in that not all federal auditors audit federal contractors, nor do all federal auditors follow the same auditing procedures for all types of audits. For instance, some federal auditors audit other government components. The research, however, may prove applicable to nongovernment auditors who audit federal contractors.

## Research Methodology

The population was a geographic region of a sizeable federal audit agency that audits the cost representations of government contractors. The single geographic region was representative of other agency regions in that all auditors receive the same training at a common educational site, follow the same audit policy prescribed by agency headquarters, adhere to the same agency-prescribed audit standards, and use the same agency audit programs. In addition, auditors transfer among the agency regions.

Two groups were included in the population; the first consisted of junior auditors at General Service (GS) grade levels GS-7, 9, and 11; and the second consisted of senior-level auditors, at GS-12 and 13 grades. At the time of the study, the group of senior-level auditors totaled about 380 and the group of junior auditors totaled about 265 (for a total of 645) in the single region. A total of 263 usable responses was received (109 junior auditors and 154 senior auditors)—a 41% response rate (263/645). Managers above the GS-13 level were excluded from the population given their small number relative to the other GS levels.



## Research Instrument

Likert Scale survey questions were developed from the AICPA core competencies described on the AICPA Educational Competency Assessment website. The AICPA grouped core competencies into three broad categories as shown in Table 2. Likert questions were coded to the AICPA core competencies in order to draw meaningful conclusions from analysis of the data. Since the survey was newly developed for purposes of this study, three federal CPA auditors were requested to match the Likert questions to the AICPA categories and competencies identified by the researcher. Fleiss' Kappa coefficients were then computed to measure inter-rater agreement. Acceptable Cronbach alpha statistics were obtained that measured internal consistency and reliability of the questions developed for each competency and for competencies within the three categories. Survey Monkey was used to administer the survey November 1–16, 2012. Survey questions are shown in Table 3.

**TABLE 3. RESEARCH SURVEY QUESTIONS**

*Question: How important is it for the federal auditor in your Agency to...?*

| No. | AICPA Core Competencies | Not Important | Little Importance | Somewhat Important | Important | Very Important |
|---|---|---|---|---|---|---|
| 1 | Analyze changes in the financial risks of the contractor's industry/sector | | | | | |
| 2 | Understand why controls cannot completely eliminate the risk of fraud | | | | | |
| 3 | Demonstrate objectivity and integrity consistent with the standards of auditing | | | | | |
| 4 | Establish working relationships with audit requestors | | | | | |
| 5 | Interact and cooperate productively and maturely with others | | | | | |
| 6 | Use technology-assisted tools to assess and control risk and document work | | | | | |
| 7 | Communicate information and concepts with conciseness and clarity when writing and speaking | | | | | |
| 8 | Interpret research findings from a variety of viewpoints | | | | | |
| 9 | Communicate the contractor's planning process, strategy, and goals | | | | | |
| 10 | Identify pros and cons of alternative methods of measurement | | | | | |
| 11 | Consider how human resource management affects a contractor | | | | | |
| 12 | Develop innovative or creative solutions to problems | | | | | |
| 13 | Report findings in accordance with auditing standards | | | | | |
| 14 | Inspire and motivate team members | | | | | |
| 15 | Analyze the impact of changes in contracting laws and regulations | | | | | |
| 16 | Use mathematical or scientific models to evaluate decision alternatives | | | | | |
| 17 | Prioritize and delegate various aspects of a project in order to allocate resources | | | | | |
| 18 | Identify global threats and opportunities impacting contractors | | | | | |

## Data Collection Procedures

Data collected from respondents were coded and entered into a computer data file for analysis using Minitab, IBM SPSS (ver. 20.0) statistical software and Microsoft Excel. Demographic data related to the number and nature of the two groups of junior and senior auditors were determined using frequencies and percentages in order to develop a profile of the respondents. Descriptive statistics were computed regarding frequencies and percentages of responses. Multiple regression determined whether competency rating was a function of GS level or a function of GS levels plus gender or age.

In order to determine whether differences existed between the two groups of junior and senior auditors, an independent *t*-test was computed to compare the means between the two groups for each of the competencies. Multiple regression determined which independent variables (demographic factors) were statistically significant in influencing the outcome of the dependent variable (responses to Likert questions).

## Results of the Study

- **Question 1.** The data supported that federal auditors found the majority of the AICPA core competencies relevant in auditing government contractors and that the competency of risk analysis is important. (See Table 4 for the listing of competencies ranked by importance.)

- **Question 2.** The data supported that auditors found the functional accounting skills as well as the personal skills, more important than the business competencies. However, the data only partially supported the hypothesis that auditors would identify strategic critical thinking as the most important business competency.

- **Question 3.** Increasing age correlated with more importance assigned to three of the six business competencies (industry/sector, strategic critical thinking and international/global), providing limited support to the hypothesis that senior auditors would appreciate business competencies more than the junior auditors.

- **Question 4.** Finally, the data did not support the hypothesis that senior auditors would identify maintaining independence as an additional required competency.

| TABLE 4. RESULTS - COMPETENCIES RANKED BY IMPORTANCE | | | |
|---|---|---|---|
| **NO.** | **SURVEY RESULTS** Competencies Ranked By Importance | **NO.** | **SURVEY RESULTS** Competencies Ranked By Importance |
| 1 | Reporting | 10 | Leadership |
| 2 | Communication | 11 | Research |
| 3 | Professional Demeanor | 12 | Problem Solving |
| 4 | Interaction | 13 | Decision Modeling |
| 5 | Marketing | 14 | Strategic Critical Thinking |
| 6 | Leverage Technology | 15 | Measurement |
| 7 | Risk Analysis | 16 | Industry Sector |
| 8 | Legal Regulatory | 17 | Resource Management |
| 9 | Project Management | 18 | International Global |

## Demographic Findings

The results of multiple regression indicated gender correlated with the response to many of the Likert questions. Therefore, in order to determine if women tended to give a higher rating in general, *t*-tests were conducted between men and women for their responses to all competency questions and for their responses to categories of competencies questions. The results indicated that women tended, in general, to rate higher than men.

However, in order to determine whether differences existed in the importance assigned to the categories of competencies between men and women, *t*-tests were conducted between two different categories of competencies, at a time, for women and for men. The results indicated that even though women tend to give a higher rating, no difference existed in how they would assign importance to the three categories of competencies when compared with men.

## The Importance of Critical Thinking

Of concern, the data were mixed in support of critical thinking as an important competency. Instead of identifying strategic critical thinking as the most important business competency, auditors ranked it third, behind the marketing and legal/regulatory competencies. Respondents also gave relatively low rankings to competencies similar to strategic critical thinking, such as decision modeling and problem solving. However, when asked to rank the three most important competencies, they identified strategic critical thinking as the third out of 18 competencies.

The mixed response is of concern given the importance of strategic critical thinking to the work of the federal auditor. Numerous researchers have found strategic critical thinking to be important for the profession of accounting/auditing (Bolt-Lee & Foster, 2003; Daigle, Hayes, & Hughes, 2007; Gupta & Marshall, 2010; Jim, Damtew, Banatte, & Mapp, 2009; Kaciuba & Siegel, 2009; Thomas, 2000). Auditors require the critical thinking skills that allow for analyzing business risk (McKnight & Wright, 2011).

The federal auditor's intent on meeting the rigidity of auditing standards or preoccupation with the knowledge content required for passing the CPA exam may account for the low standing of critical thinking as a required competency. University accounting programs continue to stress content memorization required for passing the CPA exam instead of emphasizing the critical thinking skills required of auditors by employers (Gupta & Marshall, 2010).

The implications of this finding are significant with regard to what an already overburdened accounting curriculum can be expected to deliver. The accounting course of study is currently expected to provide training in the emerging areas of forensic accounting, the international financial reporting standards, and enhanced internal controls resulting from Sarbanes-Oxley legislation, but still deliver the knowledge content demanded by the CPA exam. The inclusion of other important competencies such as ethics, identification of fraud, information literacy, communication capabilities, and strategic critical thinking challenges accounting faculty to find the time to introduce these topics without displacing other key topics in accounting courses (Young & Warren, 2011).

Faculty are additionally subject to what Vance and Stephens (2010, p. 6) refer to as the increasing pressures within colleges to "acquiesce to the needs" of the current generation whose sufficiency in a well-developed work ethic is questioned by the authors. In fact, these authors specifically note the absence of competencies such as behavioral drive and self-motivation.

While the responsibility of educating accounting students includes preparation for professional work and professional identity (Wilkerson, 2010), the research indicates graduate education or employer training programs may be better able to address the development of strategic critical thinking skills.

## Other Findings

Other noteworthy findings resulted from the author's research. Auditors identified communication and measurement as skills needing improvement. Concerning communication, one auditor noted, "effective writing skills are essential, we must document everything we do. Our audit reports are our product and the communication given must be clear and able to stand the test of time." With respect to measurement, the importance assigned to this competency may have flowed from the well-recognized auditing term "criteria" in the AICPA definition; i.e., auditors are trained to evaluate contractor performance against *criteria*—most often, the Federal Acquisition Regulation (FAR).

The study also indicated that, contrary to prevailing literature, auditors of federal contractors want better training in conventional accounting content such as general ledger accounting and, especially, cost accounting. For instance, one respondent noted "the ability to understand how the contractor's accounting systems work is very important. Having previous experience as an accountant (general ledger, accounts payable, payroll) has been extremely helpful in understanding how different systems work."

**"The accounting course of study is currently expected to provide training in the emerging areas of forensic accounting, the international financial reporting standards, and enhanced internal controls resulting from Sarbanes-Oxley legislation, but still deliver the knowledge content demanded by the CPA exam.**

Knowledge of cost accounting is important in auditing cost representations of federal contractors, especially with regard to rates computed to recover indirect cost. A respondent noted, "I remember taking cost (or managerial) accounting; but not to the extent that is needed" for federal auditing. Other respondents identified a need for "knowledge of pools and bases and the application of indirect cost to direct cost" and a need for training in "the development of a predetermined and actual indirect rate, including the allocation process for those rates."

Many of the comments referred to the need for specialized undergraduate training in the FAR criteria. For instance, one auditor noted, "they don't stress the auditing environment in the undergraduate curriculum. I had 1 class my senior semester and nothing prepared myself for federal contract auditing." Other comments included "additional concentration needs to be made on Government Procurement and Contracting" ... "understanding various contract types, Federal regulations .... contract knowledge. The documents and agreements for which the costs were incurred are largely unknown to auditors" and "understanding the acquisition and procurement process." Finally, one auditor noted "....Specifically FAR, I did not even know this existed when I started."

## Profession's Acknowledgment of the Importance of Critical Thinking

As the federal auditor continues to strive for success in an overly constrained space, both governmental and nongovernmental constituents are acknowledging the value of improving auditor critical thinking skills.

### Governmental Acknowledgment

In an August 2017 report to Congress, the DoD called for a new emphasis in acquisition workforce critical thinking that would require "a cultural change and the re-education of its workforce" (Section 809 Panel, 2018b, p. 62). In its 2016–2020 Strategic Plan, DCAA identified the development and application of critical thinking to best formulate defensible audit positions (DCAA, n.d., *Strategic Plan*). The GAO Yellow Book describes the need to evaluate "program or policy alternatives" in forming conclusions for performance audits (GAO, 2018c, para. 1.26., p. 14). The training institute of the federal Council of the Inspectors General on Integrity and Efficiency identifies critical thinking skills as a core competency (Council of the Inspectors General, n.d.).

### Nongovernmental Acknowledgment

Nongovernmental entities also acknowledge the value of critical thinking skills development. For instance, accounting professional societies are promoting the development of critical thinking skills, the integration of liberal arts into the accounting curriculum, and emphasizing nonquantitative topics such as ethics and communication for accounting students (McClure-Nelson, 2013). Likewise, and as previously noted, the AICPA includes strategic perspective and decision-making skills in its current competency framework. The AICPA Statement on Standards for Attestation Engagements (SSAE) No. 18 describes professional skepticism as a requirement for a critical assessment of evidence (AICPA, 2018c). The Institute of Internal Auditors emphasizes the usefulness of logic in its critical thinking eWorkshop training (Institute of Internal Auditors, n.d.). KPMG advertises its master's program in Data Analytics for the necessary improvement of critical thinking skills (KPMG, n.d.).

## Practical Means to Improve Auditor Critical Thinking

Critical thinking means investigating inconsistencies, questioning assumptions, and evaluating data from sources that may not be directly related to the subject at hand. The good news is that auditors are already trained in the concept of professional skepticism. However, in many cases during an audit, the exercise of professional skepticism only results in additional requests for data that validate the audit matter rather than contradict (Griffith, Hammersley, Kadous, & Young, 2015). Current research offers some practical means to develop auditor critical thinking skills that include deliberative mindset interventions, case studies review, emotional intelligence activities, and the practice of metacognitive skills.

For instance, studies show that by engaging, before the audit, in specific practices that challenge the conventional approach to conducting standard audit steps, auditors can improve critical thinking skills, and, it is hoped, audit quality. Practices can include periodic exercises unrelated to the specific audit matter in order to best prepare deliberative acuity (Griffith et al., 2015). Other means are to review case studies (Gribbin & Saini, 2016) or engage in emotional intelligence activities (Yang, Brink, & Wier, 2018).

Researchers also recommend developing metacognitive skills, that is, divergent thinking that develops multiple explanations without a concern for feasibility, followed by convergent thinking that assesses the logical validity of each explanation. The subsequent conscious elimination of explanations may help the auditor understand the relationship among various facts (Plumlee, Rixom, & Rosman, 2015). By participating in these tasks unrelated to the specific audit, auditors have been shown to better prepare and trigger a critical thinking mindset.

Federal oversight has also identified some practical remedies. In 2018, the GAO recommended that DoD develop strategy for how information related to commerciality and price reasonableness determinations could be *shared* across the department to improve procurement of commercial items (GAO, 2018a). The NDAA directed practical critical thinking when, in 2013, it provided for the access and review of auditee internal audit reports by federal auditors (GAO, 2014). The GAO recently recommended to the AICPA that coverage of GAGAS be expanded on the CPA exam in order to improve the quality of governmental audits (Dalkin, 2015). In 2016, the GAO recommended the practice of data analytics to the Department of Energy (GAO, 2017a).

## Other Suggestions for Improvements

Federal auditors can ensure inclusion of specific recommendations for corrective action in the audit report, minimize the audit jargon that frustrates report recipients, and develop qualitative metrics that measure customer satisfaction.

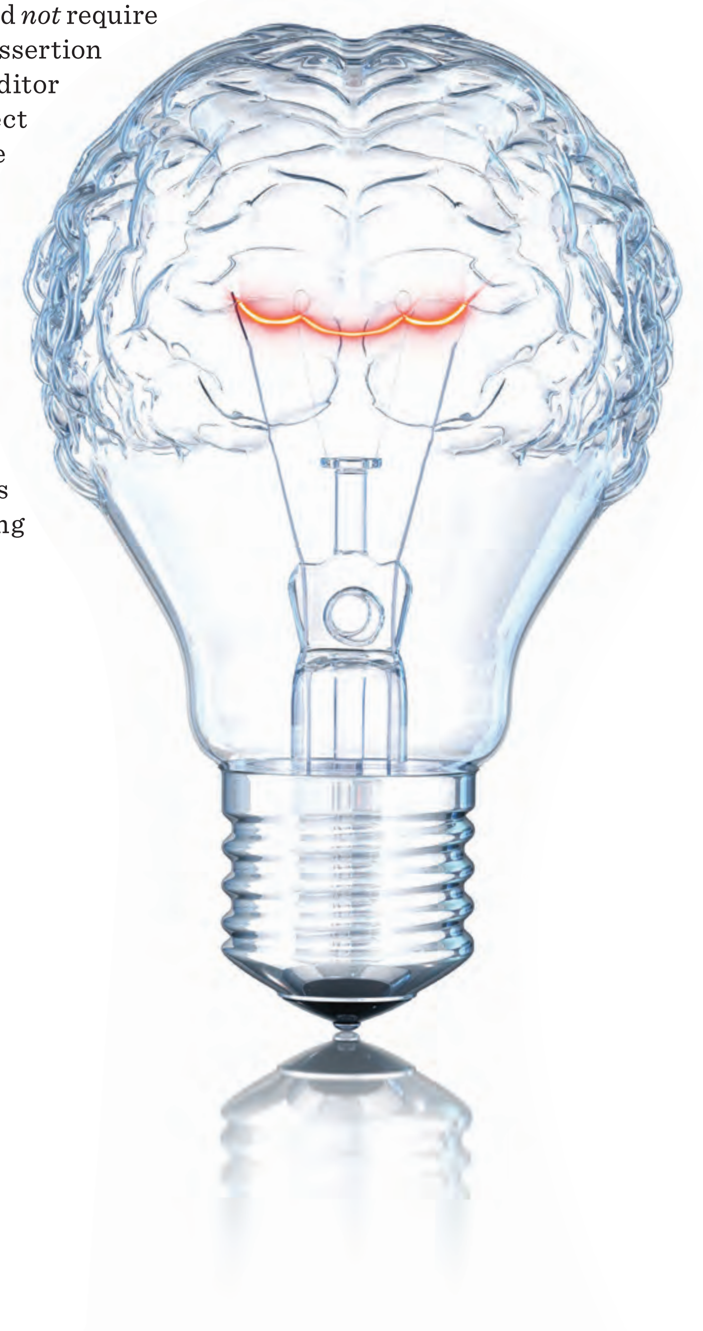
To curb the tendency to gravitate to unnecessarily conservative report opinions out of an abundance of caution, the GAO Yellow Book emphasis on the term *effect* should be referenced when selecting an audit opinion. Specifically, at SSAE No. 18 AT-C 205.A106, the auditor is advised to exercise professional judgment about the pervasiveness of the *effects* on the subject matter resulting from an inability to obtain sufficient appropriate evidence or from auditee misstatements (AICPA, 2017). A practical example may be deliberation about the effect of an untimely receipt of a corporate allocations' supporting audit when the supporting audit is known to be progressing and, historically, does not result in significant audit findings.

Auditors conducting GAGAS attestation engagement audits also need to be aware that changing audit standards can impact the nature and extent of auditing procedures. In 2011, the GAO made a significant change to the Yellow Book by introducing the term "by reference" at section 2.20a when incorporating the AICPA standards (GAO, 2011, para. 2.20a, p. 23). The term "by reference" had not been used in the predecessor 2007 Yellow Book.

The change was significant in that, unless referenced, some prescriptive financial statement audit standards were not applicable to attestation engagements. In other words, auditors need to be mindful of the diminishing utility of nonapplicable audit procedures when the engaging party is waiting for audit results.

Federal auditors might also consider implementing the Section 809 recommendation to use the "full range of audit and non-audit services available" (Section 809 Panel, 2018c, p. 52). For example, the AICPA is currently considering a revision to the standards for agreed-upon procedures that would *not* require the auditor to request a written assertion from the contractor when the auditor is reporting directly on the subject matter (AICPA, 2018b, p. 2). These very current AICPA deliberations may provide some needed flexibility for the contracting officer who requires limited auditing services in a shortened time frame.

It's hoped these suggestions can loosen the constraints on success for the federal auditor who aspires to apply greater critical thinking skills in the exercise of the audit.



## References

American Institute of Certified Public Accountants. (2017). *Statement on standards for attestation engagements No. 18, AT-C 205.A106*. Retrieved from https://www.aicpa.org/research/standards/auditattest/ssae.html

American Institute of Certified Public Accountants. (2018a). *The AICPA pre-certification core competency framework reference guide.* Retrieved from https://www.aicpa.org/content/dam/aicpa/interestareas/accountingeducation/resources/downloadabledocuments/aicpa-pre-certification-core-compentency-framework.pdf

American Institute of Certified Public Accountants. (2018b, November). *Consideration of comments received on proposed revised AT-C sections 210 and 215.* Retrieved from https://www.aicpa.org/content/dam/aicpa/research/standards/compilationreview/arsc/documents/201811/201811-item2.pdf

American Institute of Certified Public Accountants. (2018c). *Statement on standards for attestation engagements No. 18, AT-C Section 105.10.* Retrieved from https://www.aicpa.org/research/standards/auditattest/ssae.html

Bolt-Lee, C., & Foster, S. (2003). The core competency framework: A new element in the continuing call for accounting education change in the United States. *Accounting Education, 12*(1), 33–47. doi:10.1080/0963928031000074486

Council of the Inspectors General on Integrity and Efficiency. (n.d.). *Quality standards for federal offices of inspector general. audit, inspection & evaluation academy.* FY 2019 Training Program Descriptions, Critical Thinking Skills. Retrieved from https://www.ignet.gov/content/training-programs

Daigle, R. J., Hayes, D. C., & Hughes II, K. E. (2007). Assessing student learning outcomes in the introductory accounting information systems course using the AICPA's core competency framework. *Journal of Information Systems, 21*(1).

Dalkin, J. (2015). *Maintaining the relevance of the uniform CPA Examination.* GAO's Response to the American Institute of Certified Public Accountants' September 2015 Exposure Draft. Retrieved from https://www.gao.gov/products/D12262

Defense Contract Audit Agency. (n.d.). *Mission.* Retrieved from https://www.dcaa.mil/Home/AboutDCAA?title=Mission

Defense Contract Audit Agency. (n.d.). *Strategic Plan 2016–2020.* Retrieved from https://www.dcaa.mil/Home/StrategicPlan?title=Strategic%20Plan

Department of Defense Inspector General. (n.d.). *About, organization.* Retrieved from https://www.dodig.mil/About/Organization/

Department of Defense Inspector General. (2016). *Evaluation of defense contract management agency actions on reported DoD contractor business system deficiencies* (Report No. 2016-001). Retrieved from https://www.dodig.mil/reports.html/

Department of Defense Inspector General. (2017a). *Evaluation of contracting officer actions on cost accounting standard noncompliances reported by Defense Contract Audit Agency* (Report No. 2017-032). Retrieved from https://www.dodig.mil/reports.html/

Department of Defense Inspector General. (2017b). *External peer review report on the Army internal review program* (Report No. DoDIG-2017-100). Retrieved from https://www.dodig.mil/reports.html/Article/1269922/external-peer-review-report-on-the-army-internal-review-program-dodig-2017-100/

Department of Defense Inspector General. (2018a). *DoD OIG FY 2018.* Retrieved from https://media.defense.gov/2019/Feb/21/2002091518/-1/-1/1/DoD%20OIG%20FY%202018%20HIGHLIGHTS.PDF

Department of Defense Inspector General. (2018b). *Evaluation of DoD hotline complaint regarding Defense Contract Management Agency Baltimore's actions on audit findings reported by Defense Contract Audit Agency* (Report No. 2018-134). Retrieved from https://www.dodig.mil/reports.html/

Department of Defense Inspector General. (2019). *Evaluation of Defense Contract Management Agency contracting officer actions on DoD contractor executive compensation questioned by the Defense Contract Audit Agency* (Report No. 2019-070). Retrieved from https://www.dodig.mil/reports.html/

Department of Health and Human Services. (2018). *Solutions to reduce fraud, waste, and abuse in HHS Programs: Top unimplemented recommendations.* Retrieved from https://oig.hhs.gov/reports-and-publications/compendium/

Government Accountability Office. (2011). *Government auditing standards* (Report No. GAO-12-331G). Yellow Book. Retrieved from https://www.gao.gov/products/GAO-12-331G

Government Accountability Office. (2014). *Defense contract audit agency additional guidance needed regarding DCAA's use of companies' internal audit reports* (Report No. GAO-15-44). Retrieved from https://www.gao.gov/products/GAO-15-44

Government Accountability Office. (2017a). *Department of energy use of leading practices could help manage the risk of fraud and other improper payments* (Report No. GAO-17-235). Retrieved from https://www.gao.gov/products/GAO-17-235

Government Accountability Office. (2017b). *Federal contracting additional management attention and action needed to close contracts and reduce audit backlog* (Report No. GAO-17-738). Retrieved from https://www.gao.gov/products/GAO-17-738

Government Accountability Office. (2018a). *Defense contracts improved information sharing could help DoD determine whether items are commercial and reasonably priced.* (Report No. GAO-18-530). Retrieved from https://www.gao.gov/products/GAO-18-530

Government Accountability Office. (2018b). *Financial audit IRS's fiscal years 2018 and 2017 financial statements* (Report No. GAO-19-150). Retrieved from https://www.gao.gov/products/GAO-19-150

Government Accountability Office. (2018c). *Government auditing standards* (Report No. GAO-18-568G). Yellow Book. Retrieved from https://www.gao.gov/assets/700/693136.pdf

Government Accountability Office. (2019a). *Contractor business systems. DoD needs better information to monitor and assess review process* (Report No. GAO-19-212). Retrieved from https://www.gao.gov/products/GAO-19-212

Government Accountability Office. (2019b). *Department of energy contracting actions needed to strengthen subcontract oversight* (Report No. GAO 19-107). Retrieved from https://www.gao.gov/products/GAO-19-107

Gribbin, D., & Saini, J. S. (2016, Fall). Integrating practice into accounting education. *Management Accounting Quarterly, 18*(1), 1–10.

Griffith, E., Hammersley, J., Kadous, K., & Young, D. (2015). Auditor mindsets and audits of complex estimates. *Journal of Accounting Research, 53*(1), 49–77. doi:10.1111/1475-679X.12066

Gryta, T., & Lublin, J. (2018, April 6). Business: GE urged to dump auditor KPMG. *Wall Street Journal.* Retrieved from https://www.wsj.com/articles/ge-urged-to-dump-auditor-kpmg-after-109-years-by-proxy-advisers-1522964791

Gupta, S., & Marshall, L. L. (2010). Congruence between entry-level accountants' required competencies and accounting textbooks. *Academy of Educational Leadership Journal, 14*(1), 1–12.

Institute of Internal Auditors. (n.d.). *eWorkshop: Critical thinking for auditors.* Retrieved from https://www.theiia.org/centers/psac/events/Pages/eworkshop-critical-thinking-for-auditors-nov-dec.aspx

Jim, C., Damtew, D., Banatte, J., & Mapp, J. (2009). Information technology competencies expected in undergraduate accounting graduates. *Research in Higher Education Journal, 3*(1), 1–7.

Johnson, K., & Schroeder, P. (2019, March 15). PwC to pay $335 million over failed audits of Alabama's colonial bank: U.S. regulator. *Reuters Business News.* Retrieved from https://www.reuters.com/article/us-pwc-fdic-settlement/pwc-to-pay-335-million-over-failed-audits-of-alabamas-colonial-bank-u-s-regulator-idUSKCN1QW2HU

Jones, S. (2019). Leadership lessons from Satya Nadella. *Chicago Booth Magazine.* Retrieved from https://www.chicagobooth.edu/magazine/winter-2019/conversations/corner-booth-leadership-lessons-satya-nadella

Kaciuba, G., & Siegel, G. H. (2009). Activity-based management in a medical practice: A case study emphasizing the AICPA's core competencies. *Issues in Accounting Education, 24*(4), 553–577.

KPMG. (n.d.). *Master of accounting with data and analytics program.* Retrieved from https://kpmgcampus.com/campus/ourOpportunities#accounting

McClure-Nelson, G. (2013). *Assessing relevance and ranking of the AICPA core competencies in a federal audit agency region* (Order No. 3561132). Available from ProQuest Dissertations & Theses Global. Retrieved from http://search.proquest.com.ezproxy.libproxy.db.erau.edu/docview/1368981807?accountid=27203

McKnight, C. A., & Wright, W. F. (2011). Characteristics of relatively high-performance auditors. *Auditing, 30*(1), 191–206. doi:10.2308/aud.2011.30.1.191

National Defense Authorization Act for Fiscal Year 2016, 10 U.S.C. Pub. L. 114-92 § 809 (2015). Retrieved from https://www.congress.gov/114/plaws/publ92/PLAW-114publ92.pdf

Office of Personnel Management. (2018, March). *Federal workforce data* [Policy, Data Analysis & Documentation, Raw Datasets]. Retrieved from https://www.fedscope.opm.gov/ibmcognos/cgi-bin/cognosisapi.dll

Plumlee, R. D., Rixom, B. A., & Rosman, A. J. (2015). Training auditors to perform analytical procedures using metacognitive skills. *Accounting Review, 90*(1), 351–369. Retrieved from https://doi-org.mylibrary.wilmu.edu/10.2308/accr-50856

Section 809 Panel. (2018a). *Report of the advisory panel on streamlining and codifying acquisition regulations* (Vol. 1, Sec. 2). Retrieved from https://section809panel.org/wp-content/uploads/2018/01/Sec809Panel_Vol1-Report_Jan18_FINAL.pdf

Section 809 Panel. (2018b). *Report of the advisory panel on streamlining and codifying acquisition regulations* (Vol. 2). Retrieved from https://section809panel.org/wp-content/uploads/2019/01/Sec809Panel_Vol2-Report_JUN2018_012319.pdf

Section 809 Panel. (2018c). *Report of the advisory panel on streamlining and codifying acquisition regulations* (Vol. 1, Sec. 2, Recommendation 7c). Retrieved from https://section809panel.org/wp-content/uploads/2018/01/Sec809Panel_Vol1-Report_Jan18_FINAL.pdf

Section 809 Panel. (2019). *Report of the advisory panel on streamlining and codifying acquisition regulations, A roadmap to the section 809 panel reports* (Vol. 1, Sec. 2). Retrieved from https://section809panel.org/roadmap/

Securities & Exchange Commission. (2016, October 18). *Ernst & Young to pay $11.8 million for audit failures* [Press Release]. Retrieved from https://www.sec.gov/news/pressrelease/2016-219.html

Thomas, J. (2017, June). Defense contract audit agency loses focus. *National Defense.* Retrieved from http://www.nationaldefensemagazine.org/articles/2017/5/10/defense-contract-audit-agency-loses-focus

Thomas, P. B. (2000). Inside AICPA. *Journal of Accountancy, 190*(4), 128–131.

Vance, C., & Stephens, W. (2010). How does the new generation of accounting majors measure up? *CPA Journal, 80*(11), 6.

Wilkerson Jr., J. E. (2010). Accounting educators as the accounting profession's trustees: Lessons from a study of peer professions. *Issues in Accounting Education, 25*(1), 1–13. doi:10.2308/iace.2010.25.1.1

Yang, L., Brink, A. G., & Wier, B. (2018). The impact of emotional intelligence on auditor judgment. *International Journal of Auditing, 22*(1), 83–97. Retrieved from https://doi-org.mylibrary.wilmu.edu/10.1111/ijau.12106

Young, M., & Warren, D. (2011). Encouraging the development of critical thinking skills in the introductory accounting courses using the challenge problem approach. *Issues in Accounting Education, 26*(4), 859–881. doi:10.2308/iace-50065

## Author Biography


**Dr. Gabrielle G. McClure-Nelson**

is an Assistant Professor at Embry-Riddle Aeronautical University, Daytona Beach, Florida. Dr. Nelson retired after 29 years as a federal auditor, including a 25-year tenure with the Defense Contract Audit Agency (DCAA), Department of Defense, where she served as auditor, technical specialist, audit supervisor, branch manager, headquarters program manager, and regional audit manager. Dr. Nelson is a Certified Public Accountant and previously guest-instructed the Defense Acquisition University Cost Accounting Standards course. Dr. Nelson holds a DBA from Wilmington University, an MBA from the University of Delaware, and a BBA from Temple University.

*(E-mail address: mcclurg1@erau.edu)*

# COMPLEXITY IN AN **Unexpected Place:** QUANTITIES IN SELECTED ACQUISITION **REPORTS**

*Gregory A. Davis and David M. Tate*

In this article, the authors have looked at the definition of units in numerous acquisition programs and discovered that the units reported are almost never simple; in some programs, no two units are the same; and almost invariably, the units produced at the end of a long production run are substantially different from the early ones. They have identified three reasons why the units may differ. The first reason is changes over time, generally as system capabilities are improved. The second is due to mixed types, where units that are inherently dissimilar such as CH 47F and MH 47G helicopters—are produced by the same program and each is called one unit. The final reason why units can differ is reporting accidents. The authors give examples of all three and discuss possible methods of improving the reporting requirement.

**DOI:** *https://doi.org/10.22594/dau.19 832.27.01*
**Keywords:** *Selected Acquisition Report (SAR), Major Defense Acquisition Program (MDAP), Defense Acquisition Management Information Retrieval (DAMIR), Triggering, Research, Nunn McCurdy (N M) Breach*

*Image designed by Michael Krukowski*

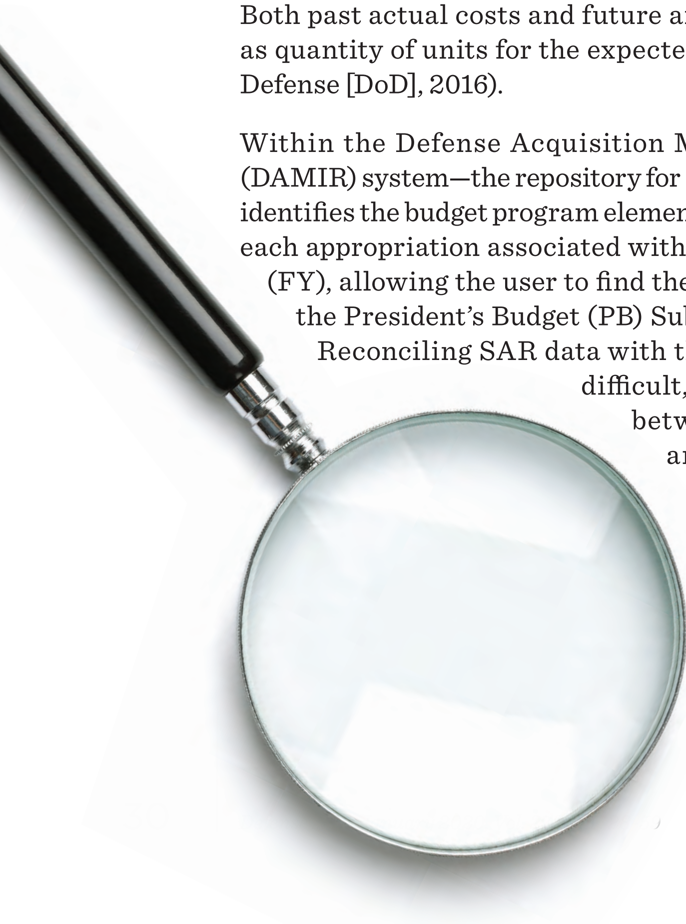
Acquisition data are primarily about a few questions: "How much funding? How many are we getting? When are we obligating the funds? And when are we getting what we paid for?" All of these questions are interesting, and none is straightforward. Most have been addressed elsewhere and continue to garner attention. However, the question of "What are we getting?" is generally treated as though it were simple. Our experience tells us that counting quantities is often not straightforward. This article describes research findings that have taken us deeper into this question, showing that quantities are almost always complicated.

The Director of Performance Assessments and Root Cause Analyses (D,PARCA)[1] asked the Institute for Defense Analyses (IDA) to review the quality and utility of data used for acquisition oversight; we started with the question of quantities.

## Acquisition Reports

Title 10 U.S.C. § 2432 (Selected Acquisition Reports, 2019) requires the Secretary of Defense to submit to the Congress a yearly status report for each Major Defense Acquisition Program (MDAP), known as the Selected Acquisition Report (SAR), which provides performance, schedule, and cost data. Each SAR includes separate cost estimates for several categories. Both past actual costs and future anticipated costs are reported, as well as quantity of units for the expected life of the program (Department of Defense [DoD], 2016).

Within the Defense Acquisition Management Information Retrieval (DAMIR) system—the repository for SAR data—the Track to Budget section identifies the budget program elements (PE) or line item numbers (LIN) for each appropriation associated with a program in a particular fiscal year (FY), allowing the user to find the equivalent cost and quantity data in the President's Budget (PB) Submission prepared in the same year.[2] Reconciling SAR data with the equivalent PB Submission proves difficult, however, as cost estimates can vary between the two sources, and some PEs and LINs are shared among multiple programs in a nontransparent way. In some cases, the SAR and PB define quantities differently.



Neither the PB nor the SAR is perfect. In general, the justification books that the Services produce annually to support the PB contain more detail, which is good for analysis, but if the data in the justification book extend beyond the Future Years Defense Program (FYDP) timeframe, then instead of year-by-year data, a single column is labeled "To Complete." The PB also does not include much history, with most of it in a single column labeled "Prior Years." The SAR reports costs in both Then Year (TY) and Base Year (BY) dollars, while the PB reports TY dollars exclusively. The SARs are the Office of the Secretary of Defense (OSD)'s primary data source for analyzing MDAPs. This dataset is what cost analysts from many different organizations typically use, per the recommendation of the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, or OUSD(AT&L) staff, who described SAR data as "the official numbers." OUSD(AT&L) no longer exists and we have not conducted any interviews with personnel in the successor offices that exist today—Office of the Under Secretary of Defense (Research and Engineering) or Office of the Under Secretary of Defense (Acquisition and Sustainment).

## Why SARs Matter

The SARs are not the dataset used most often for decision-making inside the DoD. When senior leaders make large resource decisions, analysts most often assemble datasets to suit the needs of the decision maker by pulling data from nonpublic systems or conducting data calls. Why then do we care about the quality of data in the SARs?

The SARs matter for two reasons: triggering and research. What we call triggering is why the SARs were created. The Services trigger investigations when they seek milestone authorities from OSD. OSD can also trigger analyses for program reviews based on the Service's annual submissions, such as the Program Objective Memorandum. Only the SARs provide regular information at the program level. For example, no other annual submission can tell OSD or the Congress about the projected procurement costs for a program that is expected to leave the development phase in 5 years.

Research on defense acquisition is continuously occurring in government agencies, think tanks, universities, and other organizations. In the past, researchers looking across programs have considered amount of cost growth (McNicol, 2004), setting of production rates (Rogerson, 1991), comparisons among different commodity types (Drezner, Arena, McKernan, Murphy, & Riposo, 2011), and many other subjects. This research helps the government, and SARs are the best source for comparisons across programs. While it is the nature of research that we cannot predict which research projects will yield fruitful results, we know that better quality data will generally yield better research results.

### Nunn-McCurdy Breaches

Critical Nunn-McCurdy (N-M) Act breaches are established by 10 U.S.C. § 2433 (Nunn-McCurdy Act, 1981; Selected Acquisition Reports, 2019). If an MDAP sustains too much cost growth, a review takes place that generally leads either to changes in the program or, occasionally, termination. Program managers (PMs) generally want to avoid N-M breaches. "Too much" cost growth is defined in terms of Average Procurement Unit Cost (APUC) or Program Acquisition Unit Cost (PAUC).

APUC = Procurement Costs/Procurement Quantities

PAUC = Total Program Costs/(Procurement + RDT&E Quantities)

There are four possible critical N-M breaches—two for APUC and two for PAUC. The breach calculation is performed by measuring the percentage growth in APUC or PAUC. A critical breach occurs when the variable has increased by at least 25% against the current Acquisition Program Baseline (APB) or 50% against the original APB. The original APB is the APB that was established during the Milestone (MS) B decision (formerly MS II).

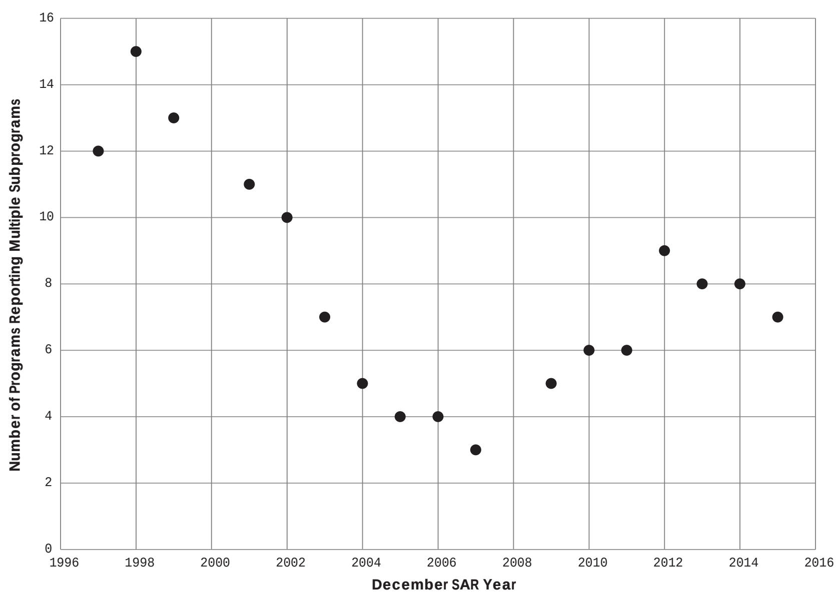
Each SAR contains a unit cost report that compares the current APUC and PAUC estimates to the original APB; and a second unit cost report compares the estimates to the current APB if the current APB is not the same as the original one.

## Subprograms

An MDAP's baseline may indicate that it has multiple subprograms to increase visibility into the program's activities. If so, each unit produced and each dollar spent is assigned to one of the subprograms. Subprograms have been used to distinguish variants of a system such as two similar but not identical missiles or to look at different parts of a system, such as engines and airframes. Each year, each subprogram has its APUC and PAUC calculated and compared to the baseline. According to the N-M Act, if any subprogram exceeds its thresholds, an N-M breach is declared for the entire program, not just the subprogram that exceeded its baseline.

The popularity of subprograms has changed through the years, as can be seen in Figure 1. The total number of programs each year did not change much, but declaring subprograms became less common from 1998 to 2009, when a rebound started. The cause of these changes is unclear.

**FIGURE 1. SUBPROGRAMS IN MDAPs 1997 2015**




## An Example of Budget and SAR Discrepancy: Gray Eagle

Quantity reporting in the SAR is the focus of this report. We begin with a few illustrative examples. The Army's MQ-1C Gray Eagle program acquires unmanned aerial systems (UAS). In the Track to Budget section of its 2015 SAR, the program identifies the following LINs within the Aircraft Procurement, Army appropriation:

- A00005 (MQ-1 UAS)
- A01001 (MQ-1 Payload, which includes funding for other programs)
- A01005 (Common Sensor Payload Full Motion Video [CSP FMV], a sub-Line Item Number to A01001)

Both A01001 and A01005 are listed as shared. The quantities and costs found in these LINs in PB 2017, however, differ from those in Gray Eagle's 2015 SAR, as shown in Table 1. Note that both sources project the program to finish in FY 2018.

**TABLE 1. GRAY EAGLE PROGRAM SAR AND BUDGET COMPARISON**

| | FY 2015 | | FY 2016 | | FY 2017 | | FY 2018 | |
|---|---|---|---|---|---|---|---|---|
| **Data Source** | **Q** | **Cost (TY $)** | **Q** | **Cost (TY $)** | **Q** | **Cost (TY $)** | **Q** | **Cost (TY $)** |
| PB 2017 | 19 | $246,490 K | 17 | $355,445 K | 0 | $60,117 K | 0 | $10,806 K |
| Dec 2015 SAR | 2 | $246,400 K | 3 | $322,200 K | 0 | $60,200 K | 0 | $15,200 K |
| **Difference** | **17** | **$90 K** | **14** | **$33,245 K** | **0** | **-$83 K** | **0** | **-$4,394 K** |

***Note.*** K = thousand; Q = quantity.

The cost differences in FY 2015 and FY 2017 are minimal, but no obvious explanation is evident for the more significant differences in FY 2016 and FY 2018 costs. In PB 2017, the unit of accounting for this program is one unmanned aircraft. However, the capability is also dependent on how many ground assets for operating the systems are acquired and on the differences between aircraft, as they are not all the same. In the SAR, the quantity is measured in companies, each of which contains several aircraft with different configurations and some amount of ground equipment. The SAR contains a standard measure for what a company is, but also reports that not all companies fit the standard description. While the SAR does include a great deal of detail in various written sections, this makes it difficult to use the quantities in the data for quantitative analysis.

## A Complex Example: The CH-47F Chinook Program

The Army's CH-47F Improved Cargo Helicopter program demonstrates challenges that can occur when counting quantities across years in both the PB and SAR. This program builds Chinook helicopters, which are easy to count, yet there are serious questions when looking at the data.

First, the CH-47F program's definition of one unit has changed over time. In the early days of the program (as reflected in the original June 1998 SAR), the plan was to SLEP[3] 300 existing CH-47D helicopters to an updated configuration, which would be called the CH-47F. In PB 2005, the plan was to SLEP 287 CH-47D helicopters to the CH 47F configuration, and 50 MH-47E Special Operations helicopters to a new MH-47G configuration. The definition of a unit had changed to include both CH-47D/F conversions and MH-47E/G conversions, which produce distinct end items and have different expected costs.

The Army's February 2007 budget justification forms expanded the set of planned activities to include all of the following:

- SLEPs of CH-47D to CH-47F
- SLEPs of MH-47E to MH-47G
- New builds of CH-47F from scratch for Active Duty Army units
- New builds of CH-47F in a different configuration for National Guard units

The reported and projected unit costs for these activities were all different. More to the point, the definition of a unit now included not only a remanufactured existing helicopter, but also a newly built helicopter of the same design. While these may be functionally identical from an operational point of view, PMs would reasonably want to know how many of each were to be built—and at what cost. To further complicate matters, the helicopters produced (both SLEP and new build) employ a mix of mission subsystems, some of which could be repurposed from a remanufactured helicopter or other existing decommissioned helicopter, and some of which had to be built (and purchased) new. The type and number of repurposed subsystems continued to vary from year to year, so that the production inputs (and price) even for new-build Active Component CH-47Fs were different from year to year.

The result of these changes is that any given unit produced by the CH-47F program might have any one of the MH-47G, CH-47F Army, or CH-47F National Guard configurations. A CH-47F unit might be remanufactured or built new. Whether remanufactured or new, it might include some unspecified mix of government-furnished (free) and contractor-furnished (at a price) mission subsystems. For example, as of the 2013 PB submission (February 2012), 43 new-build units had been produced at an average cost of $15.0 million, of which $1.1 million per unit was for government-furnished equipment (GFE). The estimated cost to complete the new-build program was $2.19 billion for 112 units, or $19.5 million per unit, of which $2.4 million per unit was expected to be GFE. This reflects the expectation that units authorized through FY 2013 would use recovered avionics suites from existing aircraft, but that half of the new-build units after that would require new-build (contractor-furnished) avionics. The program office staff clearly anticipated differences in components and cost between units produced up to that point and units expected to be produced in the future.

Furthermore, inconsistencies emerged between the SAR and the PB submissions regarding which units comprise the CH-47F program. How new builds versus SLEPs are counted in different years is unusual and is described in detail in a later subsection called "Reporting Accidents."

## Organization/Common Differences Among Unit Definitions

We have divided the common differences among unit definitions into three buckets: changes over time, mixed types of units, and reporting accidents. It is not uncommon for more than one category to apply to a given program; the Chinook has all three. The next three sections describe what each of these categories means, how confusions arise, and what cost analysts should do when trying to use cost-reporting data. At the end, we make some modest recommendations for modifications to acquisition data reporting that could help make the data more useful for many sorts of analyses. As part of those recommendations, we consider the Joint Light Tactical Vehicle (JLTV) program—how its reporting might have been done differently and what the ramifications of those differences might have been.

### Changes Over Time

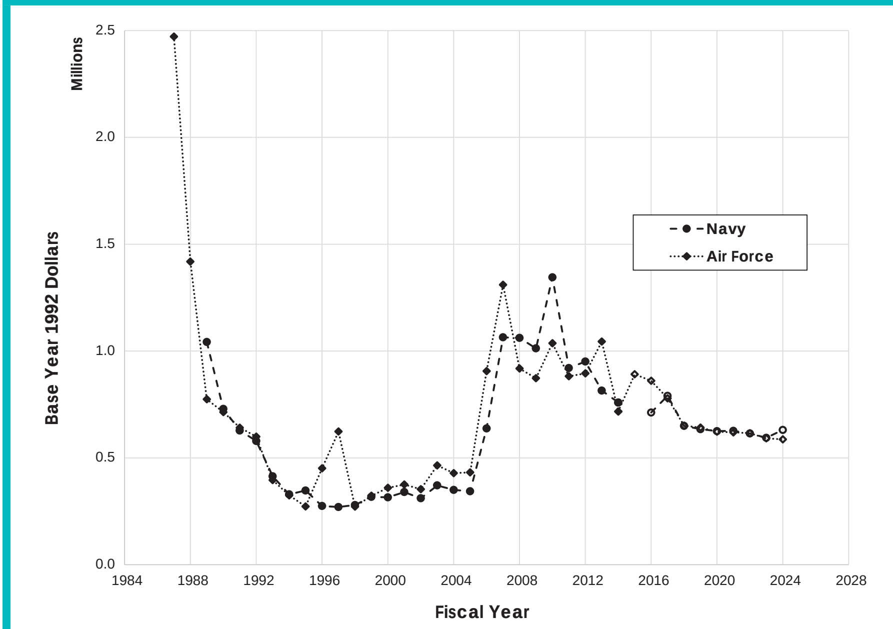
Implicit in the concept of a unit of measurement is that every instance of the unit should be identical. Every inch should be the same length, every second should have the same duration, and every run scored in a baseball game should count equally.[4] As noted earlier, this is often not true of procurement units in MDAPs. One reason that nonidentical units might arise is that the product may evolve over time. Even when counting quantities is simple, such as when counting helicopters or ships, the units procured at different times are usually different in both cost and capability. In our full report (Davis, Giles, & Tate, 2017), we detail changes over time in ships, tactical aircraft, and tactical land vehicles. In this excerpted article, we look only at one program, the Air Force's AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) program.

The AMRAAM program was established at a Defense Systems Acquisition Review Council MS I Review in November 1978. After an extended development period, an acquisition baseline of 24,320 units was set in December 1988. The first production units were authorized under the FY 1987 budget and fielded in 1991. The acquisition target was reduced to 16,427 missiles in a 1992 rebaselining that also doubled the expected per-unit cost.

The AIM-120 is still in production. The Air Force now intends to buy a total of 12,851 missiles, and the Navy an additional 4,461 missiles, for a total of 17,312. The final unit is projected to be authorized in FY 2025—almost 40 years after the first unit.

The explanation for the continued utility of the AIM-120 is that the missiles being produced today are nothing like the missiles that were produced in the early 1990s. Figure 2 shows the history of average unit cost by annual production lot for AMRAAM missiles, with filled shapes showing historical data and open shapes, projections. After a typical initial learning curve, the program has undergone major changes over its history. In fact, many upgrades, modifications, and wholesale redesigns of the missile have occurred over time; the Teal Group reports seven (Teal Group Corporation, 2014, p. 133). Some were simply improvements, while others had new functions, such as the Air Intercept Missile AIM-120C3, designed with smaller control surfaces to fit inside the weapons bay of an F-22 Raptor and the AIM 120D, which includes many new features such as Global Positioning System (GPS) navigation and a two-way datalink.

**FIGURE 2. ANNUAL AVERAGE UNIT COST FOR AMRAAM MISSILES**




There is no sense in which an AIM-120D is "the same thing" as an AIM-120A, or even an AIM-120C7. This is a clear instance in which the implicit assumption that units are interchangeable has been violated.

> **There is no sense in which an AIM-120D is "the same thing" as an AIM-120A, or even an AIM-120C7.**

Of course, within the AMRAAM program, its managers have no confusion about the kinds of missiles that are currently being produced, their capabilities, or plans for future improvements. The question, then, is how the program might adjust its data reporting to enhance transparency for planners, analysts, and oversight bodies.

## Mixed Types of Units

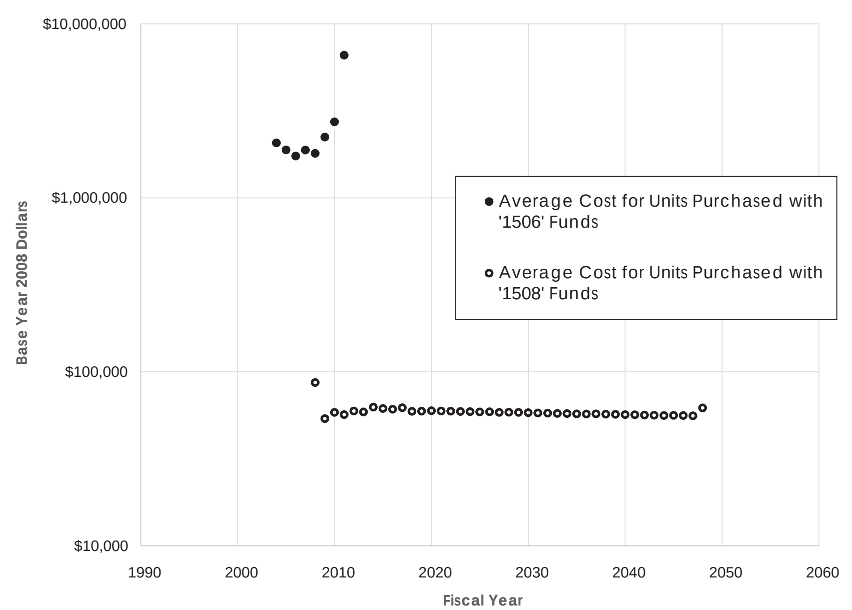
Program offices often procure different end items at the same time. These items are usually similar to one another but substantially different; yet, for quantity reporting purposes, each is considered one unit. This often comes about because of different missions or end users. Sometimes, the types are completely different. To illustrate this concept, in this article we look at an electronics suite.

The Navy's Integrated Defensive Electronic Countermeasures (IDECM) program acquires electronics suites to protect the various F/A-18 aircraft from radio frequency-guided missiles. IDECM achieved MS II approval in October 1995, although it was too small at the time to be an MDAP. Because of changes, it became an MDAP in March 2008 and its managers issued their first SAR in June 2008. The Mission and Description section of the December 2015 SAR describes the blocks as follows.

- IDECM Block 1: A federated suite, consisting of the ALQ-165 On-Board Jammer (OBJ) and ALE-50 expendable decoy
- IDECM Block 2: An integrated suite, consisting of the ALQ-214 OBJ and ALE-50 expendable decoy
- IDECM Block 3: An integrated suite, consisting of the ALQ-214 OBJ and ALE-55 Fiber Optic Towed Decoy
- IDECM Block 4: A Hardware Engineering Change Proposal to the ALQ-214 OBJ to render it suitable for operation on F/A-18C/D aircraft, while retaining all functionality when installed on F/A-18E/F

The SAR contains two subprograms: IDECM Blocks 2/3 and IDECM Block 4. The December 2015 SAR reports an APUC of $2.502 million for Block 4 and a far lower APUC of $0.090 million for Block 2/3. This is because the quantities are so different. Block 4 has a quantity of 324—roughly the number of airplanes they will be protecting. Block 2/3 has a quantity of 12,805, although the Navy bought fewer than 600 F/A-18E/Fs in total. Eighty-five of the 12,805 were purchased with 1506 Navy Aircraft Procurement funds, and the balance were bought, or will be bought, with 1508 Procurement of Ammunition, Navy and Marine Corps funds. We presume that those purchased with ammunition funding are only the disposable decoys. The unit costs based on the End Item Recurring Flyaway column in each year are presented in Figure 3.

FIGURE 3. IDECM BLOCK 2/3 ANNUAL UNIT COST BY APPROPRIATION TYPE FROM DECEMBER 2015 SAR




Even though showing two unit costs on the same chart requires plotting them on a logarithmic scale, the two are both considered units for the official unit cost calculation. Just within the more expensive 1506 units, clearly, significant changes are evident, as the cost therein does not follow a typical learning shape, which would be expected to slope downward.

While the details have changed with time, the IDECM program has used this reporting system since it issued its first SAR in June 2008.

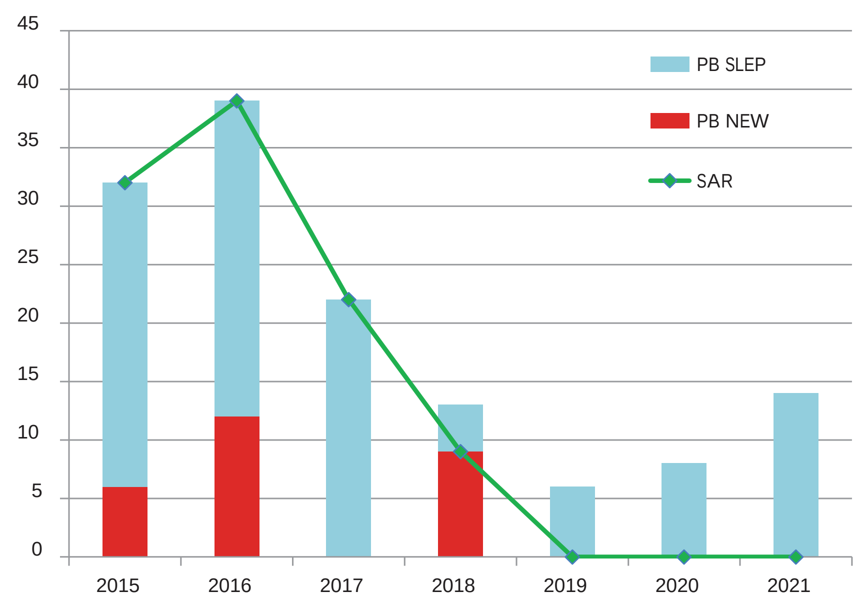
## Reporting Accidents

The confusions described in the previous section generally come about because of some decision by leadership about how the data should be presented;[5] this category, in contrast, is about cases in which it seems outright errors were also evident in how the quantity numbers were determined. We do not know how frequently this happens, but we know that it happens and can persist for several years. We do not suggest that any of the cases described in the following discussion involve intent to confuse people, but they did have that effect.

We used the term "accidents" (as opposed to mistakes or errors) because it was the term a government official in OUSD(AT&L) applied to reporting anomalies for programs like Chinook. We identified three in the December 2015 SARs: Chinook helicopters, the Evolved Expendable Launch Vehicle, and the Intercontinental Ballistic Missile Fuze modernization programs. Quite possibly, there are more. We only present the Chinook situation in detail, as the others were about how dollars were assigned within the program.

As described earlier, the CH-47F Chinook Improved Cargo Helicopter program made a number of changes to its definition of "unit" over the course of the program. In the December 2015 SAR, however, planners and cost analysts apparently lost track of how they had been defining a unit, and subsequently submitted quantity and cost forecasts that did not include all of the units identified in the simultaneous PB submission. Figure 4 shows the discrepancy between predicted future quantities in the December 2015 SAR and the corresponding 2017 PB. Through FY 2017, the total quantities match perfectly. Beginning in 2018, units described as SLEP units in the PB are missing from the SAR forecast. As a result, the projected cost of these units is not included in the SAR calculations of APUC, PAUC, APUC growth, or PAUC growth.

**FIGURE 4. SAR VERSUS PB PRODUCTION QUANTITIES FOR CH 47F**



Because 10 U.S.C. § 2432 (Selected Acquisition Reports, 2019), which has long been in effect, requires the SAR and the concurrent PB to agree on costs and quantities, this is clearly an accident.

An ongoing mismatch also exists between the SAR and PB with regard to the past quantity produced. In the SAR, every past unit produced is counted, regardless of whether it was a SLEP unit or a new build. In the PB, in the early years of the program, no top-level quantities were reported, presumably on the basis that upgrades to CH 47F configuration were collectively just one of many ongoing upgrades in the Army's helicopter fleet. Typically, programs that perform multiple types of upgrade, but are not applying all of them to every legacy platform, report the number of each type of upgrade performed separately. They do not typically roll these up into a total quantity for the program's LIN, because the individual upgrades are not comparable, and the number of platforms modified does not match the total number of any one type of modification.

When the decision was made to build CH-47F helicopters as new builds, cost analysts began reporting a total quantity of units at the line item level and chose to include both SLEP and new-build units in this total. However, they never looked back to include previously produced SLEP units in the Prior Quantity total. As a result, each new SAR and PB submission disagree, both on how many helicopters have been procured and on how many will have been procured in total when the program is finished.

## Suggested Adjustments to Reporting

One possible response to the issues described previously is to tell PMs never to change what they are buying: once the baseline is set and the program is approved, the plan should be followed and the systems should not change. This assumption is implicit in the data reporting process. And yet, this has never been government practice and we do not recommend that it be adopted. Our military goes to great lengths to provide our warfighters with the best possible equipment, and we should not forbid that just to make bookkeeping easier. We do offer some modest proposals that could make the reported data more useful, but first we need to be careful about incentives.

### Data and Incentives

Data recording systems provide incentives, sometimes in unexpected ways. "You get what you pay for" is a familiar adage. In 2007, Dr. H. Thomas Johnson wrote: "Perhaps what you measure is what you get. More likely, what you measure is all you get" (Johnson, 2007). If the acquisition system's data requirements are not aligned with the system's goals, suboptimal performance may follow. This is exacerbated when penalties are associated with data reporting. Generally, people would prefer to report accurate data, but when the data will be used to justify punishment, the reporters are incentivized to either change the facts that lead to the data—possibly in creative and unproductive ways—or to provide incorrect data.

> **"Our military goes to great lengths to provide our warfighters with the best possible equipment, and we should not forbid that just to make bookkeeping easier.**

The statute that defines the N-M breach specifies PAUC and APUC thresholds that influence program behavior. Since N-M reviews impose costs on programs, and can trigger cancellation of a program, many people in defense acquisition, including PMs, try to avoid them. This likely accounts for some of what we see in data reporting today.

Any changes made to the system need to be considered in this light. If people's careers will depend on what data they report, at times those data are more likely to reflect what is needed to satisfy the checker rather than reality. Furthermore, people will bend reality to make the data look "right" even if that will not yield the best actual result for national security.

## Monitoring Changes over Time

If we accept that the units produced during the course of a program will change over time, PMs should be given useful and standardized ways to describe (and ideally quantify) those changes, both for past units produced and planned future production.

The current taxonomy of SAR Variance Categories recognizes seven possible reasons for cost growth. Cost growth due to design changes must always be categorized as "Engineering," lumping together planned and unplanned changes, as well as optional versus necessary changes. For oversight and analysis, it would be useful to be able to distinguish at least three subcategories of "changes over time":

- Pre-Planned Product Improvements
- Unplanned changes (necessary and unnecessary)
- Block upgrades or evolutionary acquisition

**Pre-Planned Product Improvements.** Pre-Planned Product Improvements (P3I) is a form of spiral acquisition in which the first units produced do not include all of the capabilities that the procuring Service has identified as being required. The reasons for delaying might be budgetary, technical, operational, or some combination thereof. The key is that planners and cost analysts have a plan from the beginning to add specific known improvements and have developed cost and schedule estimates for those improvements. This allows P3I costs to be included in the SAR and other program submissions.

In the current SAR, or even the more detailed PB, reporting current or anticipated P3I costs in a transparent fashion is difficult. The additional costs beyond what the program would cost if the improvements were not made will be a mix of the following budgetary, technical, and operational activities.

- Research, Development, Test, and Evaluation (RDT&E) Costs (for developing and testing the new design)
- Nonrecurring Costs (for things like new documentation and tooling)
- End-Item Recurring Flyaway (EIRF) Costs (for actual production of the improved units)
- Possible Non-End-Item Recurring Flyaway (NEIRF) Costs (if improvements are made to non-end-item systems)
- Support Costs (if the cost of support and/or spares for the new design is not exactly the same as for the original design)

For the marginal cost of improvements to be visible in the SAR, reporting would need to explicitly include P3I costs. One way to do this would be as follows:

- If the planned improvements are small in number and to be done at a few discrete times during the production run, treat them like Block Upgrades (see section on Block Upgrades, p. 47).
- If the planned upgrades are more numerous and continuous, establish a Planned Upgrades subprogram, and report the RDT&E and Procurement costs associated with planned changes to the original design under that subprogram. For each year in the SAR Annual Funding report, the program should report the following:

- ° Under the main end item subprogram, report the quantity produced or planned, and the estimated cost if those units had been produced to the original design.
- ° Under the Planned Upgrades subprogram, report zero quantity, and the additional marginal procurement cost for the lot due to design changes. This additional cost should be split among EIRF, nonrecurring, and support costs in the usual reporting method.
- ° Report RDT&E costs for the original design under the primary end-item subprogram.
- ° Report RDT&E costs associated with planned design changes in the Planned Upgrades subprogram.

This system would allow cost analysts to clearly understand how much of the price change over time was driven by planned improvements and how much was unexpected. It would support meaningful learning curve modeling, and also provide some progress tracking of new capability insertions. The narrative portions of the SAR would describe the capability enhancements obtained to date, the plan for future insertion of new capabilities, and the unexpected changes made to the base program.

On the other hand, this system introduces a potentially onerous new type of reporting—namely, the hypothetical cost of the units if they had all been made to the original design. This is not information program planners and cost analysts currently possess, and potential pitfalls and perverse incentives may emerge in how they might choose to compute and report these counterfactual costs. In particular, cost growth due to design changes that may have been necessary in the base program (e.g., for safety reasons, to meet threshold requirements, or due to diminishing manufacturing sources) could be allocated either to the base subprogram or to the P3I subprogram, whichever seemed least likely to risk an N-M breach.

For N-M purposes, several regulatory changes might be beneficial. First, the primary end item and the Planned Upgrades should be treated as separate triggers. The primary end item would use the usual PAUC and APUC thresholds. The Planned Upgrades subprogram might have limits based only on total cost growth, or perhaps time-phased cost growth (e.g., average cost per year, rather than average cost per unit). Ideally, a breach on the Planned Upgrades subprogram would not imply a breach on the base subprogram (although the reverse would not be true).

Under this system, the main temptation for struggling programs would be to mischaracterize some of their core program cost growth as P3I, so as to avoid an N-M breach on the primary end item. By shedding planned improvements, the program could avoid having an N-M breach on either subprogram. This is not necessarily a bad thing. The oversight challenge would be to align operational test criteria with the phased capabilities to be produced.

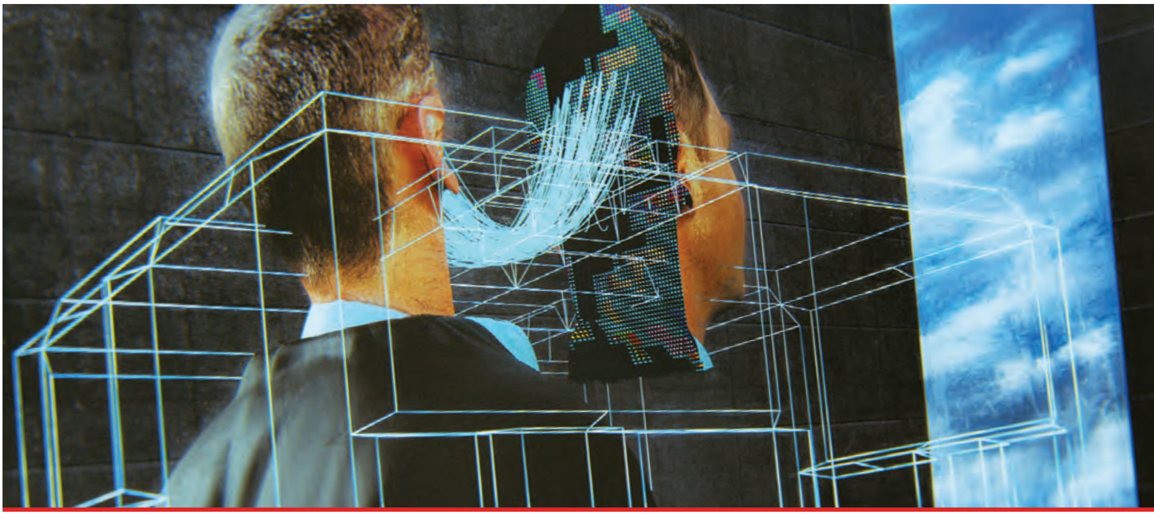
**Unplanned Changes.** It is not uncommon for systems already in production to incorporate significant design changes that were not foreseen by the planners and cost analysts. Reasons for this can include urgent operational needs from the field, correction of defects discovered postfielding, implementation of Value Engineering proposals, or response to changes in the adversary/threat environment.

Clearly, requiring PMs to report things they are not yet planning to do is unreasonable. For unplanned changes, the challenge is how to report them as they are discovered and after the fact, in ways that transparently describe the reasons for any corresponding cost and schedule changes.

It would be ideal if SAR reporting of unplanned changes distinguished clearly between design changes driven by new performance requirements and changes required to meet the original program requirements. One possible way to accomplish this would be to add a new category—"Requirements"—to the list of SAR variance categories. Cost changes due to design changes required to meet original program requirements (as of the current APB) would be classified as engineering variances. Cost changes due to new or modified performance requirements would be classified as requirements changes. For a program with a P3I subprogram, the base program and P3I subprogram would be reported as separate cost variances using the new category, where appropriate.

Unfortunately, PMs are unlikely to report these categories accurately. Not only are there strong incentives to categorize all cost growth as being due to new requirements, but genuine confusion often prevails within the program office about which requirements are part of the baseline and which have been added during the course of development and production. In theory, the Cost Analysis Requirements Document and other mandatory acquisition documents establish the baseline requirements assumed by the baseline cost estimate. In practice, this is not as clear, especially for programs that have been rebaselined at some point.

**Block Upgrades, Evolutionary Acquisition, and Agile Development.** Some program offices intend from early on to upgrade or replace the initial design with an improved future design, but do not yet know what those changes will be or what they will cost. They may not know which attributes will be enhanced, since that decision will be based on developments in the future. If multiple changes are made to the weapon system design at a few discrete points in time, these are often termed block upgrades. If many changes are made on an ongoing basis as their usefulness becomes known, this is sometimes referred to as evolutionary acquisition. The special case of software programs undergoing repeated rapid insertion of new features in close collaboration with the users of the software is called agile development.



In each of these cases, the reporting challenge is that the planners and cost analysts know that they intend to spend money in the future, but they do not know what they will be spending it on, what it will cost, or when it will happen. The challenges for oversight and management are obvious—especially when a program being managed in this way is shoehorned into a reporting system designed for unchanging units. This is part of what happened to the RQ-4 Global Hawk program, which was intended from the beginning as an evolutionary acquisition, but program planners were required to guess both content and schedule of future upgrades as part of its original acquisition baseline. Those guesses were then treated as firm requirements by the acquisition system, even after Air Force leaders had changed their minds about both priorities and threshold performance.

In the case of block upgrades, one possibility is to simply declare a new program for each block. This is the approach taken by the AIM-9, AIM-9X, AIM-9X Block II missile programs; the F/A-18C/D and F/A-18E/F fighter aircraft programs; and the UH-60L and UH-60M Black Hawk helicopter programs (among many others).

Other programs have treated successive blocks as distinct official subprograms. This approach was taken by the Joint Air-to-Surface Standoff Missile (JASSM) program. The original program had no subprograms and developed the AGM-158 missile. During that development, the Air Force studied possible improvements to the missile, and decided to develop a second variant with longer range. The original AGM-158 was redesignated AGM-158A, and the new "JASSM-ER" (Extended Range) was designated AGM-158B. The program was split into two subprograms for reporting purposes, with JASSM-ER schedule, development costs, and production costs (and cost variances) reported separately. The Navy went even further with the new AGM-158C (LRASM) variant, deciding to make it a distinct program[6] rather than creating a new subprogram within the JASSM program. This may be because the new program is Navy-only, while JASSM is an Air Force program.[7]

An advantage of these approaches is that they isolate the unit cost of the new block from the past, rather than computing an average over all past blocks. It would defeat the purpose of the N-M legislation if 50% APUC growth in what is essentially a new weapon system became invisible because it was being averaged together with thousands of past units of completely different design.[8] A second advantage is that the block upgrade is clearly identifiable as design changes to meet new requirements, as opposed to design changes to overcome technical difficulties in achieving the original requirement.

One disadvantage of the subprogram approach, as currently implemented, is that an N-M breach by any block triggers a mandatory review of every subprogram, as described in the discussion that follows.

A disadvantage of both subprograms and separate programs is the difficulty of accounting for shared RDT&E, nonrecurring, and support costs, such as for testing equipment or software that is used by multiple blocks. For example, the RQ-4B Global Hawk family all use a common ground station. If this program had used separate subprograms for each distinct aircraft design, it would be inappropriate for the original RQ-4A subprogram to bear the cost of all upgrades to the ground station systems and software, given that all blocks benefit from those upgrades.

A logical response to this problem would be for the Global Hawk program to make the ground station systems a separate subprogram. The difficulty with this is that it would create the possibility of an N-M breach due to cost growth in a subprogram that accounts for only a small fraction of total program cost. A more reasonable approach would be for programs to be able to declare a single subprogram responsible for procurement of items other than end items. This subprogram might only be liable for an N-M breach if its estimated total cost (RDT&E + Procurement) grew to exceed a threshold percentage of the estimated PAUC for the overall program, which would require new legislation from the Congress.

## Possible Methods for Handling Mixed Types

As the examples discussed previously show, many solutions have been found to the mixed-type problem, but all of them have drawbacks.

**Subprograms.** For some programs, subprograms have provided an elegant solution. For example, the Army's original Multiple Launch Rocket System (MLRS) program distinguished two subprograms: the mobile rocket launcher and the tactical rocket it would fire. This allowed the program to accurately track unit cost growth for both of the fully configured end items being developed and produced. The launcher was produced within its original cost estimate; the rocket experienced a critical N-M breach.[9] Similarly, the Army's PAC-3 suite of upgrades to the Patriot missile system was (after several schedule breaches in the first few years of development) divided into subprograms for the Missile Segment and the Fire Unit.

The fact that a unit cost breach in any subprogram triggers an N-M breach in the overall program under current law gives the Services an incentive to not declare subprograms at all, even when they would seem useful. A program without subprograms often gives planners and cost analysts more leeway in reporting data that will make the cost growth look smaller. For example, if the MLRS program planners and cost analysts had not defined subprograms, but had treated the rockets as the end-item units, they would have shown a lower percentage cost growth for the combined program than was seen for just the rocket subprogram. In addition, the PM could have decided to produce fewer launchers than originally planned, reducing both PAUC and APUC without changing the official number of units being produced. Doing so might have avoided the N-M breach, at the cost of greatly reduced transparency regarding cost growth and reduced capability.

Making subprograms more appealing would require congressional action, possibly in an annual authorization bill, which seems possible if some way to maintain program cost accountability could be devised. The Congress might be willing to allow the Milestone Decision Authority to designate alternative triggers for programs with subprograms, especially if some of the subprograms involve far fewer dollars than others.

**"Making subprograms more appealing would require congressional action, possibly in an annual authorization bill, which seems possible if some way to maintain program cost accountability could be devised.**

In theory, SAR reporting could be expanded so that each program could report simultaneously on multiple distinct end items without declaring subprograms. The principal distinction between this approach and subprograms would (presumably) be the mechanisms for deciding cost and schedule breaches. As with subprograms, it would be important in implementing this change to avoid creating perverse incentives to PMs. In particular, accurately defining multiple end items should not increase a program's chances of experiencing an N-M breach.

**Multiple Programs.** If a Service is planning to buy a mix of different end items in response to a given set of Mission Needs, it has some flexibility in deciding how to group those efforts into programs. It is not always obvious which grouping would best serve the needs of both the Service and the oversight community.

At one (unfortunate) extreme, the Army decided to make Future Combat Systems a single program with literally hundreds of different physical products. These ranged in size and complexity from light tanks down to man-portable UASs, along with many tens of millions of lines of software implementing communications, mission command, and networked fires. The official units for that program were Brigade Sets, of which 15 were to be produced. A prime "lead systems integrator" contract was awarded, with authority to reconsider the mix and capabilities of systems to be developed and procured in each Brigade Set. This offered no useful insight into the program's activities or progress.

At the other extreme, the Army decided to split procurement of their new AH-64E Apache helicopters into two separate programs: one for remanufactured aircraft and the other for new builds. A 2008 acquisition decision memorandum signed by the Army Acquisition Executive contains the following language:

> As a recently delegated Acquisition Category IC program, the AH-64E Apache program is comprised of two separate programs, the Remanufacture program and the New Build program. Each of these programs are (sic) separate and distinct with respect to the Acquisition Program Baselines (APB), and their funding lines; however, they have identical configurations and are produced on the same production line. (Shyu, 2013)

The choice to create two MDAPs creates challenges for both the Army and OSD because it adds extra reviews and recordkeeping. Having multiple programs, as with subprograms, creates two triggers for an N-M breach, but it also means that any breach would affect only one of the two programs, whereas creating two subprograms would expose the entire program. It also splits what naturally feels like one program—indeed, the language in Shyu's (2013) memorandum refers to it both as one program and as two in the same paragraph. Since both programs produce identical new AH-64E helicopters, why should they be separated? Although distinct for reporting purposes, they have common goals and management. They share a PM and a production contract,[10] but only the remanufacture program cost analyst reports any RDT&E costs. Even within Apache, both programs list "Other Support" funds in their SARs, and since the two programs are producing identical helicopters, how the Army decides whether a given support purchase will be credited to one program or the other remains unclear. One cannot understand what is going on in either program without considering the other, which would seem to violate the notion of what constitutes a program. Where there is only one distinct end item, having multiple programs is questionable.

Defining multiple programs should only be considered as an option in the case of block upgrades to an existing program (as discussed earlier), or when the set of things to be procured by a proposed new program involves all of the following:

- Significantly different product types with different acquisition risks
- Multiple independent contracts with no real synergies
- Few significant interoperability requirements among systems

In general, splitting a new acquisition into multiple programs is rarely appropriate.

An example of a program that perhaps should have been split into multiple programs is the Stryker (originally "Interim Armored Vehicle") program. This program involved procurement of eight specialized variants of an existing nondevelopmental armored vehicle. Of these eight variants, six were relatively minor modifications of the existing design, while two[11] required extensive engineering changes to the original. An appropriate program management strategy would have been to make the six "minor modification" variants a single program (with six subprograms), and the two major redesigns either a second program with two subprograms, or two additional separate programs. That would have isolated the development risks of the two most risky projects from the more straightforward projects, and would have given OSD and the Congress better visibility of how the various projects were progressing. As it happened, the Stryker program experienced a significant (but not critical) N-M breach, driven entirely by problems in the two major redesign vehicles.

**Different Cost Categories.** Using the different cost categories in current SAR reporting can give some visibility into what is happening in a program, but generally does not allow better identification of different unit types. The distinction between end items and non-end items was not designed to capture differences among multiple distinct end items.

The Air Force's MQ-9 Reaper UAS program plans to procure 347 units, where each unit is an aircraft. The total procurement cost for the program is $9.2 billion in BY 2008 dollars, but only 52% of that is EIRF. Another 22% is categorized as NEIRF, and the remaining 26% is Total Support. This information is useful for cost analysts, although this distribution has no impact on N-M reporting.[12] The aircraft quantity can be compared to the EIRF to understand those units, but no quantities are reported for ground stations, so an analyst can only know what has been spent on them in total, not what each costs. In this case, NEIRF is something like a subprogram for the ground stations, but it is less transparent than actual subprograms would be.

## Reducing Accidents

When humans carry out activities, accidents are inevitable. Reducing accidents requires good processes. We have not analyzed the process for generating SARs or PB submissions. In principle, that could (and perhaps should) be done from a quality assurance point of view.

We were also told that OUSD(AT&L)/Acquisition Resources and Analysis (ARA) historically performed checks on Service-submitted SARs, but that they typically did not have enough time between submission and approval to conduct a thorough validation.[13] All of the draft SARs arrived at OSD in the same season. About a week after the data arrived, ARA met with each PM for about 1 hour, at which time ARA could ask questions. They felt that this process was insufficient. Select changes could reduce the accident rate.

The best way to improve OSD's review is probably not solely to add more time. While more time might help, OSD would probably also benefit from specialized tools to help them analyze the draft SAR data and quickly compare them to budget submissions, prior year SARs, and general rules about how acquisition programs typically behave. Proposing improvements to that process is beyond the scope of this article.

## A Thought Experiment: JLTV

To illustrate the kind of reporting that would be necessary to improve both oversight and data utility for cost analysts, we looked at the JLTV program. We determined that, at the beginning of the program, as many as seven distinct subprograms might have been appropriate, as indicated in Table 2. The full analysis is in our completed report (Davis et al., 2017).

**TABLE 2. SUGGESTED INITIAL JLTV SUBPROGRAMS**

| Number | Subprogram | Description |
|---|---|---|
| 1 | Utility | Base design Utility Vehicle |
| 2 | General Purpose Vehicle (GPV) | Base design GPV |
| 3 | Heavy Guns Carrier (HGC) | Base design HGC |
| 4 | Close Combat Weapons Carrier (CCWC) | Base design CCWC |
| 5 | P3I – Common | P3I common to all variants |
| 6 | P3I – HGC and CCWC | P3I specific to HGC and CCWC |
| 7 | Support equipment | Trailers, armor kits, etc. |

This would not be practical if a Nunn-McCurdy breach could be triggered by any one of them.

## Conclusions

While the default assumption for any acquisition program is that all of the units it produces are identical and interchangeable, this is seldom true. Consider asking an F-35A to land on a ship. Any analysis that assumes interchangeable units is making an unwarranted assumption that can lead to mistaken conclusions. The importance of these mistakes will vary, both with the details of the program and the nature of the analysis. We hope that this work can lead to two kinds of changes: one for analysts using acquisition data, and a second for policy makers defining reporting requirements for programs.

For analysts, the primary message is "Beware." It is not uncommon for invisible differences between units to be important to an analysis. Without additional data from non-SAR (and sometimes non-PB) sources, it is often impossible to understand the relationships among price, cost, and quantity in many programs. Such additional data are, unfortunately, not always available. Analysts need to know the limits of what can be inferred from the existing data.

For policy makers, opportunities abound to improve data-reporting requirements and guidance, and these come in three varieties. First, there ought to be explicit acknowledgment that not all units are identical, and some effort should be made to quantify unit-by-unit or lot-by-lot differences for analysis and oversight. Second, the rules need to encourage the desired behaviors. The current N-M rules are an excellent example of how rules incentivize behavior in ways that may be counterproductive. For example, IDECM's unit costs could be *reduced* by purchasing more towed decoys than needed. When designing new reporting requirements, policy makers need to keep this in mind. Finally, the quality assurance processes applied to official data ought to be studied and improved. While some accidents are inevitable, the system today probably lets through more than it should. SARs are much like custom manufactured parts. Each one is unique, but good processes could still make them more uniform and useful.

## References


Davis, G. A., Giles, M. L., & Tate, D. M. (2017). *Complexity in an unexpected place: Quantities in Selected Acquisition Reports* (IDA Paper P-8490). Alexandria, VA: Institute for Defense Analyses.

Department of Defense. (2016). *Department of Defense Selected Acquisition Reports.* (Release No. NR-106-16). Retrieved from https://www.defense.gov/News/News-Releases/News-Release-View/Article/703529/department-of-defense-selected-acquisition-reports-sars

Drezner, J. A., Arena, M. V., McKernan, M., Murphy, R., & Riposo, J. (2011). *Are ships different? Policies and procedures for the acquisition of ship programs.* RAND Corporation, National Defense Research Institute. Retrieved from https://www.rand.org/pubs/monographs/MG991.html

Johnson, H. T. (2007). Lean dilemma: Choose system principles or management accounting controls—not both. In J. Stenzel (Ed.), *Lean accounting: Best practices for sustainable integration.* New York: John Wiley & Sons.

McNicol, D. L. (2004). *Cost growth in major weapon procurement programs* (IDA Paper P-3832). Alexandria, VA: Institute for Defense Analyses.

Nunn-McCurdy Act: Amendment to the FY 1982 National Defense Authorization Act, 10 U.S.C. § 2433. (1981). Retrieved from https://www.congress.gov/bill/97th-congress/senate-bill/815

Rogerson, W. P. (1991). Excess capacity in weapons production: An empirical analysis. *Defence Economics, 2*(3), 235–249. doi:10.1080/10430719108404695

Selected Acquisition Reports, 10 U.S.C. § 2432 (2019). Retrieved from http://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title10-section2432&num=0&edition=prelim

Shyu, H. (2013). *Acquisition decision memorandum for the AH-64H Apache new build program.* Memorandum for Program Executive Officer, Aviation. Washington, DC: Office of the Assistant Secretary of the Army.

Teal Group Corporation. (2014). *World missiles and UAVs briefing* (Briefing Book Series). Retrieved from https://shop.tealgroup.com/products/world-missiles-uav-briefing

## Endnotes

[1] PARCA was an office under the aegis of the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, or OUSD(AT&L). Neither OUSD(AT&L) nor PARCA exist any longer after the Office of the Secretary of Defense was reorganized in 2018.

[2] The PB and annual SAR submissions both generally come out in the second quarter of each FY. The years on a matching budget and SAR set differ by two. The budget is named for the year ahead and the SAR is a snapshot of the program in the recent past. For example, in the second quarter of FY 2016, the FY 2017 budget was released, quickly followed by the December 2015 SAR.

[3] SLEP is the acronym for "Service Life Extension Program," and is often used as a verb in defense circles. A SLEP can be funded with either Procurement or Operations and Maintenance dollars.

[4] It is true that sometimes we use units that are clearly not identical. A hockey team can put six players on the ice and no two players are identical. But for purposes of the "too many men" rule, they are all identical. Similarly, a car dealership might count how many cars they sell, but a day where they sold 20 isn't necessarily better than a day when they sold 19, because not all car sales generate the same profit. When using collective units like this, it may hide as well as reveal, and users of the data should be careful.

[5] Or, more precisely, leadership decides how the program should be managed and what systems it should produce, possibly without considering the impact this will have on the coherence and consistency of quantity or unit cost reporting.

[6] PNO 449, "Offensive Anti-Surface Warfare Increment 1 (Long Range Anti-Ship Missile)," abbreviated as "OASuW Inc 1 (LRASM)."

[7] The "J" in JASSM stands for "Joint" and at one point there was consideration of mounting this weapon on Navy aircraft. However, that has not happened, and all of the funds in the SAR are reported from Air Force appropriations.

[8] This is what has happened with the AIM-120 AMRAAM program, as described in the section on "Monitoring Changes over Time," p. 43.

[9] Unfortunately, the program did not similarly distinguish the variant rockets being produced, or the later conversion of the entire system from an unguided rocket launcher to a guided missile launcher.

[10] The December 2015 SAR for the remanufacture program lists four procurement contracts and two RDT&E contracts. The new-build SAR only shows one contract, which is one of the four procurement contracts in the remanufacture program.

[11] The two were the M1128 Mobile Gun System (MGS), which was designed to mount a tank-like 105 mm direct fire cannon on a relatively light wheeled vehicle; and the M1135 Nuclear, Biological, Chemical, Reconnaissance Vehicle (NBC RV), which required a suite of sophisticated environmental sensors and a positive-overpressure internal environment.

[12] One could imagine the Air Force lowering the ratio of ground stations to aircraft, not for operational reasons, but rather because they want to control APUC.

[13] ARA was disbanded in a 2018 reorganization of AT&L into R&E and A&S; it is unclear which new component of OSD (if any) has inherited this review task.

## Acknowledgments

Thank you first to Dr. Peter Eggan of PARCA for supporting us throughout this project, even as we shifted gears so significantly. We also want to express our gratitude to Kathy Conley, Strider McGregor-Dorsey, and Brian Rieksts, all of IDA, whose technical reviews kept us moving (and complaining), leading to a better final product. And lastly, we thank Meg Giles of IDA who made important contributions to our research, but fell barely short of warranting authorship credit.

## Author Biographies

### Dr. Gregory A. Davis

has conducted research at the Institute for Defense Analyses (IDA) since 2006, on as broad a range of topics as he can find. Before joining IDA, he was an American Association for the Advancement of Science (AAAS) Science and Technology Policy Fellow in the former Office of the Secretary of Defense (Program Analysis & Evaluation)—now Office of the Secretary of Defense (Director, Cost Assessment and Program Evaluation). Most of his recent work has focused on major defense acquisition programs that have experienced cost growth. Except for GPS-OCX, all of them had complicated definitions of a unit. Dr. Davis holds an AB in Physics from Keynon College and an MA and PhD in Physics from the University of Rochester.

*(E-mail address: gdavis@ida.org)*

### Dr. David M. Tate

joined the research staff of IDA's Cost Analysis and Research Division in 2000. Prior to that, he was a Senior Operations Research Analyst (Telecom) at Decision-Science Applications and an Assistant Professor of Industrial Engineering at the University of Pittsburgh. Dr. Tate holds two BAs in Philosophy and Mathematical Sciences from the Johns Hopkins University. He also holds an MS and PhD in Operations Research from Cornell University.

*(E-mail address: dtate@ida.org)*

Image designed by Michael Krukowski

# Risk-Based ROI, CAPITAL BUDGETING, AND PORTFOLIO OPTIMIZATION IN THE DEPARTMENT OF DEFENSE

Johnathan Mun

This article shows a reusable, extensible, adaptable, and comprehensive advanced analytical modeling process to help the U.S. Department of Defense (DoD) with risk based capital budgeting and optimizing of acquisition and program portfolios with multiple stakeholders while subject to budgetary, risk, schedule, and strategic constraints. The article covers traditional capital budgeting methodologies in industry and explains how these methods can be applied in the DoD by using DoD centric, noneconomic, logistic, readiness, capabilities, and requirements variables. Portfolio optimization for the purposes of selecting the best combination of programs and capabilities is also addressed, as are alternative methods such as average ranking, risk metrics, lexicographic methods, PROMETHEE, ELECTRE, and others. Finally, an illustration from the Program Executive Office Integrated Warfare Systems (PEO IWS) and Naval Sea Systems Command (NAVSEA) showcases the methodology's application in developing a comprehensive and analytically robust case study that senior leadership at the DoD may utilize to make optimal decisions.

**DOI:** *https://doi.org/10.22594/dau.19 829.27.01*
**Keywords:** *Risk Analysis, Decision Modeling, Simulation, Predictive Forecasting*

The United States Department of Defense (DoD) is always looking for better, theoretically justifiable, and quantitatively rigorous analytical methods for capital budgeting and portfolio optimization. Specific interest lies in how to identify and quantify the value of each program to the military and optimally select the correct mix of programs, systems, and capabilities that maximizes some military "value" (strategic, operational, economic) while subject to budgetary, cost, schedule, and risk constraints.

This research applies some private-sector and industry common practices coupled with advanced analytical methods and models to help create these methodologies. However, the uniqueness of the DoD requires that additional work be done to determine the concept of value to the military while considering competing stakeholders' needs. We still need a defensible, quantitatively robust concept of military value to use in the modeling.

The purpose of this research is to illustrate and recommend approaches of modeling methodology and development of military value metrics, and how to combine them into a defensible, reusable, extensible, and practical approach within portfolios of programs.

This research specifically showcases how capital budgeting and portfolio optimization methods can be applied in the U.S. Navy as well as across the DoD in general, where multiple stakeholders (e.g., Office of the Secretary of Defense, Office of the Chief of Naval Operations, Congress) have their own specific objectives, constraints, or domain requirements. Objectives, for example, might be capability, efficiency, cost effectiveness, competitiveness, or lethality; while constraints might include time, budget, schedule, manpower, or policy objectives. Domain requirements could mean balancing the needs of anti-submarine warfare, anti-aircraft warfare, or missile defense.

## Capital Budgeting and Portfolio Optimization

The concept of capital budgeting and portfolio optimization has far-reaching consequences beyond the DoD. Private industry can greatly benefit from the concepts and methodologies developed in this research to apply portfolio optimization to its respective capital investment portfolios. These optimized portfolios are, by definition, the best and most efficient usage of a firm's capital to generate the greatest amount of value while mitigating risks for the organization and keeping limited budgetary and human resource constraints in check. More technically savvy individuals can apply the same methodologies in their retirement and investment portfolios, and portfolio managers can also leverage the knowledge and insights from the research to apply efficient frontier analyses for their clients' invested portfolios.

A portfolio, by definition, is any combination of two or more assets, projects, capabilities, or options. The whole portfolio is usually assumed to be greater than the sum of its parts, based on outcome performance measures, expected return on investment (ROI), capabilities, and other metrics (Mun, 2015). This assumption is due to the potential risk reduction, leverage, and synergy in terms of lower cost, interoperability, and flatter learning curve when multiple programs or capabilities are combined into a more cohesive portfolio (Mun, 2015, 2016).

In today's competitive global economy, companies in the private sector are faced with many difficult decisions. These decisions include allocating financial resources, building or expanding facilities, managing inventories, and determining product-mix strategies. The decisions the U.S. military faces are no different. The DoD, as a whole, has often struggled with trying to find the best force mix, or optimal programs that maximize military capabilities within set budgetary, scheduling, and human resource constraints.

Such decisions might involve thousands or millions of potential alternatives. Considering and evaluating each of them would be impractical or even impossible. An optimization model can provide valuable assistance in incorporating relevant variables when analyzing decisions and finding the best solutions for making decisions. These models capture the most important features of a problem and present them in a form that is easy to interpret. Models often provide insights that intuition alone cannot. An optimization model has three major elements: decision variables, constraints, and an objective. In short, the optimization methodology finds the best combination or permutation of decision variables (e.g., which programs or capabilities the DoD should acquire and which projects to eliminate) in every conceivable way such that the objective is maximized (e.g., maximum capabilities, highest expected military value, maximum military utility) or minimized (e.g., cost risk and schedule risk) while still satisfying the constraints (e.g., budget, political, human resources, and other noneconomic resources).

**"Private industry can greatly benefit from the concepts and methodologies developed in this research to apply portfolio optimization to its respective capital investment portfolios.**

Obtaining optimal values generally requires that you search in an iterative or ad hoc fashion. This search involves running one iteration for an initial set of values, analyzing the results, changing one or more values, rerunning the model, and repeating the process until you find a satisfactory solution. This process can be very tedious and time-consuming even for small models, and often it is not clear how to adjust the values from one iteration to the next. Using the proposed modeling process can eliminate the negatives of searching in an iterative or ad hoc fashion.

## Research Questions and Objectives

The proposed research attempts to answer the following research questions:

- Can the DoD perform credible and defensible portfolio optimization on capabilities and programs?
- How are military-based definitions of value created and used in developing optimal portfolios?
- What are the best approaches and algorithms that are most amenable to defense acquisition portfolios?

The proposed modeling methodology and process to be developed have the following objectives:

- Create and model multiple-objective optimization models based on competing stakeholders.

- Develop models based on the integrated risk management (IRM) methodology where Monte Carlo risk simulation methods will be employed to analyze risks and uncertainties in the portfolio's inputs.
- Optimize the portfolio of options (i.e., given a set of projects, programs, acquisition, or capability options with different costs, benefits, capabilities, and uncertainties, models help identify which programs or capabilities should be chosen given constraints in budget, schedule, and capability requirements).
- Consider various viewpoints from different stakeholders including Navy leadership, field commanders, technical engineering, and economic and strategic points of view.

Consider that, to maintain a high level of competitiveness, corporations in the private sector need to continually invest in technology, research and development (R&D), and other capital investment projects. But resource constraints require organizations to strategically allocate resources to a subset of possible projects. A variety of tools and methods can be used to select the optimal set of technology projects. However, these methods are applicable only when projects are independent and are evaluated in a common funding cycle. When projects are interdependent, the complexity of optimizing even a moderate number of projects over a small number of objectives and constraints can become overwhelming. Dickinson, Thornton, and Graves (2001) presented a model developed for the Boeing Company in Seattle to optimize a portfolio of product development improvement projects. The authors illustrated how a dependency matrix (modeling of interdependencies among projects) is applied in a nonlinear integer programming methodology to optimize project selection. The model also balances risk, overall objectives, and the cost and benefit of the entire portfolio. Once the optimum strategy is identified, the model enables the team to quickly quantify and evaluate small changes to the portfolio.

In the U.S. military context, risk analysis, real options analysis, and portfolio optimization techniques enable a new way of approaching the problems of estimating ROI and the risk value of various strategic real options. There are many DoD requirements for using more advanced analytical techniques. For instance, the Clinger-Cohen Act of 1996 mandates the use of portfolio management for all federal agencies. The General Accounting Office's 1997 report entitled *Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making* requires that IT investments apply ROI measures. DoD Directive (DoDD) 8115.01 mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments (DoD, 2005). DoDD 8115.02 (DoD, 2006) implements policy and assigns responsibilities for the management of DoD IT investments as portfolios within the DoD enterprise, where it defines a portfolio to include outcome performance measures and an expected ROI. The DoD *Risk Management Guide for Defense Acquisition Programs* (2014) requires that alternatives to the traditional cost estimation need to be considered because legacy cost models tend to inadequately address costs associated with information systems or the risks associated with them (Mun, Ford, & Housel, 2012).

# Literature Review

## Portfolio Modeling in Military Applications

Optimization is a rich and storied discipline designed to use data and information to guide decision making in order to produce an optimal, or very close to optimal, outcome. However, "government agencies have been much slower to use these approaches to increase efficiency and mission effectiveness, even though they collect more data than ever before" (Bennett, 2017). For these government agencies, optimization solutions can utilize the large amounts of data from different sources to provide decision makers with alternative choices that optimally meet agency objectives.

Greiner, McNutt, Shunk, and Fowler (2001) correctly stated that standard economic measures such as internal rate of return (IRR), net present value (NPV), and ROI are commonly used in evaluating commercial-based R&D projects to help identify optimal choices. However, such economic measures in their commercial form are of little use in evaluating weapon systems development efforts. Therefore, their paper examines the challenges faced by the DoD in determining the value of weapon systems during the R&D portfolio selection processes.

Similarly, Burk and Parnell (2011) reviewed the use of portfolio decision analysis in military applications, such as weapon systems, types of forces, installations, and military R&D projects. They began with comparing military and commercial portfolio problems in general and discussing the distinguishing characteristics of the military decision environment: hostile and adaptive adversaries, a public decision process with multiple stakeholders, and high system complexity. Based on their work, the authors observed that the "most widespread prominent feature of these applications is the careful modeling of value from multiple objectives" (Burk & Parnell, 2011). What they found surprising was that "quantitative methods of measuring and valuing risk are surprisingly rare, considering the high level of uncertainty in the military environment" (Burk & Parnell, 2011). Their analysis examined portfolio applications in more detail, looking at how military analysts model portfolio values, weight assessments, constraints and dependencies, and uncertainty and risk.


Within the military environment, Davendralingam and DeLaurentis (2015) looked at analyzing military capabilities as a system of systems (SoS) approach. According to the authors, this approach creates significant development challenges in terms of technical, operational, and programmatic dimensions. Tools for deciding how to form and evolve SoS that consider performance and risk are lacking. Their research leveraged tools from financial engineering and operations research perspectives in portfolio optimization to assist decision making within SoS. The authors recommended the use of more robust portfolio algorithms to address inherent real-world issues of data uncertainty, internodal performance, and developmental risk. A naval warfare situation was developed in the paper to model scenario applications to find portfolios of systems from a candidate list of available systems. Their results show how the optimization framework effectively reduces the combinatorial complexity of trade-space exploration by allowing the optimization problem to handle the mathematically intensive aspects of the decision-making process. As a result, the authors concluded that human decision makers can be tasked to focus on choosing the appropriate weights for risk aversion in making final decisions rather than on the mathematical constructs of the portfolio.

In contrast, when it comes to mathematical constructs, Sidiropoulos, Sidiropoulou, and Lalagas (2014) ran a portfolio management analysis with a focus on identifying and assessing current commercial off-the-shelf

Portfolio Analysis software products and solutions. The authors used *Risk Simulator* to develop portfolio models. These models were populated with relevant data and then run through an appropriate number of simulation iterations to assess candidate projects with respect to risk and Expected Military Value. The examples and models used in this paper discuss Portfolio Management Analysis (PMA) during various stages of project management and systems engineering. The goal for PMA is realized after the entire project design infrastructure is implemented and the end users' instruments are provided for implementation. The authors' intent was to identify "approaches and tools to incorporate PMA net-centric strategies to meet warfighter and business operations requirements, while continuing to maintain current levels of service, ensuring conservation of manpower and meeting infrastructure resource requirements" (Sidiropoulos, Sidiropoulou, & Lalagas, 2014).

Flynn and Field (2006) looked at quantitative measures that were under development to assess the Department of the Navy (DON)'s portfolio of acquisitions to improve business practices through better analytical tools and models. The authors found that the DON's time would be better served by shifting its attention from analyzing individual acquisition programs (now studied exhaustively) to analyzing a portfolio of systems as a whole. This approach is similar to the methodology employed as a best practice in the private sector. According to the research, this high-level view provides senior military leaders valuable metrics for measuring risks and uncertainties of costs, capabilities, and requirements. Armed with these metrics, senior leaders can make better choices, among a set of plausible portfolios, to satisfy the Navy's national security objectives. To support their analysis, a subset of the then-current DON portfolio was selected by financial management and acquisition staff with which to test a methodology of portfolio analysis in the area of Mine Countermeasures—a diverse, representative system of programs. This pilot model was a multiphase process that included gathering life-cycle cost data for the various systems to be analyzed, establishing a scoring system using subject matter experts (SME) to determine how effectively current and future systems match capabilities to requirements, and developing a means to display results by which decision makers can examine risk-reward analysis and conduct trade-offs. The researchers' ultimate goal was to assess military investments using portfolio analysis methodology.

The GAO (General Accounting Office, 1997; Government Accountability Office, 2007) emphasized the approach of optimizing a portfolio mix to manage risk and maximize the rate of return. Although the DoD produces superior weapons, the GAO reported that the department has failed to deliver weapon systems on time, within budget, and with desired capabilities. While recent changes to the DoD's acquisition policy held the potential to improve outcomes, programs continue to experience significant cost and schedule overruns. The GAO was asked to examine how the DoD's processes for determining needs and allocating resources can better support weapon system program stability. To do this, according to the report, the GAO compared the DoD's processes for investing in weapon systems to the best practices that successful commercial companies use to achieve a balanced mix of new products, including companies such as Caterpillar, Eli Lilly, IBM, Motorola, and Procter and Gamble. Based on the reports, the GAO found that to achieve a balanced mix of executable development programs and ensure a good return on their investments, the successful commercial companies the GAO reviewed take an integrated, portfolio management approach to product development. Through this approach, companies assess product investments collectively from an enterprise level, rather than as independent and unrelated initiatives. These commercial entities weigh the relative costs, benefits, and risks of proposed products using established criteria and methods, and select those products that can exploit promising market opportunities within resource constraints and move the company toward meeting its strategic goals and objectives. In these firms, investment decisions are frequently revisited, and if a product falls short of expectations, companies make tough go/no-go decisions over time.

Wismeth (2012) noted that the Army has implemented the Army Portfolio Management Solution to facilitate the collection and analysis of information necessary to prioritize the thousands of IT investments within its portfolio. IT investments are grouped according to the mission capabilities they support: Warfighter, Business, and Enterprise Information Environment Mission Areas, each of which is led by a three- or four-star-level general officer or senior executive.

Janiga and Modigliani (2014) recommended that the DoD foster dynamic and innovative solutions for tomorrow's warfighter by designing acquisition portfolios that deliver an integrated suite of capabilities. Program executive officers today often focus on executing a dozen similar but independent programs. In contrast, large commercial businesses manage integrated product lines for items ranging from automobiles and electronics to software and health services. The DoD could leverage this model as a basis for constructing portfolios of similar programs that deliver enhanced capabilities in shorter timeframes.

> **"With each passing year, the infusion of ever more complex technologies and integrated systems places increasing burdens on acquisition officers to make decisions regarding potential programs with respect to the joint capability portfolio. Furthermore, significant cost overruns in recent acquisition programs reveal that, despite efforts since 2010 to ensure the affordability of systems, additional work is needed to develop enhanced approaches and methods.**

The Institute for Defense Analyses prepared a document for the Office of the Director, Acquisition Resources and Analysis, under a task titled "Portfolio Optimization Feasibility Study" (Weber et al., 2003). The objective was to study the feasibility of using optimization technology to improve long-term planning of defense acquisition. The model described in this document is an example of optimization technology that can estimate and optimize production schedules of Acquisition Category I programs over a period of 18 years.

Vascik, Ross, and Rhodes (2015) found that the modern warfighter operates in an environment that has dramatically evolved in sophistication and interconnectedness over the past half century. With each passing year, the infusion of ever more complex technologies and integrated systems places increasing burdens on acquisition officers to make decisions regarding potential programs with respect to the joint capability portfolio. Furthermore, significant cost overruns in recent acquisition programs reveal that, despite efforts since 2010 to ensure the affordability of systems, additional work is needed to develop enhanced approaches and methods. Vascik et al.'s paper discussed research that builds on prior work that explored system design trade-spaces for affordability under uncertainty, extending it to the program and portfolio level. Time-varying exogenous factors, such as resource availability, stakeholder needs, or production delays, may influence the potential for value contribution by constituent systems over the life cycle of a portfolio and make an initially attractive design less attractive over time. Vascik et al. introduced a method to conduct portfolio design for affordability by augmenting Epoch-Era Analysis with aspects of Modern Portfolio Theory. The method is demonstrated through the design of a carrier strike group portfolio involving the integration of multiple legacy systems with the acquisition of new vessels.

According to DoDD 5100.96 (DoD, 2017), the Principal DoD Space Advisor (PDSA) monitors and oversees the performance of the entire DoD space portfolio. The PDSA, in assessing space-related threats, requirements, architectures, programs, and their synchronization, advises senior DoD leadership and recommends enterprise-level adjustments. It conducts an annual strategic assessment, or Space Strategic Portfolio Review when directed, assisted by the Defense Space Council and Director, Cost Assessment and Program Evaluation, to address space posture and enterprise-level issues and provides the Secretary and Deputy Secretary of Defense with results of the analysis, which may include prioritized programmatic choices for space capabilities.

## Capital Budgeting and the Value Concept

### The Traditional Views

*Value* can be defined in many ways, depending on the needs and views of the stakeholder. For the purposes of this research, one of the ways we will define value is the single time-value discounted number that is representative of all future net profitability. In contrast, the market price of an asset may or may not be identical to its value ("assets," "projects," and "strategies" are used interchangeably). For instance, when an asset is sold at a significant bargain, its price may be somewhat lower than its value, and one would surmise that the purchaser has obtained a significant amount of value. The idea of valuation in creating a fair market value is to determine the price that closely resembles the true value of an asset. This true value comes from the physical aspects of the asset as well as its nonphysical, intrinsic, or intangible aspects. Both aspects have the capability to generate extrinsic monetary value or intrinsic strategic value. Traditionally, valuation is established based on three methodologies, namely, the market approach, the income approach, and the cost approach (Mun, Hernandez, & Rocco, 2016). Other approaches used in valuation, more appropriately applied to the valuation of intangibles, rely on quantifying the economic viability and economic gains the asset brings to the firm. Several well-known methodologies can be utilized to establish intangible-asset valuation, particularly in valuing trademarks and brand names. These methodologies apply the combination of the market, income, and cost approaches just described. Although the financial theories underlying these approaches are sound in the more traditional deterministic view, they cannot be reasonably used in isolation when analyzing the true strategic flexibility value of a firm, project, or asset.

## Portfolio Optimization

In today's competitive global conditions, the DoD is faced with many difficult decisions. These decisions include allocating financial resources, building or expanding facilities, managing inventories for maintenance, and determining force-mix strategies. Such decisions might involve thousands or millions of potential alternatives. Considering and evaluating each of them would be impractical or even impossible. A model can provide valuable assistance in incorporating relevant variables when analyzing decisions and in finding the best solutions for making decisions. Models capture the most important features of a problem and present them in a form that is easy to interpret. Models often provide insights that intuition alone cannot. An optimization model has three major elements: decision variables, constraints, and an objective. In short, the optimization methodology finds the best combination or permutation of decision variables (e.g., which products to sell and which projects to execute) such that the objective is maximized (e.g., in revenues and net income) or minimized (e.g., in risk and costs) while still satisfying the constraints (e.g., budget, schedule, and resources).

As discussed, obtaining optimal values generally requires a search in an iterative or ad hoc fashion. Such searches involve running one iteration or test for a set of values, analyzing the results, then proceeding to change one or more values, rerunning the model, and repeating the entire process until you find a satisfactory solution. The approach is very tedious and time consuming, and it is often not clear how to adjust the values from one iteration to the next.

A more rigorous method systematically enumerates all possible alternatives. This approach guarantees optimal solutions if the model is correctly specified. Suppose that an optimization model depends on only two decision variables. If each variable has 10 possible values, trying each combination requires 100 iterations (10 × 10). If each iteration is very short (e.g., 2 seconds), then the entire process could be done in approximately 3 minutes of computer time.

However, instead of two decision variables, consider six, then consider that trying all combinations requires 1,000,000 iterations ($10^6$ alternatives). Complete enumeration can easily take weeks, months, or even years to carry out (Mun, 2015). The timing of course also depends on the complexity of the model, the number of objectives and constraints interacting, as well as exogenous impacts such as a simulation of the input variables (e.g., dynamic and stochastic optimization). Adding more complexity will generally add more computational time. (Mun [2015] shows more detailed explanations of how the computational time is computed and how it can increase exponentially.)

To run the analysis, we use the *Portfolio Optimization* tool in the ROV PEAT (Real Options Valuation Project Economics Analysis Tool) software application (courtesy of http://www.realoptionsvaluation.com). In the Portfolio Optimization section of this tool, the individual projects can be modeled as a portfolio and optimized to determine the best combination of projects for the portfolio.

The projects can be modeled as a portfolio and optimized to determine the best combination of projects for the portfolio in the *Optimization Settings* subtab. Analysts start by selecting the optimization method (Static or Dynamic Optimization). Then they select the decision variable type *Discrete Binary* (choose which Project or Options to execute with a go/no-go binary 1/0 decision) or *Continuous Budget Allocation* (returns percentage of budget to allocate to each *option* or *project* as long as the total portfolio is 100%); select the *Objective* (Max Net Present Value [NPV], Min Risk, etc.); set up any *Constraints* (e.g., budget restrictions, number of projects' restrictions, or create customized restrictions); select the options or projects to optimize/allocate/choose (default selection is *all options*); and when completed, click *Run Optimization*.

Figure 1 illustrates the *Optimization Results*, which returns the results from the portfolio optimization analysis. The main results are provided in the data grid, showing the final *Objective Function* results, final *Optimized Constraints*, and the allocation, selection, or optimization across all individual options or projects within this optimized portfolio. For instance, with the 10 independent projects (each with its own value metrics, cost, and risk parameters), we can see that if the budget is set at $2.5 million, projects 3, 7, 9, and 10 would be selected in the portfolio, constituting the best combination possible given the budgetary constraint (of course, additional constraints can be added as required). If additional funds are now available, such that the budget is $3.5 million, the program can now afford to add project 5 to the portfolio, and so forth.

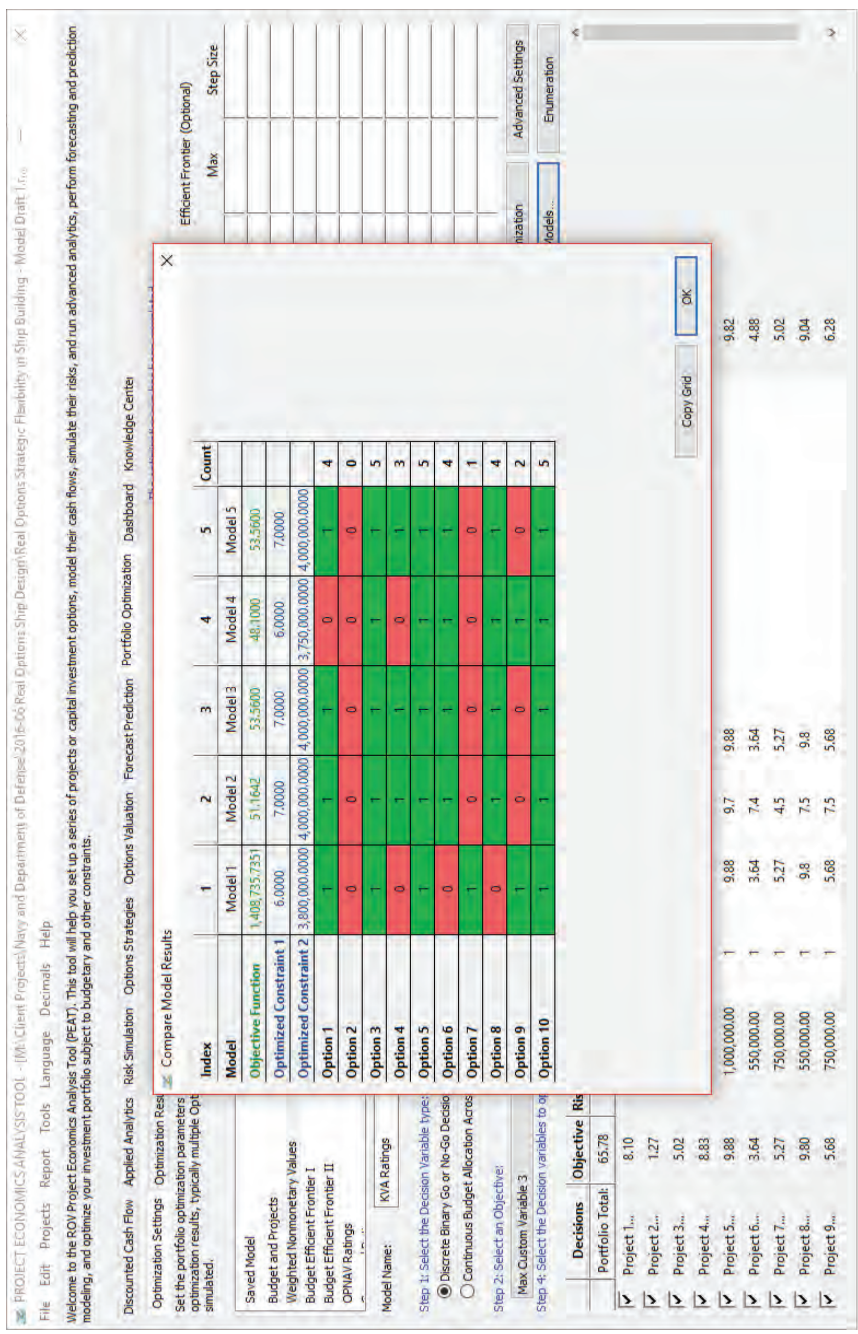
The top left portion of the screen shows the textual details and results of the optimization algorithms applied, and the chart illustrates the final objective function (the y-axis is the objective, which, in this case, is to be maximized; whereas the x-axis is the budgetary constraint, with a graduated step of $2.5 million, $3.5 million, $4.5 million, and $5.5 million). The chart shows the investment efficient frontier curve.

Figures 1 and 2 are critical results for decision makers as they allow them flexibility in designing their own portfolio of options. For instance, Figure 1 shows an efficient frontier of portfolios, where each of the points along the curve is an optimized portfolio subject to a certain set of constraints. In this example, the constraints were the number of options that can be selected in a ship and the total cost of obtaining these options, which is subject to a budget constraint. The colored columns on the right in Figure 1 show the various combinations of budget limits and maximum number of options allowed. For instance, if a program office in the Navy only allocates $2.5 million (see the Frontier Variable located on the second row) and no more than four options per ship, then only options 3, 7, 9, and 10 are feasible; and this portfolio combination would generate the biggest bang for the buck while simultaneously satisfying the budgetary and number-of-options constraints. If the constraints were relaxed to, say, five options and a $3.5 million budget, then option 5 is added to the mix. Finally, at $4.5 million and no more than seven options per ship, options 1 and 2 should be added to the mix. Interestingly, even with a higher budget of $5.5 million, the same portfolio of options is selected. In fact, the Optimized Constraint 2 shows that only $4.1 million is used. Therefore, as a decision-making tool for the budget-setting officials, the maximum budget that should be set for this portfolio of options should be $4.1 million. Similarly, the decision maker can move backwards, where, say, if the original budget of $4.5 million

was slashed by Congress to $3.5 million, then options 1 and 2 should be eliminated. While Figure 1 shows the efficient frontier where the constraints such as number of options allowed and budget were varied to determine the efficient portfolio selection, Figure 2 shows multiple portfolios with different objectives. For instance, the five models shown were to maximize the financial bang for the buck (minimizing cost and maximizing value while simultaneously minimizing risk), maximizing Naval Operations (OPNAV) value, maximizing knowledge value added (KVA), maximizing Command value, and maximizing a Weighted Average of all objectives. This capability is important because, depending on who is doing the analysis, their objectives and decisions will differ based on different perspectives. Using a multiple criteria optimization approach allows one to see the scoring from all perspectives. The option with the highest count (e.g., option 5) would receive the highest priority in the final portfolio, as it satisfies all stakeholders' perspectives and, hence, would be considered first, followed by options with counts of 4, 3, 2, and 1.

**FIGURE 1. PORTFOLIO OPTIMIZATION RESULTS**

**FIGURE 2. MULTI CRITERIA PORTFOLIO OPTIMIZATION RESULTS**



# Alternative Analytical Approaches

This section delves into some alternative analytical approaches that can be used to determine an optimal portfolio. This discussion is included to provide the reader and decision maker a better sense of what else lies beyond the realm of portfolio optimization, as well as some basic technical aspects and their pros and cons. Finally, this section suggests opportunities for future research.

## Lexicographic Average Rank for Evaluating Uncertain Multi-Indicator Matrices with Risk Metrics

In many situations, projects are characterized by several criteria or attributes that can be assessed from multiple perspectives (financial, economic, etc.). Each criterion is quantified via performance values, which can either be numerical or categorical. This information is typically structured in a multi-indicator matrix **Q**. A typical problem faced by a decision maker is to define an aggregate quality (AQ) able to synthesize the global characteristics of each project and then derive the rankings from the best to the worst base-case ranking (Mun et al., 2016). Ranking techniques can be classified as parametric and nonparametric. A parametric technique requires information about decision-maker preferences (e.g., criterion weights). According to Dorini, Kapelan, and Azapagic (2011), some examples of parametric techniques include the ELECTRE (Elimination Et Choix Traduisant la Realité or Elimination and Choice Expressing Reality) methods (Roy, 1968) and PROMETHEE—Preference Ranking Organization Methods for Enrichment Evaluations (Brans & Vincke, 1985). Nonparametric techniques, such as Partial Order Ranking (Bruggemann, Bücherl, Pudenz, & Steinberg, 1999) and Copeland Scores (Al-Sharrah, 2010), do not require information from the decision maker. In general, all of these techniques are able to produce a ranking of the alternatives from the best to the worst.

Therefore, given a matrix **Q**, the selected procedure generates a ranking, defined as the base-case rank (BCR). As a result of this assessment, for each alternative, a specific rank $R_i$ that considers the multiple perspectives defined by the decision maker is obtained. The set of $R_i$ corresponds to the global evaluation under the first synthetic attribute, defined and named as *base ranking*, and capable of characterizing the alternatives in the base case.

However, each performance value could be affected by uncertain factors. Several approaches have been presented for analyzing how the uncertainty in the performance values (the input) affects the ranking of the objects (the output; Corrente, Figueira, & Greco, 2014; Hyde & Maier, 2006; Hyde, Maier, & Colby, 2004; Rocco & Tarantola, 2014; Yu, Guikema, Briaud, & Burnett, 2012). The approaches, based on Monte Carlo simulation, consider each uncertain factor as a random variable with known probability density functions. As a result, the AQ of each alternative, and therefore its ranking, also become random variables, with approximated probability distributions. In such situations, the decision maker could perform probability distribution evaluations. For example, the decision maker could be interested in determining not only what the worst rank of a specific alternative is, but also its probability and volatility (risk evaluation).

In the standard approach, the probability of an alternative being ranked as in the BCR is selected as the synthetic attribute *probability* able to characterize the alternatives under uncertainty. The stochastic nature of the AQ of each alternative could be further assessed in order to reflect the risk evaluation induced by uncertainty. In this case, it is required to compare several random variables synthesized through their percentiles and statistical moments. Several approaches have been proposed to this end, such as a simple comparison of the expected value, the expected utility (Von Neumann & Morgenstern, 1947), the use of low order moments (Markowitz, 1952), risk measures (Jorion, 2007; Mansini, Ogryczak, & Speranza, 2007; Rockafellar & Uryasev, 2000), the Partitioned Multiobjective Risk Method (Asbeck & Haimes, 1984; Haimes 2009), and the stochastic dominance theory (Levy, 2006), among others.

Therefore, the final assessment is derived using a combined approach based on a *nonparametric aggregation rule* (using the concept of average rank) for attributes 1 and 2; a simple procedure for score assignment for attribute 3; and a *lexicographic rule*. In addition, a preliminary analysis of the alternatives is performed by using a Hasse diagram (Bruggemann & Patil, 2011). To the best of the researcher's knowledge, this type of combined assessment has not been reported in the literature.

## Average Rank Approach

Let $P$ define a set of $n$ objects (e.g., alternatives) to be analyzed and let the descriptors $q_1$, $q_2$..., $q_m$ define $m$ different attributes or criteria selected to assess the objects in $P$ (e.g., cost, availability, environmental impact). It is important that attributes are defined to reflect, for example, that a low value indicates low rankings (best positions), while a high value indicates high ranking (worst positions; Restrepo, Brüggemann, Weckert, Gerstmann, & Frank, 2008). However, for a given problem or case study, this convention could be reversed.

If only one descriptor is used to rank the objects, then it is possible to define a total order in *P*. In general, given $x, y \in P$, if $q_i(x) \leq q_i(y)\ \forall i$, then *x* and *y* are said to be comparable. However, if two descriptors are used simultaneously, the following could happen: $q_1(x) \leq q_1(y)$ and $q_2(x) > q_2(y)$. In such a case, *x* and *y* are said to be incomparable (denoted by $x||y$). If several objects are mutually incomparable, set *P* is called a partially ordered set or *poset*. Note that since comparisons are made for each criterion, no normalization is required.

A nonparametric ranking technique can be used to perform ranking decisions from the available information without using any aggregation criterion. However, while it cannot always provide a total order of objects, it does provide an interesting overall picture of the relationships among objects.

A useful approach to produce a ranking is based on the concept of the average rank of each object in the set of linear extensions of a poset (De Loof, De Baets, & De Meyer, 2011). Since the algorithms suggested for calculating such average ranks are exponential in nature (De Loof et al., 2011), special approximations have been developed, such as the Local Partial Order Model (LPOM; Bruggemann, Sorensen, Lerche, & Carlsen, 2004), the extended LPOM (LPOMext; Bruggemann & Carlsen, 2011), or the approximation suggested by De Loof et al. (2011).

From the Hasse diagram, several sets can be derived (Bruggemann & Carlsen, 2011). If $x \in P$,

1. $U(x)$, the set of objects incomparable with $x$: $U(x) := \{y \in P: x||y\}$
2. $O(x)$, the *down* set: $O(x) := \{y \in P: y \leq x\}$
3. $S(x)$, the successor set: $S(x) := O(x) - \{x\}$
4. $F(x)$, the *up* set: $F(x) := \{y \in P: x \leq y\}$

Then, the following average rank indices are defined:

a. $LPOM(x) = (|S(x)| + 1) \times (n + 1) \div (n + 1 - |U(x)|)$

b. $LPOMext(x) = |O(x)| + \sum_{y \in U(x)} \frac{p_y^<}{p_y^< + p_y^>}$

where $n$ is the number of objects,

$|V|$ defines the cardinality of the set $V$,

$p_y^< = |O(x) \cap U(y)|$, $p_y^> = |F(x) \cap U(y)|$, and $y \in U(x)$

## Lexicographic Approach

A lexicographic approach allows decision makers to introduce decision rules in which they select more objects impacting on their most-preferred criteria. According to Saban and Sethuraman (2014), when two objects have the same impact on the most-preferred criteria, decision makers prefer the one with the highest impact on the second most-preferred criteria, and so forth. This lexicographic representation models the problems where decision makers strictly prefer one criterion over another or they are managing noncompensatory aggregation (Pulido, Mandow, & de la Cruz, 2014; Yaman, Walsh, Littman, & Desjardins, 2011).

Finally, decision makers can model their strong preferences over the criteria selected mainly because, after further analysis of the problem, they are not indifferent or only weakly sure about their preferences on the criteria taken into consideration. In other words, they will always prefer one criterion to another without considering criterion weights explicitly.

## Risk Metrics and Compliance

Risk metrics are statistical indicators or measurements that allow decision makers to analyze the dispersion (volatility) of certain events or outcomes. Hence, a random variable can be evaluated using statistical moments (e.g., mean, variance, skewness, kurtosis), or risk measurements can be used to analyze extreme values, such as Value at Risk (VaR) and Conditional VaR (Bodie, Kane, & Marcus, 2009; Fabozzi, 2010; Matos, 2007; Mun, 2015).

In decision problems, risk metrics play an important role in analyzing the volatility or stability of a set of options or a portfolio of alternatives, for example, in financial risk management (Chong, 2004), portfolio risk management (Bodie et al., 2009), and enterprise risk management (Scarlat, Chirita, & Bradea, 2012), as well as a variety of other areas (Fabozzi, 2010; Szolgayová, Fuss, Khabarov, & Obersteiner, 2011).

In order to determine how risky an object is and its relationship with other objects, a compliance approach is followed, that is, the definition of a set of rules to guide decision makers (Hopkins, 2011). Various analysts have proposed several approaches for assessing compliance. For example, Barrett and Donald (2003) propose a stochastic dominance analysis to compare probability distributions before establishing a hierarchy; Boucher, Danielsson, Kouontchou, and Maillet (2014) rely on risk metrics and forecasting to adjust models by historical performance; and Zanoli, Gambelli, Solfanelli, and Padel (2014) analyze impacts of risk factors on noncompliance in UK farming.

The compliance approach is more user-friendly for decision making because it allows evaluating whether an object performs according to decision-makers' preferences over defined risk metrics. The basic idea is to dichotomize the risk continuum (Hopkins, 2011). Therefore, the higher the compliance with a defined risk metric, the higher the alignment with the decision-makers' preferences. Similar approaches are considered by Scarlat et al. (2012) and Tarantino (2008) relying on key risk indicators.

## Multicriteria Analysis

In addition to uncertainty and flexibility, another complexity appears when decision makers need to introduce potentially conflicting decision criteria (quantitative or qualitative, monetary and nonmonetary) into project management. Such complexity might include legal (taxes, compliance, social responsibility, etc.), environmental (level of pollution, noise, watershed issues, etc.), economic (level of economic growth, national income, inflation, unemployment, etc.), and social (number of employees, value to society, safety and security, community development). Furthermore, those criteria might have different relative importance or weights.

To address this concern, multicriteria analysis (MCA) has become a powerful mechanism to handle multidimensional problems and to obtain an AQ supporting the final decision (Bouyssou, Marchant, Pirlot, Tsoukias, & Vincke, 2006; Brito, de Almeida, & Mota, 2010). MCA refers to a set of methods, techniques, and tools that help people with their decision problems (description, clustering, ranking, and selection) by simultaneously considering more than one objective or criterion (Afsordegan, Sánchez, Agell, Zahedi, & Cremades, 2016; Ghafghazi, Sowlati, Sokhansanj, & Melin, 2010; Kaya & Kahraman, 2011; Roy, 1996).

PROMETHEE (Behzadian, Kazemzadeh, Albadvi, & Aghdasi, 2010; Brans & Mareschal, 2005; Goumas & Lygerou, 2000; Tavana, Behzadian, Pirdashti, & Pirdashti, 2013) has been proposed as a proper MCA technique. PROMETHEE methods are based on outranking the relationship *S*. This concept does not determine if the relationship among two alternatives *a* and *b* is a strong preference (*a P b*), weak preference (*a Q b*), or indifference (*a I b*), but instead it establishes if "the alternative *a* is at least as good as the alternative *b*" (Brans & Mareschal, 2005).

PROMETHEE methods are suitable because of their theoretical and practical advantages. For instance, they can associate to each project an AQ index that maximizes the available information in terms of decision-makers' preferences over the criteria selected, as well as the preferences' intensities among alternatives and the nature of each criteria (Bouyssou et al., 2006).

Other methods could also be allowed to handle this multicriteria approach, for example, the ELECTRE methods (Bouyssou et al., 2006), the Analytical Hierarchy Process (Desai, Bidanda, & Lovell, 2012; Saaty, 2013), MACBETH, or Measuring Attractiveness Through a Categorical-Based Evaluation Technique (Cliville, Berrah, & Mauris, 2007; Costa, De Corte, & Vansnick, 2012), and TOPSIS, or Technique for Order of Preference by Similarity to Ideal Solution (Kaya & Kahraman, 2011; Sakthivel, Ilangkumaran, Nagarajan, & Shanmugam, 2013), to name some. However, these other methods do not clearly state the advantages aforementioned, and the AQ is difficult to interpret.

## Capital Budgeting and Portfolio Optimization in DoD

Just as alternative analytical approaches exist, there are also alternative value measures, depending on the stakeholder, organization, and application. For instance, in the DoD, the concept of value is difficult to grasp in some situations and operations that involve purely logistical support, mission readiness, or dependability. This section therefore provides some alternative measures that can be used in lieu of a strict financial or economic value. Clearly, within the DoD there are other inherent competing and overriding criteria, including but not limited to domain requirements (sea, air, land, subsurface), symmetric vs. asymmetric warfare, informational warfare, peacekeeping, humanitarian missions, deterrence, drug interdiction, and others. These specialized areas' outputs can be obtained using a Delphi method to solicit SME opinions, and their metrics can be obtained and used in the optimization models. Therefore, the portfolio optimization approach introduced can be similarly applied regardless of the metric selected.

## Operational and Logistics Metrics

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

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

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

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

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

  $$MR = ORR * IR$$

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

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

- **Mean Down Time** (MDT), **Mean Maintenance Time** (MMT), **Logistics Delay Time** (LDT), and their combinations.

- **Achieved Availability** (AA), **Operational Availability** (OA), **Mission Availability** (MA).

## Financial and Economic Metrics

- **Cost Deterrence and Avoidance.** Soft or shadow-revenue (cost savings) over the economic and operational life of the program or system. Milestones A, B, C.

- **Traditional Financial Metrics. Net Present Value** (NPV), **Internal Rate of Return** (IRR), **Return on Investment** (ROI), and other metrics, as long as there are financial and monetary values.

- **Budget Constraint.** Fiscal Year (FY) budget limitations and probabilities of budgetary overruns.
- **Total Ownership Cost (TOC)** and **Total Lifecycle Cost (TLC).** Accounting for the cost of developing, producing, deploying, maintaining, operating, and disposing of a system over its entire lifespan. Uses Work Breakdown Structures (WBS), Cost Estimating Categories (CEC), and Cost Element Structures (CES).
- **Knowledge Value Added (KVA).** Monetizing Learning Time, Number of Times Executed, Automation, Training Time, and Knowledge Content.
- **Strategic and Capability.** Multiple value metrics can be determined from SMEs: Expected Military Value and Strategic Value.

### Future Weapon Strategy Metrics

**Capability Measures** (CM). Difficult to quantify and need SME judgment: Innovation Index, Conversion Capability, Ability to Meet Future Threats; Force Structure (size/units), Modernization (technical sophistication), Combat Readiness, Sustainability; Future Readiness (ability to meet evolving threats, ability to integrate future weapon systems).

### Domain Capabilities (DC)

Portfolios are divided into different domains, and each domain is optimized separately and then combined into the enterprise level and re-optimized; example domains include Coastal Defense, Anti-Air Surface Warfare, Anti-Surface Warfare, Anti-Submarine Warfare, Naval Strike, Multi-Mission Air Control, Sea Control, Deep Strike, Missile Defense, and so on. Constraints can be added whereby each domain needs to have a minimum amount of capability or systems, and within each domain, different "value" parameters can be utilized.

## Optimization Application at PEO-IWS and NAVSEA

The following is a case illustration of portfolio optimization. The values and variables shown are nominal and used for illustration only; they should not and have not been used for making any actual decisions. Nonetheless, all that has to be done in any future real-life applications is to change the names of these options and the values. The analytical process and portfolio methodology remain the same.

The Program Executive Office–Integrated Warfare Systems (PEO-IWS) at the DoD engaged a graduate student team from the Naval Postgraduate School to conduct a study to apply the Integrated Risk Management (IRM) method to estimate the value stream and cost savings in its Advanced Concept Build (ACB) for Navy ships, and to provide a set of solid recommendations to its multiple stakeholders going forward. Every few years, Navy destroyers will receive ACB updates to the Aegis ship defense system. These updates include basic hardware enhancement, but they are mostly software patches and updates for their various capabilities (e.g., ballistic missile defense [BMD] systems, or BMD 5.X; carry-on cryptologic programs, or CCOPS; weather sensor algorithm updates, or Weather NOW; and many others). The issue is that there are more ACB capabilities than money available to fund them. The cost to implement new ACB updates can be rather high, and sometimes there are several implementation paths or strategic options to consider in each ACB capability. The task is to model each of these approaches and provide an assessment and recommendation of the best path forward. By modeling each capability, analysts can then recommend the best combinatorial portfolio that maximizes the utility to the Navy, both monetary (cost savings, KVA analysis, benefits) and nonmonetary (OPNAV leadership requirements, force readiness, systems integration, obsolescence, etc.).

One of the modeling problems is that the DoD is not in the business of selling its products and services, and, consequently, obtaining a solid set of revenues would prove to be difficult. In such situations, one can resort to using KVA analysis or cost savings approaches. KVA allows us to generate market comparables as proxy variables to determine a shadow price and provide comparable *revenues*. Alternatively, cost savings, or the amount of money that would not have to be spent, can similarly be used as proxy for benefits or revenues in a discounted cash flow model. In addition, there might be competing stakeholders and requirements. For instance, BMD 5.X is very expensive, provides low cost savings (monetary benefits), and is not used often (sometimes not used at all between ACB cycles), but OPNAV and the Office of the Chief of Naval Operations may want this update to maintain readiness for the fleet and see this upgrade as critical. These considerations need to be modeled.

To summarize, this case illustration requires the following assumptions:

- Each of these ACB capabilities was modeled and compared as a portfolio of static NPV, IRR, ROI, and so forth.

- Using the ROV PEAT software, Monte Carlo risk simulations were run on the main inputs based on the *Air Force Cost Analysis Agency Handbook (AFCAA Handbook)* and used to interpret the dynamic results.
- Portfolio optimization algorithms were run using budgetary and project constraints, and efficient frontier analyses based on changing budgets were then executed. Finally, OPNAV requirements, KVA valuation, and other noneconomic military values were used to run multi-criteria portfolio optimizations.

The following are the parameters of the ACB program under consideration:

For all models, we assumed a 10-year time horizon for the cost savings (all future savings past Year 10 after discounting will be assumed to be negligible). The discounting base year is 2017 (Year 0 and Capital Investment is required in 2017), whereas immediate savings and short-term benefits and maintenance savings start in Year 1 (2018). This means Year 10 is 2027.

  - The following Table shows the remaining relevant information needed to run the models. "Savings Now" is the immediate monetary cost savings benefits obtained by implementing the new upgraded system (e.g., lower overhead requirements, reduced parts and labor requirements). This amount is applied in the first year of the cash flow stream only (Year 1 or 2018), as its effects are deemed to be immediate.

**TABLE. REMAINING RELEVANT INFORMATION NEEDED TO RUN ALL PORTFOLIO OPTIMIZATION MODELS**

| Capability Acronym | Savings Now | Short-Term Benefits | Maintenance Savings | Capital Cost | Fixed Cost | Operating Cost | OPNAV Value | Command Value | KVA Value |
|---|---|---|---|---|---|---|---|---|---|
| **MH-60R** | $550 | $30 | $60 | $400 | $3 | $2 | 8.1 | 1.2 | 9.11 |
| **CCOPS** | $650 | $5 | $10 | $300 | $3 | $2 | 1.27 | 2.5 | 1.43 |
| **Weather** | $700 | $35 | $10 | $350 | $3 | $2 | 5.02 | 7.5 | 5.65 |
| **SSDS** | $1,000 | $50 | $20 | $600 | $3 | $2 | 8.83 | 4.5 | 9.93 |
| **BMD** | $2,000 | $100 | $20 | $1,000 | $3 | $2 | 9.88 | 9.7 | 11.11 |
| **NIFC-CA** | $1,000 | $10 | $20 | $550 | $3 | $2 | 3.64 | 7.4 | 4.09 |
| **SPQ-9B** | $2,000 | $100 | $20 | $750 | $3 | $2 | 5.27 | 4.5 | 5.93 |
| **CIWS-CEC** | $850 | $75 | $20 | $550 | $3 | $2 | 9.8 | 7.5 | 11.02 |
| **RDDL** | $1,500 | $125 | $20 | $750 | $3 | $2 | 5.68 | 7.5 | 6.39 |
| **SM-2 BLK** | $1,000 | $125 | $20 | $550 | $3 | $2 | 8.29 | 8.5 | 9.33 |

***Note.*** All monetary values are in thousands of dollars.

- "Short-Term Benefits" is the savings per year for the first 5 years, stemming from reduction in staffing requirements, but these savings are deemed to be reabsorbed later on. Savings apply from 2018 to 2022.
- "Maintenance Savings" is the savings each year for all 10 years, starting in 2018, where system maintenance cost is reduced and saved.
- "Capital Cost" is applied in Year 0 or 2017 as a one-time capital expenditure.
- Assume a "Fixed [Direct] Cost" and constant "[Indirect] Operating Cost" per year for all 10 years starting in 2018. The new equipment upgrades will require some fixed overhead cost and operating expenses to maintain. The idea is that these will be less than the total sum of benefits obtained by implementing the capability.

    - Value metrics on Innovation, Capability, Time to Intercept, Warfighting Impact, Health, and Execution were compiled with the help of SMEs, and these values are weighted and summarized as "OPNAV" (Innovation, Capability, and Execution Health) and "Command" (Time to Intercept and Warfighting Impact) variables. These are weighted average values of multiple SMEs' estimates of the criticality (1–10, with 10 being the highest) of each capability. "KVA" is unit equivalence (this can be multiplied by any market price comparable such as $1 million per unit or used as-is in the optimization model). These will be used later in the optimization section that follows.

- Tornado analysis was run using ROV PEAT.

- The *AFCAA Handbook* recommendations for uncertainty and risk distributions were used, with the following parameters for simulation:

    - Savings Now and Capital Investment inputs were set using Triangular distributions based on the risk and uncertainty levels perceived by the SMEs, or they can be based on a fitting of historical data.

    - Run 10,000 to 1,000,000 simulation trials.

    - The multiple simulated distributions' results were compared using Overlay Charts and Analysis of Alternatives.

- Finally, multiple portfolio optimization models were run in this case illustration using the following parameters:

    - Constraints for the portfolio optimization were a $4,000,000 budget and less than or equal to 7 Opportunities. The portfolio's NPV was maximized.

    - Investment Efficient Frontier was run between $2,500,000 and $5,500,000 with a step of $1,000,000 and no more than 7 Opportunities. The portfolio's NPV was maximized.

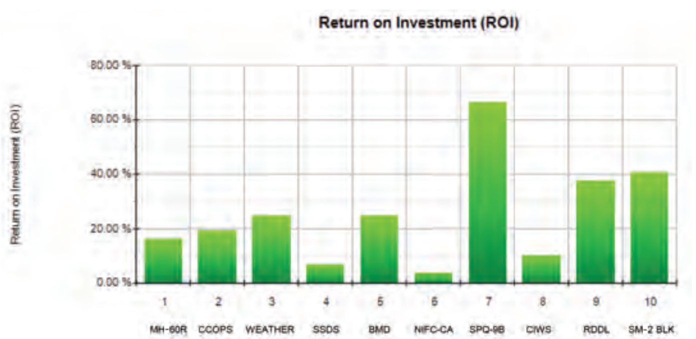
    - Another Investment Efficient Frontier was run between $2,500,000 and $5,000,000 with a step of $500,000 and no more than 7 Opportunities. The portfolio's NPV was maximized.

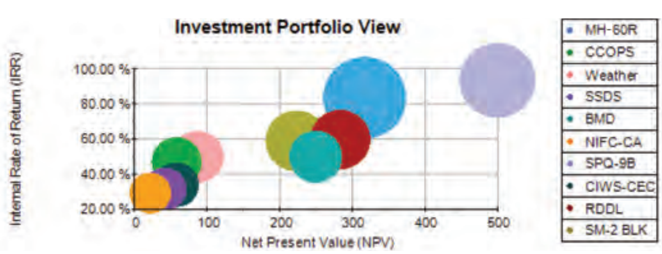
- Finally, a series of portfolios using the nonmonetary, noneconomic military OPNAV, COMMAND, and KVA estimates was applied in the portfolio model but using budgetary constraints. The relevant custom military values and their weighted average values for the portfolio were maximized.

Figure 3 shows the results of a capital budgeting analysis. The 10 programs under consideration were evaluated based on their financial and economic viability. The standard economic metrics such as NPV, IRR, MIRR, ROI, and others are shown. The bar chart provides a visual representation of one of the metrics, whereas the bubble chart shows multiple result metrics at once (e.g., the NPV on the x-axis and the IRR on the y-axis, and size represents NPV with Terminal Value). In this chart, the large-ball programs on the top far right of the chart would be better ranked than smaller ball projects on the bottom left.

**FIGURE 3. CAPITAL BUDGETING RESULTS COMPARISON**

| Economic Results | MH-60R | CCOPS | Weather | SSDS | BMD | NIFC-CA | SPQ-9B | CIWS-CEC | RDDL | SM-2 BLK |
|---|---|---|---|---|---|---|---|---|---|---|
| Net Present Value (NPV) | 66,086.45 | 58,344.30 | 86,785.26 | 42,214.01 | 249,615.61 | 22,292.73 | 499,615.61 | 57,914.81 | 283,316.41 | 223,316.41 |
| Net Present Value (NPV) with Terminal Value | 83,109.93 | 59,891.88 | 88,332.84 | 46,856.77 | 254,258.37 | 26,935.49 | 504,258.37 | 62,557.57 | 287,959.17 | 227,959.17 |
| Internal Rate of Return (IRR) | 36.02% | 47.04% | 49.72% | 31.53% | 49.84% | 29.20% | 93.31% | 33.94% | 59.65% | 58.85% |
| Modified Internal Rate of Return (MIRR) | 26.93% | 27.24% | 27.80% | 25.85% | 27.82% | 25.50% | 31.55% | 26.26% | 29.07% | 29.33% |
| Profitability Index (PI) | 1.17 | 1.19 | 1.25 | 1.07 | 1.25 | 1.04 | 1.67 | 1.11 | 1.38 | 1.41 |
| Return on Investment (ROI) | 16.52% | 19.45% | 24.80% | 7.04% | 24.96% | 4.05% | 66.62% | 10.53% | 37.78% | 40.60% |
| Payback Period (PP) | 0.9691 | 0.6993 | 0.7277 | 0.8667 | 0.7274 | 0.8255 | 0.5456 | 0.9002 | 0.7036 | 0.7422 |
| Discounted Payback Period (DPP) | 3.2718 | 0.8741 | 0.9096 | 2.8857 | 0.9093 | 2.7933 | 0.6819 | 2.7933 | 0.8795 | 0.9278 |




According to the analysis, the top five recommended ACB capabilities based on Static Portfolio Analysis are SPQ-9B, SM-2 BLK, MH-60R, BMD, and RDDL. Figure 4 shows a summary of the ranking. Three main distinctions are the following:

- The highest NPV belongs to SPQ-9B.
- Middle range NPVs belong to BMD, RDDL, and SM-2 BLK.
- The lowest range of NPVs belongs to MH-60R, CCOPS, Weather, SSDS, NIFC-CA, and CIWS-CEC.

**FIGURE 4. PROGRAM RANKINGS**

| PEAT NPV Probabilities | |
|---|---|
| 100% | SPQ-9B |
| 99.94% | SM-2 BLK |
| 99.62% | RDDL |
| 97.61% | Weather |
| 95.41% | BMD |
| 89.90% | MH-60R |
| 89.37% | CCOPS |
| 77.58% | CIWS-CEC |
| 70.11% | SSDS |
| 61.34% | NIFC-CA |

This distinction is generally true for all other metrics. Data from all metrics are compared to create a numerical ranking from key figures. Although not black and white, this linear ranking helps in decision-making comparative analysis. Figure 5 shows the Probability Density Function (PDF) Curve Overlay where all the programs' simulation results are overlaid on top of each other. Only the SPQ-9B has a positive NPV across all trials. This finding is consistent with the results of the ACB Capability Comparison.

**FIGURE 5. COMPARISON OF SIMULATED NPV PROBABILITY DISTRIBUTIONS**

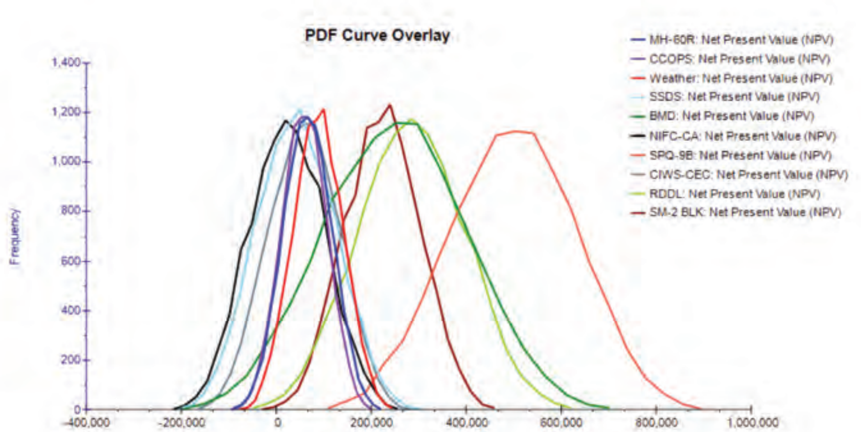


Figure 6 shows the probability of success of each program. These are currently based on using NPV, but can be applied to any noneconomic variable. The definition used here is the probability (PROB) of NPV > 0. Based on the values, (1 – PROB)% is the probability of failure.

**FIGURE 6. ECONOMIC PROBABILITY OF SUCCESS**

| NPV | | ROI | | ROI | |
|---|---|---|---|---|---|
| RANK | PROJECT | RANK | PROJECT | RANK | PROJECT |
| 1 | SPQ-9B | 1 | SPQ-9B | 1 | SPQ-9B |
| 2 | RDDL | 2 | SM-2 BLK | 2 | CCOPS |
| 3 | BMD | 3 | RDDL | 3 | RDDL |
| 4 | SM-2 BLK | 4 | BMD | 4 | BMD |
| 5 | Weather | 5 | Weather | 5 | Weather |
| 6 | MH-60R | 6 | CCOPS | 6 | SM-2 BLK |
| 7 | CCOPS | 7 | MH-60R | 7 | NIFC-CA |
| 8 | CIWS-CEC | 8 | CIWS-CEC | 8 | SSDS |
| 9 | SSDS | 9 | SSDS | 9 | CIWS-CEC |
| 10 | NIFC-CA | 10 | NIFC-CA | 10 | MH-60R |

Figure 7 shows the results of Portfolio Optimization 1, which assumes a budget of $4.0 million, Portfolio Size ≤ 7, and the goal of Maximizing Portfolio NPV. In this simple optimization, the model recommends excluding CCOPS, SSDS, NIFC-CA, and CIWS-CEC from the portfolio. Figure 8 shows Portfolio Optimization 2, which runs an Investment Efficient Frontier. It assumes a budgetary range of $2.5–$5.0 million with a step size of $500,000. It also assumes a Portfolio Size ≤ 7 and the explicit goal of Maximizing Portfolio NPV. Weather, SPQ-9B, RDDL, and SM-2 BLK were consistently in the optimal portfolio. Based on budget, other capabilities were recommended. Above $4.5 million, the portfolio remains unchanged.

**FIGURE 7. PORTFOLIO OPTIMIZATION 1**

| | |
|---|---|
| Objective Function | 1,408,736 |
| Optimized Constraint 1 | 7.0000 |
| Optimized Constraint 2 | 3,800,000 |
| MH60R | 1 |
| CCOPS | 0 |
| Weather | 1 |
| SSDS | 0 |
| BMD | 1 |
| NIFC-CA | 0 |
| SPQ-9B | 1 |
| CIWS-CEC | 0 |
| RDDL | 1 |
| SM-2BLK | 1 |

**FIGURE 8. PORTFOLIO OPTIMIZATION 2**

| Objective Function | 1,093,034 | 1,159,120 | 1,342,649 | 1,408,736 | 1,467,080 | 1,467,080 |
|---|---|---|---|---|---|---|
| Frontier Variable | 2,500,000 | 3,000,000 | 3,500,000 | 4,000,000 | 4,500,000 | 5,000,000 |
| Optimized Constraint | 2,400,000 | 2,800,000 | 3,400,000 | 3,800,000 | 4,100,000 | 4,100,000 |
| MH60R | 0 | 1 | 0 | 1 | 1 | 1 |
| CCOPS | 0 | 0 | 0 | 0 | 1 | 1 |
| Weather | 1 | 1 | 1 | 1 | 1 | 1 |
| SSDS | 0 | 0 | 0 | 0 | 0 | 0 |
| BMD | 0 | 0 | 1 | 1 | 1 | 1 |
| NIFC-CA | 0 | 0 | 0 | 0 | 0 | 0 |
| SPQ-9B | 1 | 1 | 1 | 1 | 1 | 1 |
| CIWS-CEC | 0 | 0 | 0 | 0 | 0 | 0 |
| RDDL | 1 | 1 | 1 | 1 | 1 | 1 |
| SM-2BLK | 1 | 1 | 1 | 1 | 1 | 1 |

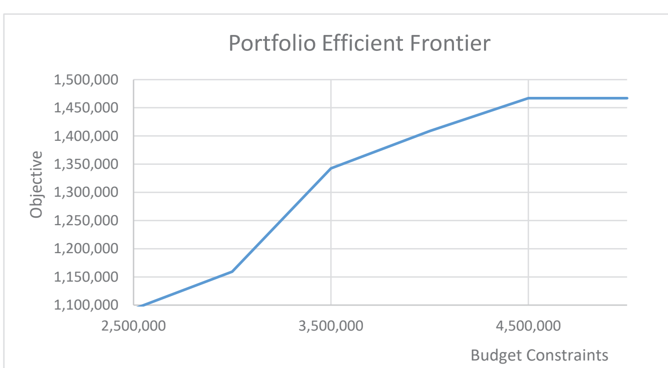



Figure 9 shows the results for OPNAV, Optimization 3. Similar results were run on COMMAND and KVA objectives. OPNAV Value is a combination of SMEs' assessments of Innovation, Capability, and Execution Health metrics. Command Value is the SMEs' assessments of Time to Intercept and Warfighting Impact.

**FIGURE 9. PORTFOLIO OPTIMIZATION 3 (OPNAV)**

| Objective Function | 40.04 | 43.68 | 49.92 | 53.56 | 56.87 | 60.87 | 64.51 |
|---|---|---|---|---|---|---|---|
| Frontier Variable | 2,500,000 | 3,000,000 | 3,500,000 | 4,000,000 | 4,500,000 | 5,000,000 | 5,500,000 |
| Optimized Constraint | 2,450,000 | 3,000,000 | 3,450,000 | 4,000,000 | 4,500,000 | 4,950,000 | 5,500,000 |
| MH60R | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CCOPS | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Weather | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SSDS | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| BMD | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| NIFC-CA | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| SPQ-9B | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| CIWS-CEC | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| RDDL | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| SM-2BLK | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Figure 10 (Optimization 7) shows a combined view where multiple optimizations were run and compared against one another. Additional constraints can be added as needed, but the case illustration applies a $4 million budget, and no more than seven programs can be chosen at a time. In other words, the following monetary and nonmonetary portfolios were optimized:

- Model 1—Maximize Monetary Values (NPV)
- Model 2—Maximize OPNAV Value (i.e., SMEs' assessments of Innovation, Capability, and Execution Health)
- Model 3—Maximize All Weighted Average Nonmonetary Values (this is a percentage weighted average of all nonmonetary military values that are part of the OPNAV and COMMAND variables, as well as any other variables of interest to senior leadership)
- Model 4—Maximize Military Command Value (i.e., SMEs' assessments of Time to Intercept and Warfighting Impact)
- Model 5—Maximize KVA Value

As seen in Figure 10, these five portfolios are combined into a matrix that shows the count of GO decisions. Clearly, for a decision maker, the lowest hanging fruits would be to execute the programs starting with the highest count. For instance, Weather, BMD, and SM-2 BLK would be considered the highest priority, as regardless of the point of view and stakeholder under consideration, these programs have always been chosen.

**FIGURE 10. PORTFOLIO OPTIMIZATION 7 (COMBINED VIEW)**

| Model | 1. NPV | 2. OPNAV | 3. W/AVG | 4. COMMAND | 5. KVA | Count |
|---|---|---|---|---|---|---|
| Objective | 1,408,735.73 | 51.16 | 53.56 | 48.10 | 53.56 | |
| Budget Constraint | 3,800,000 | 4,000,000 | 4,000,000 | 3,750,000 | 4,000,000 | |
| Program Constraint | 6 | 7 | 7 | 6 | 7 | |
| MH60R | 1 | 1 | 1 | 0 | 1 | 4 |
| CCOPS | 0 | 0 | 0 | 0 | 0 | 0 |
| Weather | 1 | 1 | 1 | 1 | 1 | 5 |
| SSDS | 0 | 1 | 1 | 0 | 1 | 3 |
| BMD | 1 | 1 | 1 | 1 | 1 | 5 |
| NIFC-CA | 0 | 1 | 1 | 1 | 1 | 4 |
| SPQ-9B | 1 | 0 | 0 | 0 | 0 | 1 |
| CIWS-CEC | 0 | 1 | 1 | 1 | 1 | 4 |
| RDDL | 1 | 0 | 0 | 1 | 0 | 2 |
| SM-2BLK | 1 | 1 | 1 | 1 | 1 | 5 |

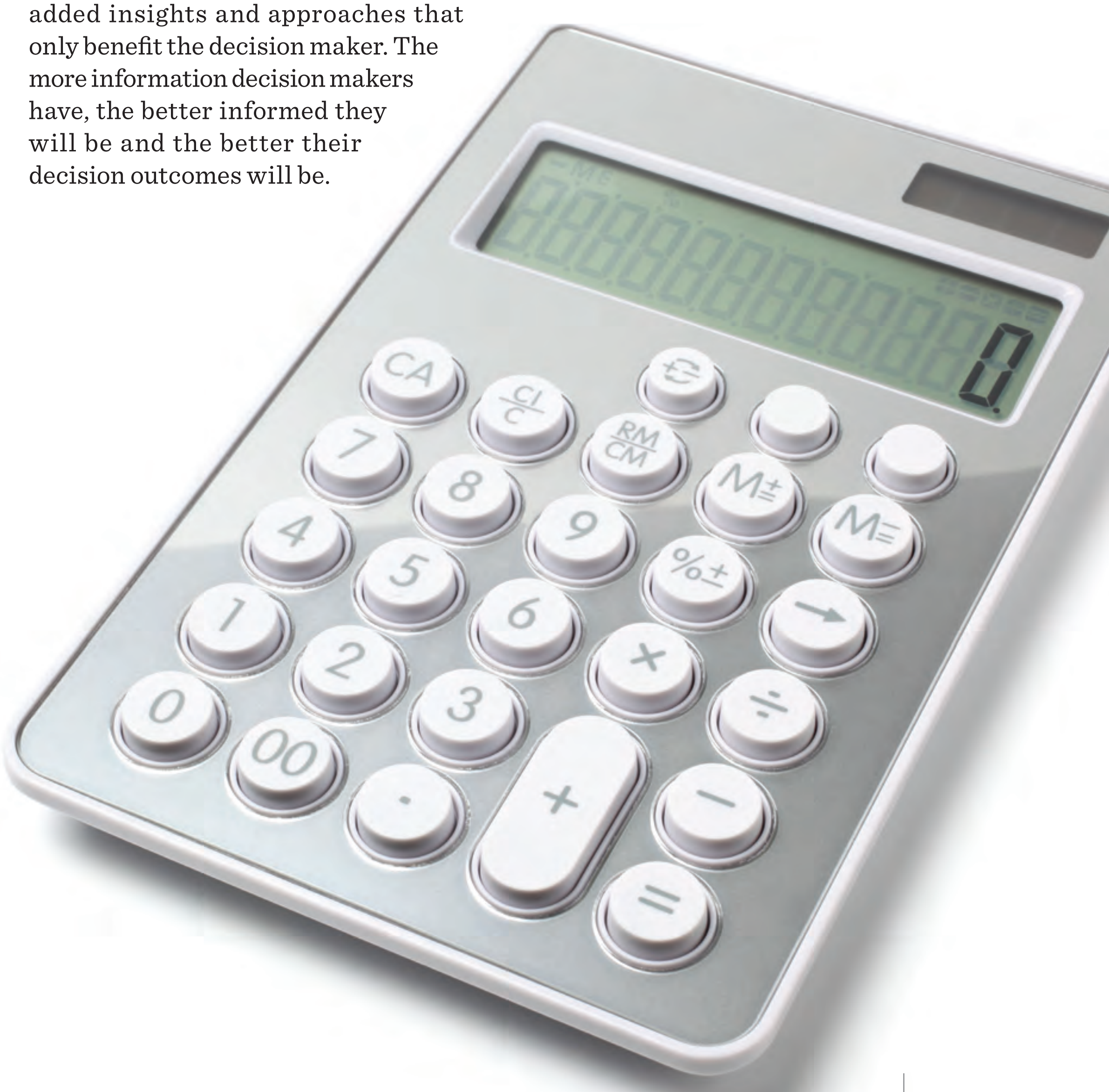
## Conclusions and Recommendations

The analytical methods illustrated in the case study apply stochastic, risk-based Monte Carlo simulations to generate tens of thousands to millions of scenarios and algorithmic portfolio optimizations by applying economic and noneconomic military values. The methods are objective, verifiable, replicable, and extensible and can be easily modified to incorporate additional constraints and limitations (e.g., manpower, force mix, minimum capability requirements, domain-specific requirements, cross-domain needs, etc.).

The author recommends that any follow-on research incorporate the following items:

- Apply the methods to actual programs with real-life data and assumptions, with SME or subject matter estimates.
- Create new or evaluate existing concepts of military value. These will incorporate:
  - Data validity tests using applied statistical tests (from basic linear and nonlinear correlations to econometric models and nonparametric hypothesis tests). These are applied over time to identify if the collected data are valid and actually describe what the researcher wants or expects the data to describe. In other words, are the collected data valid, accurate, and precise?
  - Big data analysis—trying to find patterns and analytical relationships in large data sets.
  - Historical data to perform backcasting (backtesting historical data to known historical events).
  - Tweaking and creating lighthouse events and programs in the past, assigning critical value metrics to these events and programs, and using these as guideposts for generating future SME estimates.
  - Creating more exact definitions and methods for SME assumptions that allow for collecting a more objective and defensible data set.
- Utilize multiobjective optimization. Interdependencies and competing stakeholder needs (e.g., Congress versus Office of the Secretary of Defense and other external stakeholders) need to be considered. These competing objectives need to be reconciled to determine a Pareto optimal portfolio.
- Evaluate analytical hierarchical processes, multiobjective optimization, and other algorithms and compare the results.
- Within the portfolio, model and account for risks of cost and budget overruns as well as delivery delays using risk-based simulations.

To summarize, based on the research performed thus far, the researcher concludes that the methodology has significant merits and is worthy of more detailed follow-on analysis. It is therefore recommended that the portfolio optimization methodology outlined in this research be further applied on various cases facing the U.S. Navy and DoD in general, using actual data and tracking the project's outcomes over time. The approach described does not necessarily have to be performed in lieu of existing methods, but in conjunction with them. What the DoD currently does is correct and relevant, and this article only suggests additional value-added insights and approaches that only benefit the decision maker. The more information decision makers have, the better informed they will be and the better their decision outcomes will be.



## References

Afsordegan, A., Sánchez, M., Agell, N., Zahedi, S., & Cremades, L. (2016). Decision making under uncertainty using a qualitative TOPSIS method for selecting sustainable energy alternatives. *International Journal of Environmental Science and Technology, 13*(6), 1419–1432.

Al-Sharrah, G. (2010). Ranking using the Copeland Score: A comparison with the Hasse Diagram. *Journal of Chemical Information and Modeling, 50*(5), 785–791.

Asbeck, E., & Haimes, Y. Y. (1984). The partitioned multiobjective risk method. *Large Scale Systems, 6*(1), 13–38.

Barrett, G. F., & Donald, S. G. (2003). Consistent tests for stochastic dominance. *Econometrica, 71*(1), 71–104.

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research, 200*(1), 198–215.

Bennett, S. (2017, July 13). Optimization aids in quest for government efficiency. *Federal News Network*. Retrieved from https://federalnewsradio.com/commentary-analysis/2017/07/optimization-aids-in-the-quest-for-government-efficiency/

Bodie, Z., Kane, A., & Marcus, A. J. (2009). *Investments* (8th ed.). New York, NY: McGraw-Hill.

Boucher, C. M., Danielsson, J., Kouontchou, P. S., & Maillet, B. B. (2014). Risk models-at-risk. *Journal of Banking and Finance, 44*(C), 72–92.

Bouyssou, D., Marchant, T., Pirlot, M., Tsoukias, A., & Vincke, P. (2006). *Evaluation and decision models with multiple criteria* (Operational Research and Management Sciences). New York, NY: Springer's International Series.

Brans, J. P., & Mareschal, B. (2005). Multicriteria decision aid. The PROMETHEE-GAIA solution in multiple criteria decision analysis: State of the art surveys. *International Series in Operations Research & Management Science, 78*, 163–186.

Brans, J. P., & Vincke, P. H. (1985). A preference ranking organization method: The PROMETHEE method for multiple criteria decision making. *Management Science, 31*(6), 647–656.

Brito, A. J., de Almeida, A. T., & Mota, C. M. M. (2010). A multicriteria model for risk sorting of natural gas pipelines based on ELECTRE TRI integrating utility theory. *European Journal of Operational Research, 200*(3), 812–821.

Bruggemann, R., Bücherl, C., Pudenz, S., & Steinberg, C. (1999). Application of the concept of partial order on comparative evaluation of environmental chemicals. *Acta hydrochimica et hydrobiologica, 27*(3), 170–178.

Bruggemann, R., & Carlsen, L. (2011). An improved estimation of averaged ranks of partial orders. *MATCH Communications in Mathematical and in Computer Chemistry, 65*, 383–414.

Bruggemann, R., & Patil, G. (2011). Multicriteria prioritization and partial order in environmental sciences. *Environmental and Ecological Statistics, 17*(4), 383–410.

Bruggemann, R., Sorensen, P., Lerche, D., & Carlsen, L. (2004). Estimation of averaged ranks by a local partial order model. *Journal of Chemical Information and Computer Sciences, 44*(2), 618–625.

Burk, R. C., & Parnell, G. S. (2011). Portfolio decision analysis: Lessons from military applications. In A. Salo, J. Keisler, & A. Morton (Eds.), *Portfolio decision analysis* (pp. 333–357). New York, NY: Springer.

Chong, Y. Y. (2004). *Investment risk management.* Oxford, UK: John Wiley & Sons.

Cliville, V., Berrah, L., & Mauris, G. (2007). Quantitative expression and aggregation of performance measurements based on the MACBETH multi-criteria method. *International Journal of Production Economics, 105*(1), 171–189.

Corrente, S., Figueira, J. R., & Greco, S. (2014). The SMAA-PROMETHEE method. *European Journal of Operational Research, 239*(2), 514–522.

Costa, C., De Corte, J. M., & Vansnick, J. C. (2012). MACBETH. *International Journal of Information Technology & Decision Making, 11*(2), 359–387.

Davendralingam, N., & DeLaurentis, D. (2015, May). A robust portfolio optimization approach to system of system architectures. *Systems Engineering, 18*(3), 269–283.

De Loof, K., De Baets, B., & De Meyer, H. (2011). Approximation of average ranks in posets. *MATCH Communications in Mathematical and in Computer Chemistry, 66*(1), 219–229.

Department of Defense. (2005). *Information technology portfolio management* (DoDD 8115.01). Retrieved from http://www.dtic.mil/whs/directives/corres/pdf/811501p.pdf

Department of Defense. (2006). *Information technology portfolio management* (DoDD 8115.02). Retrieved from https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/811502p.pdf

Department of Defense. (2017). *DoD space enterprise governance and principal DoD space advisor* (PDSA) (DoDD 5100.96). Retrieved from https://fas.org/irp/doddir/dod/d5100_96.pdf

Desai, S., Bidanda, B., & Lovell, M. R. (2012). Material and process selection in product design using decision-making technique (AHP). *European Journal of Industrial Engineering, 6*(3), 322–346.

Dickinson, M. W., Thornton, A. C., & Graves, S. (2001, November). Technology portfolio management: Optimizing interdependent projects over multiple time periods. *IEEE Transactions on Engineering Management, 48*(4), 518–527.

Dorini, G., Kapelan, Z., & Azapagic, A. (2011). Managing uncertainty in multiple-criteria decision making related to sustainability assessment. *Clean Technologies and Environmental Policy, 13*(1), 133–139.

Fabozzi, F. J. (2010). *An introduction to financial markets, business finance, and portfolio management.* Hoboken, NJ: John Wiley & Sons.

Flynn, B., & Field, J. (2006, January 1). Transformation of analytical tools: Using portfolio analysis techniques in defense applications. *Armed Forces Comptroller.* Retrieved from https://www.thefreelibrary.com/Transformation+of+analytical+tools%3A+using+portfolio+analysis+...-a0145158636

General Accounting Office. (1997). *Assessing risks and returns: A guide for evaluating federal agencies' IT investment decision-making* (Report No. GAO/AIMD-10.1.13). Retrieved from http://www.gao.gov/special.pubs/ai10113.pdf

Ghafghazi, S., Sowlati, T., Sokhansanj, S., & Melin, S. (2010). A multicriteria approach to evaluate district heating system options. *Applied Energy, 87*(4), 1134–1140.

Goumas, M., & Lygerou, V. (2000). An extension of the PROMETHEE method for decision making in fuzzy environment: Ranking of alternative energy exploitation projects. *European Journal of Operational Research, 123*(3), 606–613.

Government Accountability Office. (2007). *Best practices: An integrated portfolio management approach to weapon system investments could improve DOD's acquisition outcomes* (Report No. GAO-07-388). Washington, DC: Author.

Greiner, M. A., McNutt, R. T., Shunk, D. L., & Fowler, J. W. (2001). Selecting military weapon systems development portfolios: Challenges in value measurement. In *Proceedings of the Portland International Conference on Management of Engineering and Technology, 2001 (PICMET '01)* (pp. 403–410), Portland, Oregon. doi:10.1109/PICMET.2001.952153

Haimes, Y. Y. (2009). *Risk modeling, assessment, and management* (3rd ed.). Hoboken, NJ: John Wiley & Sons.

Hopkins, A. (2011). Risk-management and rule-compliance: Decision-making in hazardous industries. *Safety Science, 49*(2), 110–120.

Hyde, K. M., & Maier, H. R. (2006). Distance-based and stochastic uncertainty analysis for multi-criteria decision analysis in Excel using Visual Basic for Applications. *Environmental Modelling & Software, 21*(12), 1695–1710.

Hyde, K. M., Maier, H. R., & Colby, C. B. (2004). Reliability-based approach to multicriteria decision analysis for water resources. *Journal of Water Resource Planning Management, 130*(6), 429–438.

Janiga, M., & Modigliani, P. (2014, November–December). Think portfolios, not programs. *Defense AT&L Magazine, 43*(6), 12–16. Retrieved from https://www.dau.edu/library/defense-atl/_layouts/15/WopiFrame.aspx?sourcedoc=/library/defense-atl/DATLFiles/Nov-Dec2014/DATL_NovDec2014.pdf

Jorion, P. (2007). *Value at risk: The new benchmark for managing financial risk* (3rd ed.). New York, NY: McGraw-Hill.

Kaya, T., & Kahraman, C. (2011). Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Systems with Applications, 38*(6), 6577–6585.

Levy, H. (2006). *Stochastic dominance: Investment decision making under uncertainty.* Berlin, Germany: Springer Science+Business Media.

Mansini, R., Ogryczak, W., & Speranza, M. G. (2007). Conditional value at risk and related linear programming models for portfolio optimization. *Annals of Operations Research, 152*(1), 227–256.

Markowitz, H. M. (1952). Portfolio selection. *The Journal of Finance, 7*(1), 77–91.

Matos, M. A. (2007). Decision under risk as a multicriteria problem. *European Journal of Operational Research, 181*(3), 1516–1529.

Mun, J. (2015). *Modeling risk: Applying Monte Carlo risk simulation, strategic real options, stochastic forecasting, portfolio optimization, data analytics, business intelligence, and decision modeling* (3rd ed.). CA: Thomson-Shore and ROV Press.

Mun, J. (2016). *Real options analysis: Tools and techniques for valuing strategic investments and decisions with integrated risk management and advanced quantitative decision analytics* (3rd ed.). CA: Thomson-Shore and ROV Press.

Mun, J., Ford, D., & Housel, T. (2012). *Naval ship maintenance: An analysis of the Dutch shipbuilding industry using the Knowledge Value Added, Systems Dynamics, and Integrated Risk Management methodologies* (Report No. NPS-AM-12-204). Retrieved from https://calhoun.nps.edu/bitstream/handle/10945/33851/NPS-AM-12-204.pdf?sequence=1

Mun, J., Hernandez, E., & Rocco, C. (2016). A combined lexicographic average rank approach for evaluating uncertain multi-indicator matrices with risk metrics. In M. Fattore & R. Brüggemann (Eds.), *Partial order concepts in applied sciences* (pp. 105–118). Retrieved from http://www.springer.com/la/book/9783319454191. eBook ISBN (978-3319454214)

Pulido, F. J., Mandow, L., & de la Cruz, J. L. P. (2014). Multiobjective shortest path problems with lexicographic goal-based preferences. *European Journal of Operational Research, 239*(1), 89–101.

Restrepo, G., Brüggemann, R., Weckert, M., Gerstmann, S., & Frank, H. (2008). Ranking patterns, an application to refrigerants. *MATCH Communications in Mathematical and in Computer Chemistry, 59*(3), 555–584.

Rocco, C. M., & Tarantola, S. (2014). Evaluating ranking robustness in multi-indicator uncertain matrices: An application based on simulation and global sensitivity analysis. In R. Brüggemann, L. Carlsen, & J. Wittmann (Eds.), *Multi-indicator systems and modelling in partial order* (pp. 275–292). New York: Springer.

Rockafellar, R. T., & Uryasev, S. (2000). Optimization of conditional value-at-risk. *Journal of Risk, 2*(3), 21–41.

Roy, B. (1968). Classement et choix en presence de points devue multiples (la methode ELECTRE). *Revue d'Informatique et de recherché opérationelle, 6*(8), 57–75.

Roy, B. (1996). *Multicriteria methodology for decision aiding.* Berlin, Germany: Springer Science+Business Media.

Saaty, T. (2013). The modern science of multicriteria decision making and its practical applications: The AHP/ANP approach. *Operations Research, 61*(5), 1101–1118.

Saban, D., & Sethuraman, J. (2014). A note on object allocation under lexicographic preferences. *Journal of Mathematical Economics, 50*(C), 283–289.

Sakthivel, G., Ilangkumaran, M., Nagarajan, G., & Shanmugam, P. (2013). Selection of best biodiesel blend for IC engines: An integrated approach with FAHP-TOPSIS and FAHP-VIKOR. *International Journal of Oil Gas and Coal Technology, 6*(5), 581–612.

Scarlat, E., Chirita, N., & Bradea, I. A. (2012). Indicators and metrics used in the enterprise risk management (ERM). *Economic Computation and Economic Cybernetics Studies and Research, 46*(4), 5–18.

Sidiropoulos, L., Sidiropoulou, A., & Lalagas, S. (2014). Defense portfolio analysis. *Journal of Computations & Modelling, 4*(1), 327–347.

Szolgayová, J., Fuss, S., Khabarov, N., & Obersteiner, M. (2011). A dynamic CVaR-portfolio approach using real options: *An application to energy investments. European Transactions on Electrical Power, 21*(6), 1825–1841.

Tarantino, A. (2008). *Governance, risk, and compliance handbook: Technology, finance, environmental, and international guidance and best practices.* Hoboken, NJ: John Wiley & Sons.

Tavana, M., Behzadian, M., Pirdashti, M., & Pirdashti, H. (2013). A PROMETHEE-GDSS for oil and gas pipeline planning in the Caspian Sea basin. *Energy Economics, 36*, 716–728.

Vascik, P., Ross, A., & Rhodes, D. (2015). *A method for exploring program and portfolio affordability tradeoffs under uncertainty using Epoch-Era Analysis: A case application to carrier strike group design.* Paper presented at 12th Annual Acquisition Research Symposium, Naval Postgraduate School, Monterey, CA.

Von Neumann, J., & Morgenstern, O. (1947). *Theory of games and economic behavior.* Princeton, NJ: Princeton University Press.

Weber, C. A., Balut, S. J., Cloos, J. J., Frazier, T. P., Hiller, J. R., Hunter, D. E., . . . Tran, D. (2003, October). *The acquisition portfolio schedule costing/optimization model: A tool for analyzing the RDT&E and production schedules of DoD ACAT I systems* (IDA Document D-2835). Alexandria, VA: Institute for Defense Analyses. Retrieved from www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA421123

Wismeth, J. (2012). *Improving Army information technology asset visibility.* Strategy Research Project, U.S. Army War College. Retrieved from https://apps.dtic.mil/dtic/tr/fulltext/u2/a562133.pdf

Yaman, F., Walsh, T. J., Littman, M. L., & Desjardins, M. (2011). Democratic approximation of lexicographic preference models. *Artificial Intelligence, 175*(78), 1290–1307.

Yu, O.-Y., Guikema, S. D., Briaud, J.-L., & Burnett, D. (2012). Sensitivity analysis for multi-attribute system selection problems in onshore environmentally friendly drilling (EFD). *Systems Engineering, 15*(2), 153–171.

Zanoli, R., Gambelli, D., Solfanelli, F., & Padel, S. (2014). Assessing the risk of non-compliance in UK organic agriculture. *British Food Journal, 116*(8), 1369–1382.

## Acronyms

AA, Achieved Availability

ACB, Advanced Concept Build

AFCAA, Air Force Cost Analysis Agency

AQ, Aggregate Quality

BCR, Base-Case Rank

BMD, Ballistic Missile Defense

CCOPS, Carry-On Cryptologic Programs

CEC, Cost Estimating Categories

CES, Cost Element Structures

CIWS-CEC, Close-in Weapon System-Cooperative Engagement Capability

CM, Capability Measures

DC, Domain Capabilities

DoD, United States Department of Defense

DoDD, DoD Directive

DON, Department of the Navy

DPP, Discounted Payback Period

EA, Effective Availability

ELECTRE, Elimination Et Choix Traduisant la Realité or Elimination and Choice Expressing Reality)

GAO, General Accounting Office/Government Accountability Office

IA, Inherent Availability

IR, Inherent Reliability

IRM, Integrated Risk Management

IRR, Internal Rate of Return

KVA, Knowledge Value Added

LDT, Logistics Delay Time

LPOM, Local Partial Order Model

LPOMext, LPOM Extended

MA, Mission Availability

MACBETH, Measuring Attractiveness Through a Categorical-Based Evaluation Technique

MCA, Multicriteria Analysis

MDT, Mean Down Time

MH-60R, Seahawk Helicopter

MIRR, Modified Internal Rate of Return

MMT, Mean Maintenance Time

MR, Mission Reliability

MT, Mean Time

MTBF, Mean Time Between Failure

MTTR, Mean Time to Repair

NAVSEA, Naval Sea Systems Command

NIFC-CA, Naval Integrated Fire Control - Counter Air

NPV, Net Present Value

OA, Operational Availability

OD, Operational Dependability

OPNAV, Naval Operations

ORR,

PDF, Probability Density Function

PEO-IWS, Program Executive Office-Integrated Warfare Systems

PDSA, Principal DoD Space Advisor

PI, Profitability Index

PMA, Portfolio Management Analysis

PP, Payback Period

PROB, Probability

PROMETHEE, Preference Ranking Organization Methods for Enrichment Evaluations

R&D, Research and Development

RDDL, Radar Designated Decoy Launch

ROI, Return on Investment

ROV PEAT, Real Options Valuation Project Economics Analysis Tool

SM-2 BLK, SM-2 Block IVA missile

SME, Subject Matter Expert

SoS, System of Systems

SPQ-9B, Radar Set

SSDS, Ship Self-Defense System

TLC, Total Lifecycle Cost

TOC, Total Ownership Cost

TOPSIS, Technique for Order of Preference by Similarity to Ideal Solution

VaR, Value at Risk

WBS, Work Breakdown Structures

## Author Biography

**Dr. Johnathan Mun**

is a research professor at the Naval Postgraduate School and is a specialist in advanced decision analytics, quantitative risk modeling, strategic flexibility real options, predictive modeling, and portfolio optimization. He has authored 24 books, holds 22 patents and patents pending, created over a dozen software applications in advanced decision analytics, and written over a hundred technical notes, journal articles, and white papers. He is currently the CEO of Real Options Valuation, Inc., and his prior positions include Vice President of Analytics at Oracle/Crystal Ball and a senior manager at KPMG Consulting. Dr. Mun holds a PhD in Finance and Economics from Lehigh University, an MBA and MS from Southeastern University, and a BS in Physics and Biology from the University of Miami.

*(E-mail address: jcmun@nps.edu)*

# PROFESSIONAL READING LIST

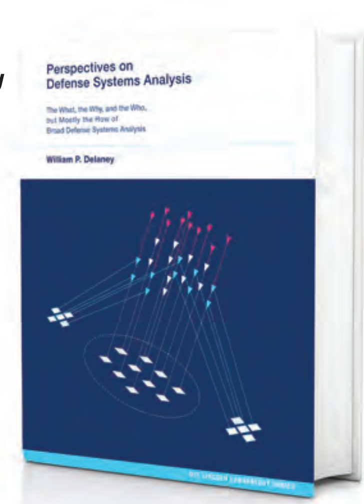
The Defense Acquisition Professional Reading List is intended to enrich the knowledge and understanding of the civilian, military, contractor, and industrial workforce who participate in the entire defense acquisition enterprise. These book recommendations are designed to complement the education and 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 relevancy to defense acquisition. Please send your reviews to the managing editor, *Defense Acquisition Research Journal* at *DefenseARJ@dau.edu*.context for the reader, not prescriptive practices explain its relevancy to defense acquisition. Please send your reviews to the managing editor, *Defense Acquisition Research Journal* at ***DefenseARJ@dau.edu.***

---

## Featured Books

***Perspectives on Defense Systems Analysis: The What, the Why, and the Who, but Mostly the How of Broad Defense Systems Analysis***




**Author:** William P. Delaney, with Robert G. Atkins, Alan D. Bernard, Don M. Boroson, David J. Ebel, Aryeh Feder, Jack G. Fleischman, Michael P. Shatz, Robert Stein, and Stephen D. Weiner
**Publisher:** The MIT Press
**Copyright Date:** 2015
**Hard/Softcover/Digital:** Hardcover, 288 pages
**ISBN-10:** 0262029359
**ISBN-13:** 978-0262029353
**Reviewed by:** Kevin Garrison, Research Staff Member, Institute for Defense Analyses

**Review:**

This is a deeply interesting and occasionally very technical book that covers the history and practice of defense systems analysis.

It consists of three sections. The first (by Delaney) is an overview of Defense Systems Analysis, which covers what is meant by the term and how such analysis is done. It provides a few examples from the early days of the Defense Science Board, as well as details about the founding of Lincoln Laboratories.

Section two consists of four chapters that provide a variety of views about Defense Systems Analysis. The chapters include a historical and practice review (by Stein), red teaming (by Feder), blue teaming (by Atkins), and some ruminations on truth and uncertainty (by Bernard).

The third section covers specific subject areas: air defense; ballistic missile defense; air, space, and cyberspace; bioterrorism; and communications to and from Mars. These chapters are very technical and detailed, and include, for example, two separate derivations of the radar range equation.

The book's target audience is "analysts and engineers in industry, government, and research." It describes issues in systems analysis, in order to provide a roadmap to a solution and an understanding of alternative solutions' relative value.

The authors are all veterans in the field, with 20–40 years of experience, which comes through clearly in their individual discussions of the challenges involved in applying systems analysis practices to often ill-informed problems.

The first five chapters give an excellent history of defense systems analysis, how to organize and manage Defense Science Board studies, and how to think about complex problems. The remaining chapters are more narrowly focused on specific subjects. While interesting, they are very domain-specific and can be quite technical.

The book is well written and organized, and a reader will come away with a great appreciation for the application of science and systems analysis to defense problems. Defense systems analysis, however, is focused on the prerequirements phase of defense acquisition and, while providing fascinating and illuminating anecdotes about systems analysis, the book is mainly useful only to acquisition professionals involved in systems engineering.


# DAU ALUMNI ASSOCIATION

## Join the Success Network!

The DAU Alumni Association opens the door to a worldwide network of Defense Acquisition University graduates, faculty, staff members, and defense industry representatives—all ready to share their expertise with you and benefit from yours.

Be part of a two-way exchange of information with other acquisition professionals.

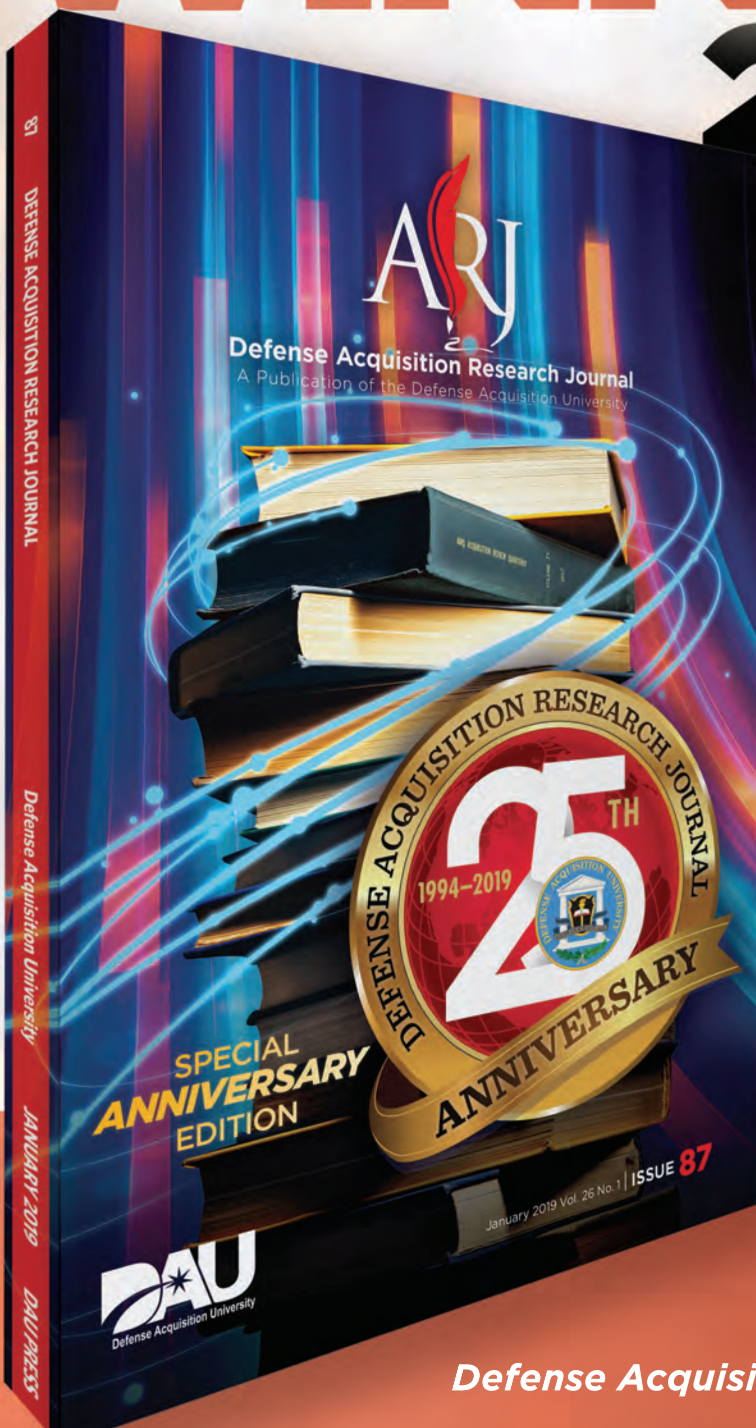
- Stay connected to DAU and link to other professional organizations.
- Keep up to date on evolving defense acquisition policies and developments through DAUAA newsletters and the DAUAA LinkedIn Group.
- Attend the DAU Annual Acquisition Training Symposium and bimonthly hot topic training forums—both supported by the DAUAA and earn Continuous Learning Points toward DoD continuing education requirements.
- Scholarship opportunities for dependent graduating high school seniors of current members.

**Membership is open to all DAU graduates, faculty, staff, and defense industry members. It's easy to join right from the DAUAA Website at *www.dauaa.org*, or scan the following QR code:**

***For more information, call 703-960-6802 or 800-755-8805, or e-mail dauaa2@aol.com.***

HERMES AWARD FOR PRINT MEDIA | PUBLICATION

# WINNER 2019





Norene Johnson, Emily Beliles,
and Michael Bubar Krukowski

***Defense Acquisition University Press***

***Fort Belvoir, VA***

# Current Research Resources in DEFENSE ACQUISITION

## "OTHER TRANSACTION AUTHORITY"

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 Knowledge Repository (KR) librarian team in collaboration with DAU's Director of Research. Both government civilian and military Defense Acquisition Workforce (DAW) readers will be able to access papers publicly and from licensed resources on the DAU KR Website: https://identity.dau.edu/EmpowerIDWebIdPForms/Login/KRsite.

Nongovernment DAW 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 Knowledge Repository librarian 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**.

# Jurisdiction over Federal Procurement Disputes: The Puzzle of Other Transaction Agreements.

*Nikole R. Snyder*

**Summary:**

The article analyzes sovereign immunity in view of its association with what is commonly referred to as the Other Transaction Authority (OTA) statute. It discusses how provisions of the Contract Disputes Act (CDA), provides a waiver of sovereign immunity that enables contractors to sue the government for procurement contract disputes. It mentions that due to the lack of express congressional abrogation of sovereign immunity, the federal government cannot be sued for OTA disputes.

**APA Citation:**

Snyder, N. R. (2019). Jurisdiction over Federal procurement disputes: The puzzle of Other Transaction Agreements. *Public Contract Law Journal, 48*(3), 515–550. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=ip&db=asn&AN=138330775&site=ehost-live&scope=site

# Organized for Innovation: An Empirical Observation of Innovation Adoption within Defense Organizations

*Christopher A. Lynn*

**Summary:**

This thesis will analyze the behavior of three organizations in order to better understand the DoD's adoption of other transaction authority (OTA).

**APA Citation:**

Lynn, C. A. (2018, June). *Organized for innovation: An empirical observation of innovation adoption within defense organizations.* Naval Postgraduate School. Retrieved from https://calhoun.nps.edu/bitstream/handle/10945/59714/18Jun_Lynn_Christopher.pdf?sequence=1&isAllowed=y

# Department of Defense Use of Other Transaction Authority: Background, Analysis, and Issues for Congress

*Moshe Schwartz and Heidi M. Peters*

**Summary:**

This research addresses DoD use of other transaction authority (OTA) to pay for goods and services without triggering most of the standard acquisition statutes and regulations that govern DoD acquisition. It further examines how OTA works, why it was legislated, potential benefits and risks of using OTAs, and whether data are available against which to measure their effectiveness. A legislative history of the DoD OTA is also provided.

**APA Citation:**

Schwartz, M., & Peters, H. M. (2019, February). *Department of Defense use of Other Transaction Authority: Background, analysis, and issues for Congress.* Congressional Research Service. Retrieved from https://congressional.proquest.com/congressional/docview/t21.d22.crs-2019-crs-191477?accountid=40390

## 'Other Transactions' Are Government Contracts, and Why It Matters

*Nathaniel Castellano*

**Summary:**

Other Transaction Authority might clear away many burdensome procurement statutes and regulations, but principles of sovereign immunity and separation of powers, along with the pervasive precedents of the United States Court of Appeals for the Federal Circuit, will continue to ensure that doing business with the federal government, even by "Other Transaction," is never quite the same as doing business in the commercial market.

**APA Citation:**

Castellano, N. (2019, Spring). 'Other Transactions' are government contracts, and why it matters. *Public Contract Law Journal, 48*(3). Retrieved from https://ssrn.com/abstract=3435062

## Procuring Innovation

*Fred Kaplan*

**Summary:**

When DIUx 2.0 got underway, Raj Shah and his team talked to Lauren Schmidt, the program's "pathways director" responsible for contracts, who told them of a discovery she had made of enormous consequence. Previously, Schmidt had worked in the Army's acquisition branch, where she had learned of a type of contracting blandly named "other transaction authority." In an OTA contract, the government and commercial companies can design prototype projects without the onerous rules and regulations of the traditional defense acquisition process.

**APA Citation:**

Kaplan, F. (2017). Procuring innovation. *MIT Technology Review, 120*(1). Retrieved from http://search.ebscohost.com/login.aspx?direct=true&AuthType=ip&db=a9h&AN=120167138&site=ehost-live

# Other Transaction Authority: Saint or Sinner for Defense Acquisition?

*William J. Weinig*


## Summary:

This article provides an overview and history of Other Transaction Authority (OTA), as well as substantiates whether to advocate expansion or seek curtailment of this powerful business instrument. This analysis will show that, to date, the benefits of OTAs have outweighed their risks.



## APA Citation:

Weinig, W. J. (2019). Other transaction authority: Saint or sinner for defense acquisition? *Defense Acquisition Research Journal, 26*(2), 106–127. https://doi.org/10.22594/dau.19-818.26.02


# MARCOM AWARD FOR PEER REVIEWED ACADEMIC JOURNAL

# WINNER 2019


Norene Johnson, Emily Beliles,
and Michael Krukowski

***Defense Acquisition University Press***

***Fort Belvoir, VA***


ALUMNI
DAU
ASSOCIATION
NOW ACCEPTING SUBMISSIONS
UNTIL MARCH 15, 2020

2020

# EDWARD HIRSCH ACQUISITION and WRITING COMPETITION

## THEME: DELIVERING CAPABILITIES FASTER

## CALL FOR PAPERS

***Suggested research topics may include, but are not limited to:***

- Defense Acquisition Case Histories
- Other Transaction Authorities
- Mid-tier Acquisition
- Agile Software Development and Program Management
- System Cyber Hardness
- Cyber Training and Concepts
- Controlling Costs Throughout the Product Life Cycle
- Acquisition of Defense Business Systems
- Intellectual Property
- Acquisition Readiness
- Emerging Changes to Earned Value Management
- Career Path and Incentives
- Improving Professionalism of the Total Acquisition Workforce
- Incorporating Foreign Military Sales and Direct Contractor Sales Strategies into Programs
- Services Management
- Should Cost Management
- Artificial Intelligence
- Data Visualization
- Digital Twin Engineering

## GROUND RULES

- The competition is open to anyone interested in the DoD acquisition system and is not limited to government or contractor personnel.
- Employees of the federal government (including military personnel) are encouraged to compete and are eligible for cash awards unless the paper was researched or written as part of the employee's official duties or was done on government time. If the research effort is performed as part of official duties or on government time, the employee is eligible for a non-cash prize, i.e., certificate and donation of cash prize to a Combined Federal Campaign registered charity of winner's choice.
- ***First place Jacques S. Gansler Award is $1,000***. Second and third prizes, if awarded, are each $500.
- Papers are to be submitted to the DAU Director of Research: ***research@dau.edu.***
- The format of the paper must be in accordance with guidelines for articles submitted for publication in the ***Defense Acquisition Research Journal***.
- Papers will be evaluated by a panel selected by the DAUAA Board of Directors and the DAU Director of Research.
- Award winners will present their papers at a DAU event in June/July 2020 at the DAU Fort Belvoir campus.
- Papers must be ***submitted by March 15, 2020,*** and awards will be announced by April 2020.

JACQUES S. GANSLER AWARD FIRST PLACE

**$1,000 & $500** 2nd & 3rd Prize

***DON'T MISS OUT ON GETTING PUBLISHED!***

# Defense ARJ Guidelines **FOR CONTRIBUTORS**

The *Defense Acquisition Research Journal (ARJ)* is a scholarly peer-reviewed journal published by the Defense Acquisition University (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 lifecycle 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.org/ethics/. Finally, the corresponding author as well as each coauthor is required to sign the copyright release form available at our website: www.dau.edu/library/arj.

## COPYRIGHT

The *Defense ARJ* is a publication of the United States Government and as such is not copyrighted. We will not accept copyrighted manuscripts that require special posting requirements or restrictions. If we do publish your copyrighted article, we will print only the usual caveats. The work of federal employees undertaken as part of their official duties is not subject to copyright except in rare cases.

Web-only publications will be held to the same high standards and scrutiny as articles that appear in the printed version of the journal and will be posted to the DAU website at www.dau.edu.

In citing the work of others, please be precise when following the author date-page number format. It is the contributor's responsibility to obtain permission from a copyright holder if the proposed use exceeds the fair use provisions of the law (see the latest edition of *Circular 92: Copyright Law of the United States of America and Related Laws Contained in Title 17 of the United States Code,* Washington, DC: U.S. Government Printing Office). Contributors will be required to submit a copy of the writer's permission to the managing editor before publication.

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

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 703-805-3801 (fax: 703-805-2917), or via the Internet at norene.johnson@dau.edu.

The DAU Homepage can be accessed at:
***https://www.dau.edu***

DEPARTMENT OF DEFENSE

DEFENSE ACQUISITION UNIVERSITY

ATTN: DAU PRESS (*Defense ARJ*)

9820 BELVOIR RD STE 3

FORT BELVOIR, VA 22060-5565


CALL FOR
AUTHORS

**We are currently soliciting articles and subject matter experts for the 2020-2021 *Defense Acquisition Research Journal (ARJ)* print year.**

Please see our guidelines for contributors for submission deadlines.

## Even if your agency does not require you to publish, consider these career-enhancing possibilities:

- Share your acquisition research results with the Acquisition and Sustainment (A&S) community.
- Change the way Department of Defense (DoD) does business.
- Help others avoid pitfalls with lessons learned or best practices from your project or program.
- Teach others with a step-by-step tutorial on a process or approach.
- Share new information that your program has uncovered or discovered through the implementation of new initiatives.
- Condense your graduate project into something beneficial to acquisition professionals.

# ENJOY THESE BENEFITS:

- Earn 30 continuous learning points for publishing in a refereed (peer reviewed) journal.
- Earn a promotion or an award.
- Become part of a focus group sharing similar interests.
- Become a nationally recognized expert in your field or specialty.
- Be asked to speak at a conference or symposium.

**We welcome submissions from anyone involved with or interested in the defense acquisition process—the conceptualization, 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.**

If you are interested, contact the *Defense ARJ* managing editor ***(DefenseARJ@dau.edu)*** and provide contact information and a brief description of your article. Please visit the *Defense ARJ* Submissions page at ***https://www.dau.edu/library/arj/p/Defense-ARJ-Submissions***.

## *Statement Required by the Act of August 12, 1970 Section 3685, Title 39, U.S.C. Showing Ownership, Management, and Circulation*

The ***Defense Acquisition Research Journal*** *(ARJ)* is published at the Defense Acquisition University (DAU), Fort Belvoir, VA. The University publishes four issues annually. The Director of the Defense Acquisition University (DAU) Press is Randy Weekes, the Managing Editor of the *Defense ARJ* is Norene Johnson, and the publisher is the DAU Press. All are collocated at the following address:

***Defense Acquisition University***
***Attn DAU Press (Defense ARJ)***
***9820 Belvoir Road, Suite 3***
***Fort Belvoir, VA 22060-5565***

### Average Number of Copies Each Issue During the Preceding 12 Months:

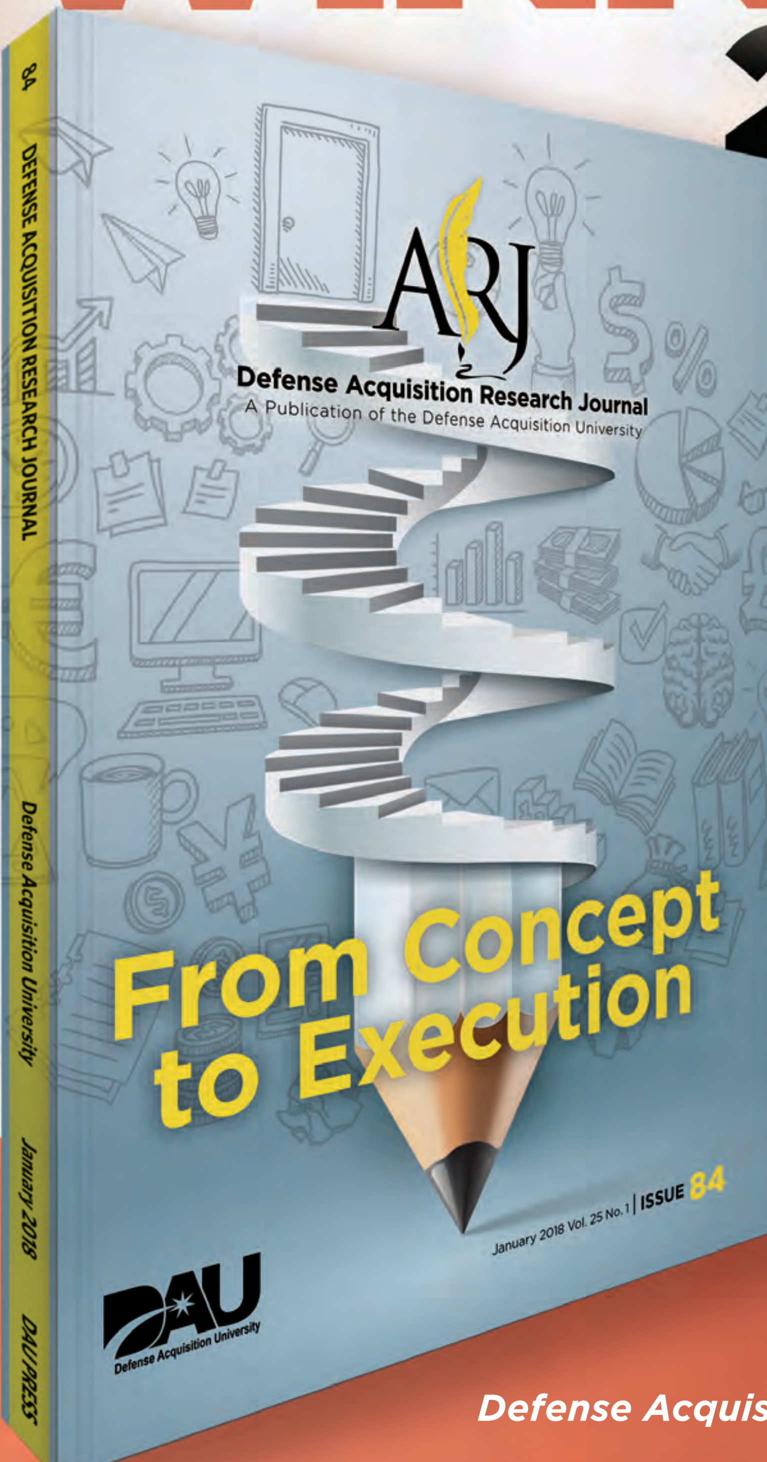
A. Total number of copies printed (net press run) . . . 3,269
B. Paid and/or requested circulation:
  1. Sales through dealers and carriers, street vendors, and counter sales . . . 0
  2. Mail subscriptions paid and/or requested . . . 3,068
C. Total paid and/or requested circulation . . . 3,068
D. Free distribution by mail, carrier, or other means; samples, complimentary, and other free copies . . . 112
E. Total distribution . . . 3,180
F. Copies not distributed:
  1. Office use, leftover, unaccounted, spoiled after printing . . . 89
  2. Returns from news agents . . . 0
G. Total . . . 3,269

### Actual Number of Copies of Single Issue Published Nearest to Filing Date:

A. Total number of copies printed (net press run) . . . 3,286
B. Paid and/or requested circulation:
  1. Sales through dealers and carriers, street vendors, and counter sales . . . 0
  2. Mail subscriptions paid and/or requested . . . 3,008
C. Total paid and/or requested circulation . . . 3,008
D. Free distribution by mail, carrier, or other means; samples, complimentary, and other free copies . . . 180
E. Total distribution . . . 3,188
F. Copies not distributed:
  1. Office use, leftover, unaccounted, spoiled after printing . . . 98
  2. Returns from news agents . . . 0
G. Total . . . 3,286

HERMES AWARD FOR PRINT MEDIA | PUBLICATION

# WINNER 2018





Norene Johnson, Emily Beliles,
and Michael Krukowski

***Defense Acquisition University Press***

***Fort Belvoir, VA***

# RECOGNITION OF REVIEWERS FOR PRINT YEAR 2019

We would like to express our appreciation to all of the subject matter experts who volunteered to participate in the *Defense Acquisition Research Journal* peer review process. The assistance of these individuals provided impartial evaluation of the articles published during the 2019 print year. We would also like to acknowledge those referees who wished to remain anonymous. Your continued support is greatly appreciated, and we look forward to working with many of you again in print year 2020.

**Dr. Craig Arndt**
Director
*The MITRE Corporation*

**Dr. Michael A. Balazs**
Generation AI Neuromancer;
Technology Integrator, Global Operations and Intelligence Programs;
Acting Department Head & Site Lead, Charlottesville Operations
*The MITRE Corporation*

**Dr. Alan Ballard**
Assistant Professor
*Naval Postgraduate School*

**Dr. Donald Birchler**
Senior Research Scientist
*The CNA Corporation*

**Mr. Alexander M. Brofos**
Senior Principal Engineering
*The MITRE Corporation*

**Professor Penny Brooks**
Professor of Contract Management
*Defense Acquisition University*

**Professor Joel D. Brown**
Professor of Contract Management and Facilities Engineering
*Defense Acquisition University*

**Mr. Philip J. Candreva, JD**
Senior Lecturer of Budgeting & Public Policy
*Naval Postgraduate School*

**Mr. Kurt Chelf**
Professor of Contracting
*Defense Acquisition University*

**Dr. David Coleman**
Chief Engineer,
Navy Enterprise Sea Systems
*The MITRE Corporation*

**Dr. Amanda Pare Court**
Lead Behavioral Scientist
*The MITRE Corporation*

**Mr. Brian Duddy**
Professor of Program Management
*Defense Acquisition University*

**Ms. Susan Filocco**
Principal – Program Management
*The MITRE Corporation*

**Dr. James Hasik**
Associate Professor
*National Defense University, Eisenhower School*

**Mr. Jay N. Kanavos**
Co-Department Head
*The MITRE Corporation (CAMS)*

**Mr. Robert J. Kruchten**
Multi-Discipline Systems Engineering – Principal
*The MITRE Corporation*

**MAJ Timothy Landucci, USAF**
Professor of Program Management
*Defense Acquisition University*

**Mr. John L. Larson**
Professor of Systems Engineering Management
*Defense Acquisition University*

**Mr. Terrence Leary**
Acquisition Management, Principal
*The MITRE Corporation*

**Mr. William Lucyshyn**
Research Professor
*University of Maryland, School of Public Policy*

**Dr. David W. Marsh**
Senior Program Acquisition Specialist
*The MITRE Corporation*

**COL Mary Lowe Mayhugh, USA (Ret.)**
Principal
*The MITRE Corporation*

**Mr. Scott Miller**
Professor
*Defense Acquisition University*

**Maj Jeffrey Allen Mueller, USAF**
Professor, Test and Systems Engineering Acquisition
*Defense Acquisition University*

**Dr. Charles K. Pickar**
Senior Lecturer
*Naval Postgraduate School*

**Mr. Thomas "Lou" Rauls**
Professor of Program Management
*Defense Acquisition University*

**Mr. David M. Riel**
Professor of Acquisition Management
*Defense Acquisition University*

**Dr. Jeanette Robinson**
Professor of Small Business Administration
*Defense Acquisition University*

**Dr. Stanley Rosen**
Professor of Acquisition Management
*Defense Acquisition University*

**Mr. Gary William Spohn**
Professor of Contract Management
*Defense Acquisition University*

**Mr. Matthew Summers**
Lecturer
*Cranfield University, UK*

**Professor Trevor Taylor**
Professorial Fellow in Defence Management
*Royal United Services Institute*

**Dr. Charlette W. Watkins**
Program Management Acquisition – Principal
*The MITRE Corporation*

**CDR E. Cory Yoder, USN (Ret.)**
Senior Lecturer
*Naval Postgraduate School – Graduate School of Business and Public Policy*

# ONLINE EDITIONS

## Defense ARJ and Defense Acquisition Magazine

***PLEASE SUBSCRIBE***

or resubscribe so you will not miss out on accessing future publications.


Online presence for easier use on mobile and desktop devices:

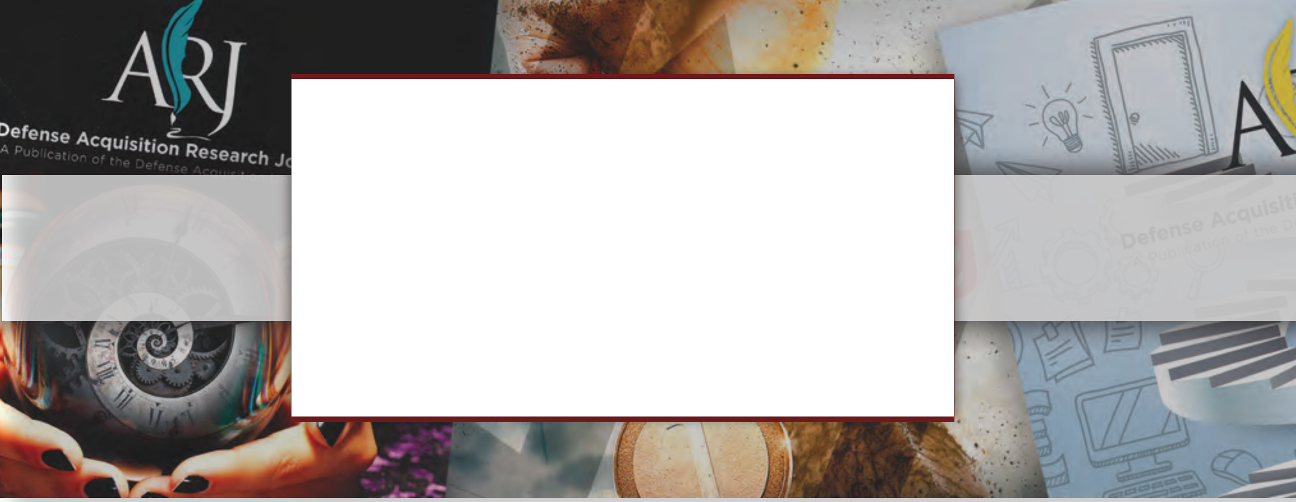
**https://www.dau.edu/library/arj**

**https://www.dau.edu/library/defense-atl**

Send an e-mail to **darjonline@dau.edu** and/or **datlonline@dau.edu**, giving the e-mail address with which you want us to notify you when a new issue is posted

Type "Add to **LISTSERV**" in the subject line

Also use this address to notify us if you change your e-mail address




☐ ***Defense ARJ*** ***Defense Acquisition Magazine*** ☐

Thank you for your interest in ***Defense Acquisition Research Journal*** and ***Defense Acquisition*** magazine. To receive your complimentary online subscription, please write legibly if hand written and answer all questions below—incomplete forms cannot be processed.

***When registering, please do not include your rank, grade, service, or other personal identifiers.**

☐ *New Online Subscription* ☐ *Cancellation* ☐ *Change E-mail Address*

---

Date: ____________

Last Name: ____________

First Name: ____________

Day/Work Phone: ____________

E-mail Address: ____________

Signature: ____________
*(Required)*

---

***PLEASE FAX TO: 703-805-2917***

***OR EMAIL TO: defensearj@dau.edu***

## The Privacy Act and Freedom of Information Act

In accordance with the Privacy Act and Freedom of Information Act, we will only contact you regarding your ***Defense ARJ*** and ***Defense Acquisition Magazine*** subscriptions. If you provide us with your business e-mail address, you may become part of a mailing list we are required to provide to other agencies who request the lists as public information. If you prefer not to be part of these lists, please use your personal e-mail address.

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

**BUSINESS REPLY MAIL**

FIRST-CLASS MAIL PERMIT NO. 12 FORT BELVOIR,VA

POSTAGE WILL BE PAID BY ADDRESSEE

DEFENSE ACQUISITION UNIVERSITY
ATTN: DAU PRESS
9820 BELVOIR RD STE 3
FORT BELVOIR VA 22060-9910

# ARJ Defense Acquisition Research Journal SURVEY

## Please rate this publication based on the following scores:

**5 — Exceptional   4 — Great   3 — Good   2 — Fair   1 — Poor**

*Please circle the appropriate response.*

1. How would you rate the overall publication? 5 4 3 2 1
2. How would you rate the design of the publication? 5 4 3 2 1

| | True | False |
|---|---|---|
| a) This publication is easy to read | | |
| b) This publication is useful to my career | | |
| c) This publication contributes to my job effectiveness | | |
| d) I read most of this publication | | |
| e) I recommend this publication to others in the acquisition field | | |

**If hand written, please write legibly.**

3. What topics would you like to see get more coverage in future *Defense ARJs*?

4. What topics would you like to see get less coverage in future *Defense ARJs*?

5. Provide any constructive criticism to help us to improve this publication:

6. Please provide e-mail address for follow up (optional):

*YOU CAN ALSO FIND THE SURVEY ONLINE AT*

**https://www.dau.edu/library/arj**

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

**BUSINESS REPLY MAIL**

FIRST-CLASS MAIL PERMIT NO. 12 FORT BELVOIR,VA

POSTAGE WILL BE PAID BY ADDRESSEE

DEFENSE ACQUISITION UNIVERSITY
ATTN: DAU PRESS
9820 BELVOIR RD STE 3
FORT BELVOIR VA 22060-9910

DEFENSE ACQUISITION RESEARCH JOURNAL
A Publication of the Defense Acquisition University

We're on the Web at:
http://www.dau.edu/library/arj

ARJ

DEFENSE ACQUISITION RESEARCH JOURNAL

A Publication of the Defense Acquisition University

***Current. Connected. Innovative.***

HERMES CREATIVE AWARDS 2019 PLATINUM WINNER

WINNER 2019 APEX® AWARDS FOR PUBLICATION EXCELLENCE

2019 MARCOM PLATINUM WINNER