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**ISSN 2156-8391 (print) ISSN 2156-8405 (online)
DOI: <https://doi.org/10.22594/dau.042021-96.28.02>**

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

Articles represent the views of the authors and do not necessarily reflect the opinion of DAU or the Department of Defense.



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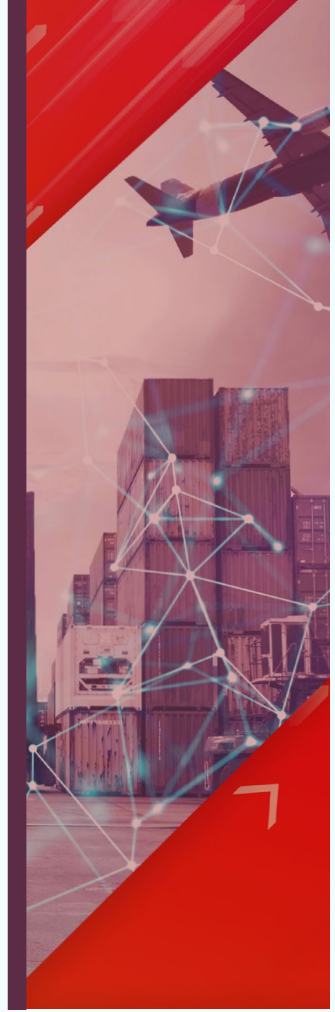
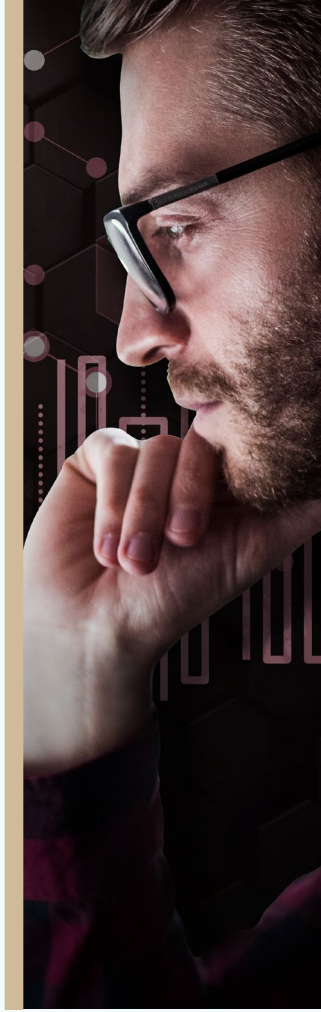
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Engineering a Better IT Program Manager: A Comparative Study of IT PM Education and Training

William J. Parker

This quantitative, exploratory article examines the relationship between Department of Defense information technology (IT) program managers (PMs), their technical education, commercial project management certification, and project management success—also known as project efficiency—for IT PMs. It also examines to what extent project management success in scope, schedule, and cost compares with PMs' technical education, commercial project management certification, and the effects of interaction between education type and commercial PM certification.

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How to Bail Out a Defense Contractor: Cases on Securing a Supply Chain *in extremis*

James M. Hasik

Nine cases of bailouts of defense contractors provide lessons on how to secure a supply chain *in extremis*.



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Effective Decision-Making Behaviors for Defense R&D: Accounting for Dynamic Competition

Mark Calafut, Shahram Sarkani, and Thomas A. Mazzuchi

R&D decision making is a key source of value and competitive advantage, which can be optimized for the Post-Competition Value (PCV) of R&D opportunities, rather than for their initial value. Applying this new methodology, the authors determine effective decision-making behaviors that enhance the value of R&D investments for defense industry companies, government laboratories, and nonprofits.

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Call for Authors

We are currently soliciting articles and subject matter experts for the 2021 *Defense ARJ* print year. Please see our guidelines for contributors for submission deadlines



FROM THE CHAIRMAN AND EXECUTIVE EDITOR

Dr. Larrie D. Ferreiro



The theme for this issue is “Building It Better.” The first paper is “Engineering a Better IT Program Manager: A Comparative Study of IT PM Education and Training,” by William J. Parker. It evaluates the relationship between technical education/commercial project management certification and project management success, using data for information technology (IT) program managers (PMs).

The author concludes that there is no relationship between undergraduate technical degree, commercial PM certification, and project management success.

The second paper, by James Hasik, “How to Bail Out a Defense Contractor: Cases on Securing a Supply Chain *in extremis*,” reviews nine prominent bailouts of defense contractors from the past 50 years. The author concludes that providing short-term infusions of cash may be necessary but insufficient to maintain industry structures, while providing long-term demand is both necessary and likely sufficient to maintain those structures.

The third paper, “Effective Decision-Making Behaviors for Defense R&D: Accounting for Dynamic Competition,” by Mark Calafut, Shahram Sarkani, and Thomas A. Mazzuchi provides a fresh examination of competition in research and development (R&D) in the ecosystem of defense industry companies, government

laboratories, and not-for-profit organizations. The study identifies behaviors that achieve greater average value than standard alternatives that do not account for competition.

This issue's Current Research Resources in Defense Acquisition focuses on DevSecOps (Development, Security, Operations).

The featured work in the Defense Acquisition Reading List book review is *12 Seconds of Silence: How a Team of Inventors, Tinkerers, and Spies Took Down a Nazi Superweapon* by Jamie Holmes, reviewed by Emily Beliles.

Dr. Joseph Ilk has left the Editorial Board. We thank him for his service.

We welcome Mr. Patrick Morrow to the Editorial Board.

Dr. Larrie D. Ferreira

*Chairman and Executive Editor
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DAU ALUMNI ASSOCIATION

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

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- 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.
- Take advantage of scholarship opportunities for dependent graduating high school seniors of current members.

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DAU CENTER FOR DEFENSE ACQUISITION

RESEARCH AGENDA 2021

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

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

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

Affordability and Cost Growth

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

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

Industrial Productivity and Innovation

Industry insight and oversight

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

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

Independent Research and Development

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

Competition

Measuring the effects of competition

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

Strategic competition

- Is there evidence that competition between system portfolios is an effective means of controlling price and costs?
- Does lack of competition automatically mean higher prices? For example, 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 long-term historical trends for competition guidance and practice in defense acquisition policies and practices?
- To what extent are contracts awarded noncompetitively by congressional mandate, for policy interest reasons? What is the effect on contract price and performance?
- What means 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 a simple head count of providers?
- Has the change in 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 performance of awards based on varying levels of competition: (a) “Effective Competition” (two or more offers; (b) “Ineffective Competition” (only one offer received in response to competitive solicitation; (c) “Split Awards” versus winner take all; and (d) “Sole Source.”

Improve DoD outreach for technology and products from global markets

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

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

Comparative studies

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

Cybersecurity

General questions

- How can we perform analyses of the investment savings associated with institution of robust cybersecurity measures?
- How can we measure the cybersecurity benefits associated with using continuous integration and continuous deployment methodologies?

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

Costs associated with cybersecurity

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

Acquisition of Services

Metrics

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

Industrial base

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

Industry practices

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

Make/Buy

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

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

Category management/strategic sourcing

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

Contract management/efficacy

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

Policy

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

Administrative Processes

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

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

Human Capital of Acquisition Workforce

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

Defense Business Systems

Organizational structure and culture in support of Agile software development methodologies

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

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

Defense Acquisition and Society

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

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ISSUE **96**
APRIL 2021
VOL. 28 NO. 2

ENGINEERING

— A BETTER —

IT PROGRAM MANAGER: A COMPARATIVE STUDY OF IT PM EDUCATION AND TRAINING



William J. Parker

This article examines the relationship between Department of Defense information technology (IT) program managers (PMs), their technical education, commercial project management certification, and project management success—also known as project efficiency—for IT PMs. The researcher asked, “To what extent does project management success in scope, schedule, and cost compare among PMs, specifically their technical education, commercial project management certification, and interaction effects between education type and commercial PM certification?” A gap in research exists on whether IT PMs with a technical education positively or negatively impact project outcomes. The IT PM community needs more studies on the extent to which commercial PM certifications affect project efficiency. The researcher used factorial multivariate analysis of variance (MANOVA) to compare education and PM certification to project efficiency. MANOVA provided for the examination of the interactive effects. A Mann-Whitney post hoc test confirmed the MANOVA results. Both tests concluded that no relationship exists between undergraduate technical degree, commercial PM certification, and project management success.

DOI: <https://doi.org/10.22594/dau.20-856.28.02>

Keywords: *Information Technology, Project Management, PM Certification, IT PM Education, Project Success.*

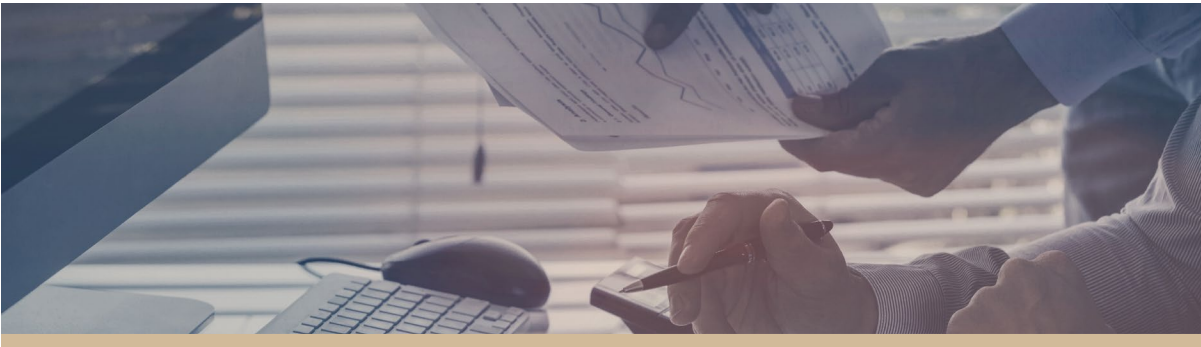


Information technology (IT) project managers (PMs) lead IT project teams and are ultimately accountable for the overwhelming number of IT project failures. Typically, IT PMs fail to deliver on scope, schedule, and cost, which threatens the organization's competitive advantage. IT project failures are well documented in literature, and modern agile software development practices have failed to stem the tide. According to the CHAOS reports of The Standish Group (2013, 2015), nearly two-thirds of IT projects fail to deliver on initial scope, schedule, and cost. The problem becomes more pronounced on large IT projects versus smaller efforts where agile approaches have demonstrated success. Bloch et al. (2012, pp. 1–6) found that large IT projects—those over \$15 million—fail more than half of the time. IT project failure is hindering the ability of organizations to capitalize on IT innovation and limits the realization of the technological benefit.

Failure of large projects can threaten the viability of a company. In one case, a large retailer failed on successive \$1.7 billion and \$600 million IT projects and had to file for bankruptcy (Bloch et al., 2012). The Department of Defense (DoD) defines major automated information systems (MAIS) projects as those exceeding \$165 million (DoD, 2015). One DoD MAIS IT project, USAF Expeditionary Combat Support System Program, failed to deliver any capability with \$1.1 billion lost (Aronin et al., 2011). The United Kingdom Social Security Department and Post Office Counters, Ltd., launched a software project (£1 billion or approximately \$1.6 billion) to change how post offices would operate and how benefit recipients would receive payments. Four years later, the project was abandoned based on a projected 3-year schedule delay and 30% budget overrun (Budzier & Flyvbjerg, 2012). IT PM competence contributes to project success (Pinto & Slevin, 1987; Ramazani & Jergeas, 2015). Organizational leaders need to select and develop better IT PMs to improve outcomes.

“ IT project failures are well documented in literature, and modern agile software development practices have failed to stem the tide. ”

In the public sector, PMs continue to be selected based on technical expertise and general problem-solving ability (Darrell et al., 2010). IT professional skills, like software engineering, are considered hard skills. These technical skills by which IT professionals are selected as PMs differ from the soft skills required to manage the project. Scholars in the literature define soft skills as the combination of leadership and project management (Carvalho & Rabechini, 2015; Pandya, 2014; Stevenson & Starkweather, 2010). PMs selected for their technical expertise do not possess the managerial skills



required to oversee the many processes involved in developing software (Agrawal & Thite, 2006; Darrell et al., 2010). Dulaimi (2005) also suggested that PMs with engineering education and background focus too much on the technical aspects of the project and overlook essential leadership requirements. Müller and Turner (2010) identified development of personnel and strategic managerial perspective as contributing to IT project success. Researchers suggest a combination of technical hard skills and project leadership soft skills to build the PM competence required for project success (Ballesteros-Sanchez et al., 2017; Ramazani & Jergeas, 2015).

This research compared project efficiency to the PM's undergraduate education type and commercial project management certification, for U.S. Department of Defense (DoD) IT projects. The research examined the possible relationship to project outcomes of combinations of technical and nontechnical education and project management training certification. Undergraduate degree and commercial project management certification are used as constructs to represent PM competency. Using education degrees and PM certifications to represent PM competency is consistent with existing research (Ahsan et al., 2013; Ballesteros-Sanchez et al., 2017). Understanding the relationship between project efficiency and PMs' education and training on U.S. DoD IT projects will provide valuable information to the greater IT PM community.

Literature Review

To alter the trend of high failure in IT development projects, IT community members recognize the need for better leadership and project management training to supplement IT technical education. IT project success rates will not continue to grow to acceptable rates without PMs who combine project management and leadership competence with technical competence. IT PM competency and project efficiency have been widely addressed in project management academic literature.

Theoretical Orientation

The contingency theory of project management provides the underpinning for this research. Contingency theory expands on the earlier theory of critical success factors (CSF) by emphasizing project differences. CSF project management theory posits that project success can be achieved by following a set of project management best practices. The seminal work of Pinto and Slevin (1987) codified the literature on CSF theory. Pinto, Slevin, and associates provided the preponderance of oft-cited work on project management (Pinto & Mantel, 1990; Pinto & Prescott, 1988; Pinto & Slevin, 1989; Slevin & Pinto, 1986). The work of Pinto, Slevin, and associates closely links to the Project Management Body of Knowledge (PMBOK) (Project Management Institute, 2013), the most recognized publication on project management in the United States.

Context matters. Building on CSF theory, contingency theory of project management asserts that the application of success factors varies with the project context. Differing project environments, such as government IT projects, require different application of project management practices. Shenhar, Dvir, and associates led contingency project management research (Dvir & Shenhar, 1992; Shenhar & Dvir, 1996; Shenhar et al., 2002). Shenhar and Dvir (1996) developed a model contingent on project types

with expanded independent and dependent variables from CSF-based studies. According to contingency theory, projects exhibit consistent relationships among factors and measurements within a given project context versus a

general set of universal factors (Söderlund, 2011). Other contingency theory-based studies expanded success factors, criteria, and project typology (Ahimbisibweet et al., 2015; Cserhati & Szabo, 2014; Mazur et al., 2014). Contingency theory provides the foundation for examining the relationship between project success and PM education and training, within the specific context of DoD IT projects.



PM Education and Training Background

Trepidation around the influence of the PM's education and training on IT project performance has been an ongoing concern addressed in the literature. Chua (2009) identified three internal project risk factors contributing to IT project failure: people, process, and technical. The PM competencies contributing to project outcomes include hard technical skills, leadership soft skills, and application of project management skills (also considered soft skills). In his seminal work, Brooks (1974) states that the software PM's lack of knowledge leads to overoptimistic estimates that in turn significantly contribute to project failure. Similarly, Flyvbjerg (2013, pp. 321–344) distinguishes between causes and root causes in explaining project underperformance, identifying the root cause as PM ignorance of project risk, also considered optimism. Research identified PM competency as critical to project success (Pinto & Slevin, 1989; Shenhar et al., 2002). Technical knowledge is needed to understand the scope for the product or service. Soft skills are those leadership and project management skills required to motivate the team and influence stakeholders.

“ IT project success rates will not continue to grow to acceptable rates without PMs who combine project management and leadership competence with technical competence. ”

Researchers continue to seek the right balance of technical and project management training in educational institutions and training agencies (Ballesteros-Sanchez et al., 2017; Pandya, 2014). Udechukwu et al. (2015) identified the importance of a holistic curriculum combining both engineering and project management content. Ramazani and Jergeas (2015) suggested that educational institutions and training agencies should consider both project management and technical skills versus maintaining “just technical skills” (p. 51). Niederman et al. (2016) identified the need to achieve “the right balance of technical and nontechnical skills within an education program” for management positions (p. 45). Ramazani and Jergeas (2015) recommended that universities and training activities include both project management and technical skills.

Project management literature has identified the need for technical competence in education and training. Some researchers have suggested technical competence as a prerequisite for selection as a PM. While significant research points to project management and leadership skills as more important to project success, practitioners cannot ignore technical factors. PMs require technical expertise to keep pace with changing technology

(Marion et al., 2014; Pandya, 2014). Agrawal and Thite (2006) cited the need to keep up with the latest technology and continuous learning about challenges experienced by software project leaders. Some project management literature emphasized the importance of technical skill for project management success (Brill et al., 2006; Dubois et al., 2015; Niederman et al., 2016; Oak & Laghate, 2016).

“ Soft skills are those leadership and project management skills required to motivate the team and influence stakeholders. ”

Technical skills that IT professionals selected as PMs possess differ from the soft skills required to manage the project. Project managers selected based on technical expertise too often do not possess the leadership and management skills required for successful team supervision (Agrawal & Thite, 2006; Darrell et al., 2010). Dulaimi (2005) suggests that IT PMs with engineering backgrounds focus too much on the technical details. IT professionals list project management and leadership skills as more critical to IT project success than software engineering technical knowledge (Agrawal & Thite, 2006). Orchestrating the entire project demands a significantly different skill set than providing technical leadership. Lack of project management skills contributes to IT project failure (Carvalho & Rabechini, 2015; Catanio et al., 2013; Rivera-Ruiz & Ferrer-Moreno, 2015).

While these studies recommend combining technical and soft skill education based on independent evaluation, the studies do not examine the interactive effects of technical education and soft skills training on project outcomes. McLeod and MacDonell (2011) note that “many factor-based studies implicitly assume” that individual factors in software projects are independent, when this is not the case in practice (p. 46). This study addressed that gap in the literature by examining the interactive effects of education and training.



PM Certification Impact on Project Outcomes

With the exponential growth in Project Management Professional (PMP) certifications and the PMBoK becoming the de facto commercial guide to project management, researchers might start with the hypothesis that project management certifications are critical to project success. PMP certifications have grown from 1,000 in 1993 to 412,503 in 2010 (Catania et al., 2013). Other IT project management certifications, such as PRINCE 2, ITIL Foundation, Scrum Alliance's Scrum Master, and SAFe credentials have also thrived (Catania et al., 2013; Cicmil & Gaggiotti, 2018). Contingency theory suggests that one certification might be more appropriate for a specific type of IT project; however, research has not supported a link between certifications and improved project outcomes. Several studies reviewed just the PMP (Robertson, 2015; Starkweather & Stevenson, 2011), while others addressed multiple certifications (Abu-rumman, 2014; Nazeer & Marnewick, 2018; Shackman, 2015) or did not specify the certification type (Catania et al., 2013).



The academic literature does not support a relationship between project management certifications and a project manager's success in scope, schedule, and cost. Nazeer and Marnewick (2018) concluded that project management certification did not influence project performance on South African IT projects. Catania et al. (2013) found no higher project success rate among certified PMs and uncertified PMs in a quantitative study. For PMs with a PMP, Abu-rumman (2014) found "limited evidence to suggest it has any significant impact on the relative success or failure of projects" (p. 5). Findings by Starkweather and Stevenson (2011) indicated no difference in project success rates between PMP-certified PMs and uncertified PMs. Robertson (2015), in a study using secondary data from 1,444 RGS consulting firm projects, found PMP certification correlated with poorer



project outcomes. Shackman (2015) found “insufficient evidence to indicate whether accreditation, certification, and credentialing will improve program outcomes” (p. 110). More research is required to confirm or refute the findings. The extent to which the combined PM’s education and PM certification predict project efficiency has not been sufficiently studied. The researcher found no evidence of the possible interactive effects of the IT PM’s education and certification on project efficiency.

Qualitative studies show the importance of certifications for selecting PMs, PM career enhancement, and perceptions of success. In a study of PMs seeking voluntary project management certifications “collected 10 years apart (2004 and 2014),” Blomquist et al. (2018) found that voluntary project management certifications’ benefit is more aligned with looking good to prospective employers than being good at project management (p. 498). Other qualitative studies suggest earning a commercial project management certification helps the career progression of an IT PM by demonstrating dedication to the guild (Armstrong, 2015; Dubois et al., 2015; Rivera-Ruiz & Ferrer-Moreno, 2015).

Summary

The PM must guide the project team and influence stakeholders to create the collaborative synergy for success. PMs must also manage the trifecta of project success metrics: scope, schedule, and cost. While definitions of success vary, literature consistently values the PM’s soft skills of leadership and project management as critical to project success. Gaps in the PM’s competence contribute to project failure. This study addressed possible combinations of a PM’s education and training to examine the interactive effects.

Methodology

The study involved an exploratory, comparative model to examine the statistical relationship among variables without specifying the direction of the influence. The research, based on a survey using the project success assessment questionnaire (PSAQ) (Shenhar & Dvir, 2007), compared the project efficiency for DoD IT projects to the IT project manager's undergraduate education type and project management certification. The PSAQ instrument collected data on the PM's perception of project success using the construct of project efficiency, which included scope, schedule, and cost. The addition of demographic questions on the PM's type of undergraduate education and commercial project management certification assisted the researcher in comparing combinations of education and training certification. No known study has examined the interaction effect of PMs' education and certification on project efficiency, nor has any study compared education type for PMs. An exploratory study is more appropriate because the findings may not be generalizable to the entire community of PMs (Sekaran & Bougie, 2013, p. 97).

“ The extent to which the combined PM's education and PM certification predict project efficiency has not been sufficiently studied. ”

Data Collection Methods and Procedures

The method for the collection of data was a random sample using a web-based survey tool. The researcher limited the population of PMs for the study to DoD IT PMs. For this study, the terms *project manager* and *program manager* were used interchangeably because the DoD defines the term program manager as an equivalent to project manager (DoD, 2015). DoD IT PMs are a subset of the general DoD PM population. As of October 2018, 24,534 PMs and IT acquisition professionals were members of the Defense Acquisition Workforce, each with various levels of education and certification (Defense Acquisition University [DAU], 2018). General demographics for the DoD project management and information technology population break down as follows:

- 74% male, 26% female
- 77% white, 11% black, 5% Asian, 2% multi, 5% other/unspecified
- 80% civilian, 20% military
- Average age: 46

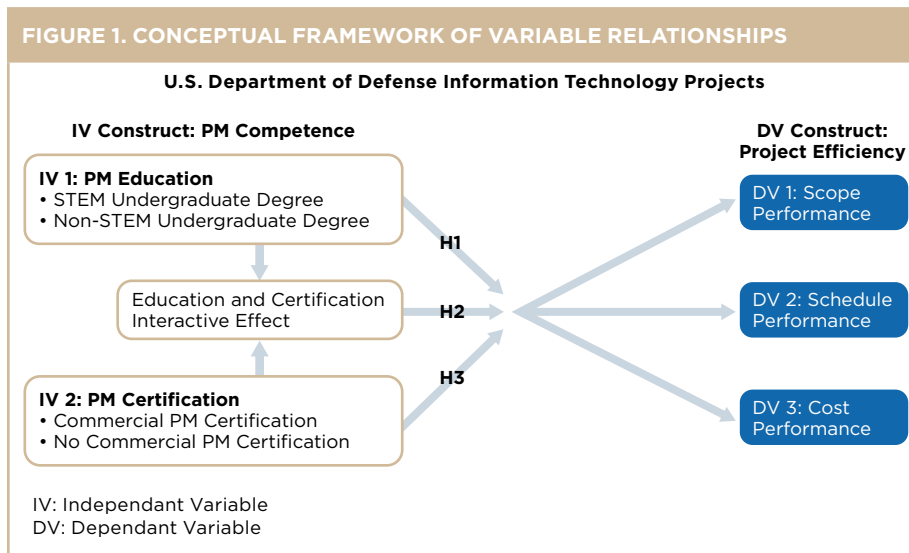
The researcher acquired the sample from a sample frame of 8,895 members of the project management and IT population. The sample acquired came from a DAU email list of the IT and PM career field members who possessed a DoD level III certification as the sample frame. (Note. Defense Acquisition Workforce members must earn a DoD level III certification before leading a DoD IT project.) Limiting the sample frame had several benefits. The limited sample frame reduced statistical model error related to various levels of DoD certification training. Also, the DoD level III certification for PM and IT requires a minimum of 4 years' experience (DAU, 2018). By restricting the sample frame to those with at least 4 years of experience, the researcher reduced error in the model resulting from inexperience. Prior studies indicated that experience positively correlated to project success (Müller & Turner, 2010; Ropponen & Lyytinen, 2000; The Standish Group, 2013). Additionally, the 8,895-person sample frame used for recruiting participants was below the 10,000 limit for surveying DoD personnel. Using a sample frame creates a source of sample error (Vogt, 2007, p. 80); however, the researcher used the sample frame to balance DoD survey limitations and the need to achieve the minimum sample size.

The researcher developed a recruitment email, which invited recipients who managed a DoD IT project to participate. The email was sent to each of the 8,895 Defense Acquisition Workforce level III certified IT PMs, ensuring an equal opportunity to respond to the survey, thus ensuring a random sample (Vogt, 2007, p. 78). The researcher used the entire sample of IT PM respondents after eliminating respondents who did not complete the survey after reading the informed consent. Demographic data included only undergraduate degree type, gender, project size, and commercial PM certification identification. The questions were multiple choice using generic categories designed to limit respondent identification risk.



Variables

The study included the independent variables of undergraduate education type defined as a science, technology, engineering, and mathematics (STEM) undergraduate degree or nontechnical undergraduate degree (non-STEM) (U.S. Department of Education, 2012) and commercial project management certifications. The researcher defined the dependent variables as scope performance, schedule performance, and cost performance per the definitions in the PMBoK (Project Management Institute, 2013). The dependent construct is project efficiency based on the dependent variables of cost, schedule, and scope from survey data (Figure 1).



The unit of analysis was IT PM, representing a case in the statistical analysis. The survey captured the PM's education type and project management certification. The survey also measured the PM's perception of project scope, schedule, and cost performance.

Research Questions

The main omnibus research question, supported by null hypotheses, simultaneously asked about differences across all project management success variables. If the omnibus test found mean differences, then the researcher probed subquestions for each variable.

1. To what extent does project management success in scope, schedule, and cost compare among PMs with STEM and non-STEM education?

Hypothesis H1₀: There is no statistically significant difference in scope, schedule, and cost performance comparing education type of STEM and non-STEM.

$$(H_0: \mu_1 = \mu_2 = \mu_3 \dots = \mu_k)$$

2. To what extent does project management success in scope, schedule, and cost compare among PMs with a commercial certification and without a commercial certification?

Hypothesis H2₀: There is no statistically significant difference in scope, schedule, and cost performance comparing commercial PM certification and no commercial PM certification.

$$(H_0: \mu_1 = \mu_2 = \mu_3 \dots = \mu_k)$$

3. To what extent do interaction between education type (STEM and non-STEM) and commercial certification compare with project management success in scope, schedule, and cost performance?

Hypothesis H3₀: There is no statistically significant difference in education type of STEM and non-STEM and commercial PM certification interaction effect comparing scope, schedule, and cost performance.

$$(H_0: \mu_1 = \mu_2 = \mu_3 \dots = \mu_k)$$

For each mean difference discovered between any groups of independent and dependent variables, the researcher applied the following subquestions. If one or more of the mean vectors differed significantly ($H_a: \mu_n \neq \mu_k$), then the alternative hypotheses would have been tested, as appropriate (Sekaran & Bougie, 2013).



Power Analysis

The estimated minimum sample size was 98. The estimate was calculated using GPower 3.1. The researcher based an estimate in GPower 3.1 on two binary IVs (predictors), resulting in four groups and three DVs (response variables). The GPower 3.1 analysis resulted in $F(6, 186) = 2.1476$,

$p < .001$ with power $(1-\beta)$ of 0.99 and a type I error α of 0.05. Chen (1999) found a 0.13 Pillai's trace to be significant in a critical success factors study of the banking industry. In this sample estimate, the researcher used a Pillai's trace value of 0.1 to be conservative. Of the four test statistics used to evaluate group differences, Pillai's trace is more robust in instances of unequal sample sizes among groups and violations of assumptions (Mertler & Vannatta, 2013, p. 125). The recommended sample size also exceeds the recommended minimum sample size of 64 for two-tailed hypotheses in a quantitative comparative study (Onwuegbuzie & Collins, 2007, p. 288).

Human Subjects Protection

The population for this study is adult, DoD government IT PMs. The most significant risk in this study is the possible compromise of personally identifiable information (PII). Since the project survey instrument did not collect PII and the survey was anonymous, the risk is assessed as low. The researcher obtained DoD information collection process approval reflected in the approval number, RCS# DD-A&S-2675.

The benefit gained from the study benefits all PMs equally by contributing to the general body of knowledge, therefore adhering to the ethical principle of justice. The results of this study provided only one data point that builds on the knowledge gained from previous work. As such, researchers and practitioners should view this study only in conjunction with similar studies in the field. A risk arises in the interpretation of findings when this study is viewed alone. The entire body of research should contribute to ongoing project management legislative and policy discussions.

Results and Discussion

The researcher undertook this study to investigate the potential relationship between project success and IT PM education and training. Factorial MANOVA and the nonparametric Mann-Whitney post hoc test were used to analyze the data in SPSS data analysis software. Discussion of the results of the analysis follows.

Sample

The sample was collected using an Internet-based survey tool. The survey was open for 2 weeks to ensure the study reached the minimum sample size. Responding to the recruitment email, 384 volunteer participants logged on to the survey web page. After reading the informed consent, 70 did not complete any portion of the survey after recognizing the survey did not apply to them. Five respondents marked not applicable to each answer, so the

researcher eliminated the cases from the study. The sample included data from the two independent variables (IVs) and three dependent variables (DVs), representing two constructs listed in Table 1.

Constructs	Variables	Level of Measurement	Operational Definition
Construct 1: Project Manager Competence	Undergraduate Education Type (IV)	Nominal	STEM vs. Non-STEM degree
	Project Management Certification (IV)	Nominal	Commercial PM Certification
Construct 2: Project Efficiency	Scope (DV)	Interval	Scope Assessment
	Schedule (DV)	Interval	Schedule Assessment
	Cost (DV)	Interval	Cost Assessment

While the sample size is more than double the minimum required, the survey response rate of approximately 4% is well below the recommended minimum response rate of 50% (Kittleson, 1997) or average online survey response rate of 33% (Nulty, 2008). The low response rate could introduce nonresponse bias resulting in a sample that is not representative of the population (Sekaran & Bougie, 2013). Field (2013) suggested bootstrapping, a method of resampling, as a method to check for potential nonresponse bias. Based on the assumption that late respondents are very similar to nonrespondents (Creswell, 2014), resampling using bootstrapping identifies the bias if the resampled means do not equate to the original sample means. Bootstrapping, with a 95% bias corrected and accelerated confidence interval using 1,000 resamples, resulted in bootstrapping means of 3.30, 3.46, and 3.06 for schedule, cost, and scope, respectively. The bootstrapping results nearly matched the sample means of 3.31, 3.46, and 3.07, respectively. The bootstrapping result combined with the male-female demographic match between the population and sample indicates a representative, random sample, which significantly reduced nonresponse bias risk.

Missing Data

The remaining data had 15 missing responses randomly scattered throughout the data set covering cost, schedule, scope, commercial certification, and education representing only 5% of the data shown in Table 2. The cases with missing data were eliminated using the pairwise method. The final sample size of 284 more than doubled the minimum sample size.

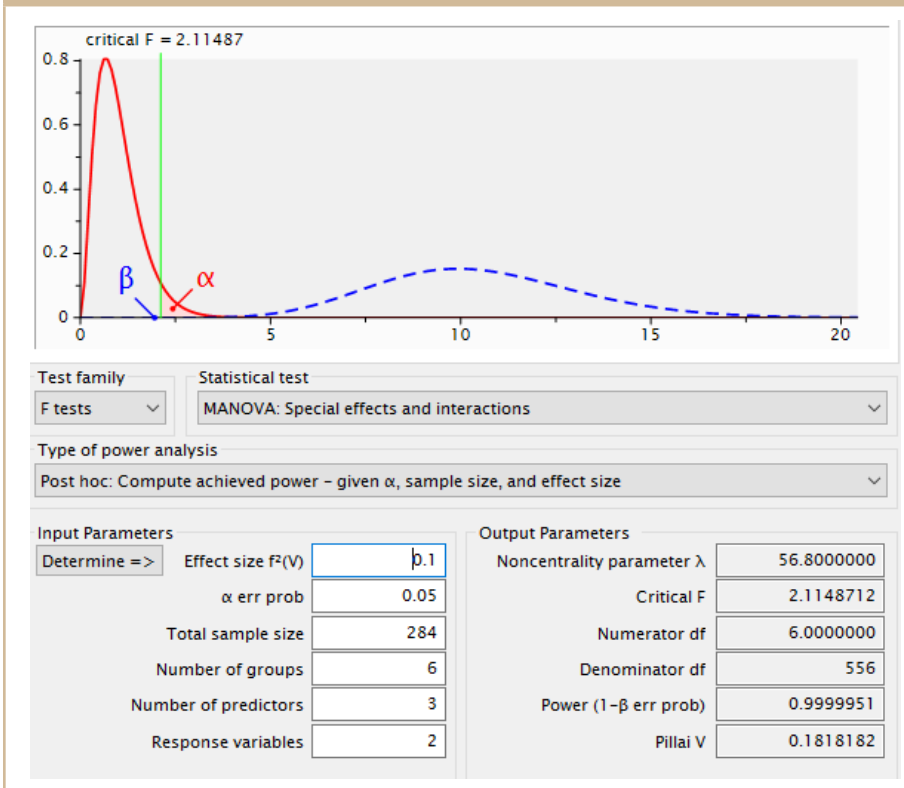
TABLE 2. SAMPLE CASES AND MISSING DATA

Dependent Variables	Valid N	Percent	Missing N	Percent	Total N	Percent
Project on Time	284	95.0%	15	5.0%	299	100.0%
Project on a Budget	284	95.0%	15	5.0%	299	100.0%
Minor Scope Change	284	95.0%	15	5.0%	299	100.0%

Sample Power

The sample had power (1-β) of 0.99 with a type I error α of 0.05 established using GPower 3.1, as outlined in Figure 2. The result aligned with the a priori power analysis in this study that reported $F(6, 186) = 2.1476, p < .001$ with power (1-β) of 0.99 and a type I error α of 0.05.

FIGURE 2. G-POWER 3.1 MANOVA POWER CALCULATION



Descriptive Statistics

The sample gender demographic was 75.2% male and 24.8% female. The sample demographic closely matched the population demographics of 74% male and 26% female, which indicates the sample is representative of the

population. IT PMs responded to the survey-based responses on both large and small IT projects, with 63.4% of projects having a contract value below \$100 million and 36.6% having a contract value at or above \$100 million. The sample had 232 (77.6%) respondents without a commercial PM certification and 67 (22.4%) with a commercial PM certification. Those claiming a commercial PM certification were asked to specify which PM certification. The respondents with a PM certification possessed the following types of certifications:

- 52 PMP
- 4 Lean Six Sigma
- 2 ITIL Foundation Basic
- 2 Certified Scrum Masters
- various PM certifications held by others

In the sample, 154 (51.5%) participants had an undergraduate STEM degree, and 145 (48.5%) did not possess a STEM degree. Table 3 outlines the descriptive statistics for the sample.

TABLE 3. UNADJUSTED MEANS FOR SCHEDULE, COST, AND SCOPE BY CATEGORIES

Dependent Variables	Compl PM Certification	STEM Degree	Mean	Std Deviation	N
Project on Time	No	No	3.29	1.343	110
		Yes	3.48	1.240	110
		Total	3.39	1.293	220
	Yes	No	3.16	1.313	25
		Yes	2.95	1.450	39
		Total	3.03	1.391	64
	Total	No	3.27	1.334	135
		Yes	3.34	1.314	149
		Total	3.31	1.322	284
Project on a Budget	No	No	3.35	1.282	110
		Yes	3.75	1.085	110
		Total	3.55	1.202	220
	Yes	No	3.24	1.200	25
		Yes	3.10	1.447	39
		Total	3.16	1.348	64
	Total	No	3.33	1.264	135
		Yes	3.58	1.220	149
		Total	3.46	1.245	284

TABLE 3. UNADJUSTED MEANS FOR SCHEDULE, COST, AND SCOPE BY CATEGORIES (CONTINUED)

Dependent Variables	Compl PM Certification	STEM Degree	Mean	Std Deviation	N
Minor Scope Change	No	No	3.05	1.210	110
		Yes	3.15	1.221	110
		Total	3.10	1.214	220
	Yes	No	2.96	1.172	25
		Yes	2.92	1.265	39
		Total	2.94	1.220	64
	Total	No	3.04	1.200	135
		Yes	3.09	1.232	149
		Total	3.07	1.215	284

Reliability and Validity

The PSAQ is a well-established instrument with published reliability and validity information. Hagen and Park (2013) reported a Cronbach's α score of 0.906 for organizational outcomes using the PSAQ project efficiency construct. Ahmed and bin Mohamad (2016) reported Cronbach's Alpha of 0.759 for the PSAQ project efficiency construct. This study computed a Cronbach's Alpha of 0.803 for the three dependent variables that constitute the construct of project efficiency. In this study, correlation coefficients were calculated with Pearson r 0.418, 0.523, 0.765 significant at $p < 0.01$ (2-tailed), for scope-schedule, scope-cost, and schedule-cost, respectively, as shown in Table 4.

TABLE 4. PEARSON R VALIDITY DATA

Dependent Variables		Project on Time	Project on Budget	Minor Scope Change
Project on Time	Pearson Correlation	1	0.765**	0.418**
	Sig. (2-tailed)		0.000	
	N	297	291	289
Project on a Budget	Pearson Correlation	0.765**	1	0.523**
	Sig. (2-tailed)	0.000		0.000
	N	291	292	285
Minor Scope Change	Pearson Correlation	0.418**	0.523**	1
	Sig. (2-tailed)	0.000	0.000	
	N	289	285	291

Note. **Correlation is significant at the 0.01 level (2-tailed).

Tests for Normality, Linearity, and Homoscedasticity

The researcher conducted tests for the assumptions of normality, linearity, and homoscedasticity using the five variables: Scope (Minor Scope Change), Schedule (Project on Time), Cost (Project on Budget), PMCert (Coml PM Certification), and STEMDegree (STEM Degree). For the Scope variable, skewness was -0.078, -0.040, -0.072, and -0.071 for no PMCert, yes PMCert, no STEMDegree, and yes STEMDegree, respectively. For the Schedule variable, skewness was -0.341, 0.016, -0.234, and -0.294 for no PMCert, yes PMCert, no STEMDegree, and yes STEMDegree, respectively. As well, cost skewness was -0.504, 0.093, -0.293, and -0.537 for the four categories, respectively. While overall skewness scores are near the normal distribution, kurtosis scores are not consistently normal, ranging from -0.837 to -1.466. Table 5 shows the Kolmogorov–Smirnov, or K-S tests with a nonnormal result of $p < .001$ for each group. Field (2013) states “that if you have a large sample size, then tests like K-S will lead you to conclude that even very minor deviations from normality are ‘significant’” (p. 191).

TABLE 5. K-S NORMALITY TEST

Dependent Variable	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Project on Time	0.267	284	0.000	0.855	284	0.000
Project on a Budget	0.258	284	0.000	0.870	284	0.000
Minor Scope Change	0.261	284	0.000	0.860	284	0.000

MANOVA is robust regarding normality with sufficient cell sample sizes and provided the nonnormality is not from outliers. With unequal sample sizes, only a few DVs, and a sample size of about 20 in the smallest cell, MANOVA is robust to violations of normality (Mertler & Vannatta, 2013, p. 124). The smallest cell in this sample is 25.

For MANOVA, the researcher tested linearity between the DVs with Pearson r correlation coefficients. Pearson r was 0.418, 0.523, 0.765 significant a $p < 0.01$ (2-tailed), for scope-schedule, scope-cost, and schedule-cost, respectively, as shown in Table 4. Overall, the linear relationships were moderate.

The researcher conducted a MANOVA homogeneity test with PMCert and STEMDegree as the IVs and scope, schedule, and cost as DVs. Table 6 shows Box’s Test of Equality of Covariance. With $F(18, 36864) = 0.904, p = .574$, equal variance can be assumed; therefore, the Wilks’ Lambda will be used as the test statistic.

TABLE 6. BOX'S TEST OF EQUALITY OF COVARIANCE MATRICES^a

Box's M	16.781
F	0.904
df1	18
df2	36,863.991
Sig.	0.574

Note. Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

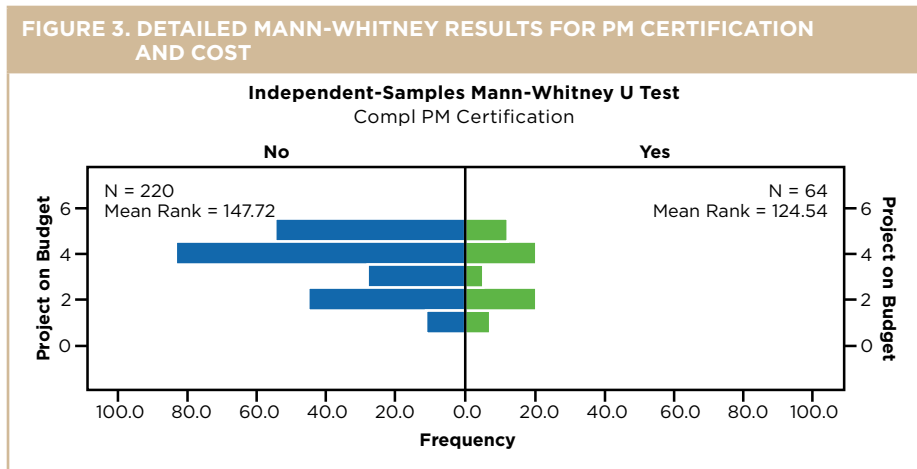
^aDesign: Intercept + PMCert + STEMDegree + PMCert * STEMDegree

Hypothesis Testing

Factorial, two-way, MANOVA was used to test the null hypothesis that there is no statistically significant difference in scope, schedule, and cost performance when comparing education type of STEM and non-STEM. Results indicate that Commercial PM Certification [Wilks' Lambda = .983, $F(3, 278) = 1.569$, $p = .197$, $\eta^2 = .017$] do not significantly affect the combined DVs of scope, schedule, and cost. STEM undergraduate degree [Wilks' Lambda = .994, $F(3, 278) = .513$, $p = .674$, $\eta^2 = .006$] does not significantly affect the combined DVs of scope, schedule, and cost. Interaction between PM certification and STEM Degree [Wilks' Lambda = .991, $F(3, 278) = .846$, $p = .470$, $\eta^2 = .009$] does not significantly affect the combined DVs of scope, schedule, and cost. The researcher could not reject the null hypotheses.

To further address concerns of violations of the assumption of multivariate normality, the nonparametric Mann-Whitney post hoc test was conducted on the main effects. MANOVA provides the capability to test interactive effects; Mann-Whitney does not. While robust parametric tests such as MANOVA are preferable to nonparametric tests in testing hypotheses, nonparametric tests overcome problems with the normalcy of the distribution (Field, 2013). Nonparametric tests also overcome objections to the use of Likert scale survey data as interval data (Robertson, 2012) by ranking the data. The results align with the MANOVA results that the null hypothesis must be accepted in each area, except for Coml PM Certification showing a significant relationship with cost in Figure 3. Scope for IT PMs with STEM Degrees ($\bar{x} = 144.31$) did not differ significantly from IT PMs without STEM Degrees ($\bar{x} = 140.50$), $U = 10,327.50$, $z = .412$, $p = .681$, $r = .024$. Schedule for IT PMs with STEM Degrees ($\bar{x} = 144.62$) did not differ significantly from IT PMs without STEM Degrees ($\bar{x} = 140.16$), $U = 10,373.00$, $z = .476$, $p = .634$, $r = .028$. Cost for IT PMs with STEM Degrees ($\bar{x} = 150.03$) did not differ significantly from IT PMs without STEM Degrees ($\bar{x} = 134.19$), $U = 11,180.00$, $z = 1.687$, $p = .092$, $r = .100$. Scope performance for IT PMs with Coml PM Certification ($\bar{x} = 134.20$) did not differ significantly from IT PMs without

Coml PM Certification ($\bar{x} = 144.91$), $U = 6,509.00$, $z = -.968$, $p = .333$, $r = .057$. Schedule for IT PMs with Coml PM Certification ($\bar{x} = 126.84$) did not differ significantly from IT PMs without Coml PM Certification ($\bar{x} = 147.05$), $U = 6,038.00$, $z = -1.808$, $p = .071$, $r = .107$. Cost performance for IT PMs with Coml PM Certification ($\bar{x} = 124.54$) did differ significantly from IT PMs without Coml PM Certification ($\bar{x} = 1470.72$), $U = 5,890.50$, $z = -2.065$, $p = .039$, $r = .123$, as shown in Figure 3.



The cost mean significant difference between IT PMs with and without Coml PM Certification ($p = .039$) is misleading when considering the size of the sample ($N = 284$). The test becomes significant at $p < .05$. The result is very close to the cutoff point. Additionally, the effect size, $r = .123$, is small. For this reason, the Mann-Whitney result does not invalidate the MANOVA result.

Conclusions, Limitations, Implications, and Recommendations

This quantitative research study expanded on the existing research regarding the relationship between commercial project management certification and project success; and limited research on PM undergraduate technical education and project management success. The study has additional significance within DoD. The U.S. Congress and the Office of the Secretary of Defense for Acquisition and Sustainment are considering legislation and policy related to STEM education and commercial PM certification requirements for DoD PMs. The recent 2016 Program Management Improvement Accountability Act requires commercial PM certification

for federal agencies with a partial exception for DoD. While the legislation exempted DoD from parts of the legislation, the results of this study could inform the discussion about the merits of commercial project management certifications for DoD IT PMs.

Conclusions Based on the Results

For the first research question, the study found no significant difference in project efficiency success between PMs with STEM and non-STEM undergraduate education. The literature results in this area are mixed. This study suggests that organizations should recruit PMs with either a STEM or non-STEM degree. Requiring a technical education as a prerequisite to becoming a project manager, as suggested by Pandya (2014), may not yield better project outcomes. Several studies in the literature emphasized the importance of technical skill for project management success (Brill et al., 2006; Dubois et al., 2015; Niederman et al., 2016; Oak & Laghate, 2016). IT PMs should pursue balanced education and training between hard technical skills and project management soft skills. Growing evidence shows the need to balance technical and project leadership soft skills (Ballesteros-Sanchez et al., 2017; Cicmil & Gaggiotti, 2018; Darrell et al., 2010). The results of this study suggest a reexamination of a technical degree as a prerequisite to assignment as an IT PM. Contingency theory posits that a deeper examination of specific degrees and specific certifications in follow-on studies may reveal educational benefits for specific IT project types.



IT PMs should pursue balanced education and training between hard technical skills and project management soft skills.

As expected, the study found no link between a commercial PM certification and project efficiency. The study confirms the findings of previous quantitative studies (Abu-rumman, 2014; Catanio et al., 2013; Nazeer & Marnewick, 2018; Quan & Cha, 2010; Robertson, 2015; Starkweather & Stevenson, 2011). This study adds to the growing body of evidence that commercial PM certifications do not impact project efficiency. Other qualitative studies suggest earning a commercial project management certification helps the career progression of an IT PM by demonstrating dedication to the trade (Armstrong, 2015; Blomquist et al., 2018; Dubois et al., 2015; Rivera-Ruiz & Ferrer-Moreno, 2015).

This study recommends that organizations seeking to improve IT project outcomes should not require their PMs to attain commercial PM certification, as the benefits balance tilts more toward the individual's career than IT

project efficiency. Voluntary commercial PM certifications do have value for the individual PM interested in career advancement. Compulsory commercial PM certification eliminates the benefit to the organization of identifying potentially successful IT PMs who pursue certification. Organizations should support the voluntary pursuit of commercial PM certifications by PM candidates versus requiring commercial certification. Industry and organization-specific project management training on contextual application of critical success factors is required to improve IT project outcomes (Pinto & Prescott, 1988; Pinto & Slevin, 1989; Shenhar et al., 1997).



Limitations

Some limitations exist for this study. First, the population of DoD IT PMs is significantly smaller than the overall population of PMs; therefore, the study may have limited applicability to the greater project management community. Second, if the study showed a relationship between PMs' education and training and project performance, a relationship does not guarantee causation. IT PMs manage IT projects in the public and private sector around the globe; however, this study focused on public sector IT PMs in DoD. External validity needed to generalize the finding to the general IT PM population in various countries for both the public and private sector is limited. Other limitations of this study included the ordinary subjectivity associated with surveys and mono-source bias (Conway & Lance, 2010). The survey measured respondents' perception of cost, schedule, and scope variance versus secondary data. The use of Likert scale survey data for parametric statistical analysis requiring interval or ratio data, while widely accepted, remains controversial (Field, 2013; Robertson, 2015).

“ This study recommends that organizations seeking to improve IT project outcomes should not require their PMs to attain commercial PM certification, as the benefits balance tilts more toward the individual's career than IT project efficiency. ”

The study population was DoD IT PMs who had completed Level III Defense Acquisition Workforce certification. For DoD IT PMs, the Defense certification is a prerequisite for selection as an IT PM on a Defense IT project. In examining the relationship of commercial PM certification and project efficiency, the DoD certified population removed possible error with differing levels of DoD certification training; however, this potentially resulted in evaluating the incremental impact of a commercial PM certification over having a DoD certification. Perry (2017) found that PMs who held certifications in addition to a PMP had better project outcomes than PMs with only a PMP. This study did not support the Perry (2017) finding that multiple certifications improved project outcomes. The relationship could limit the external validity of the study.

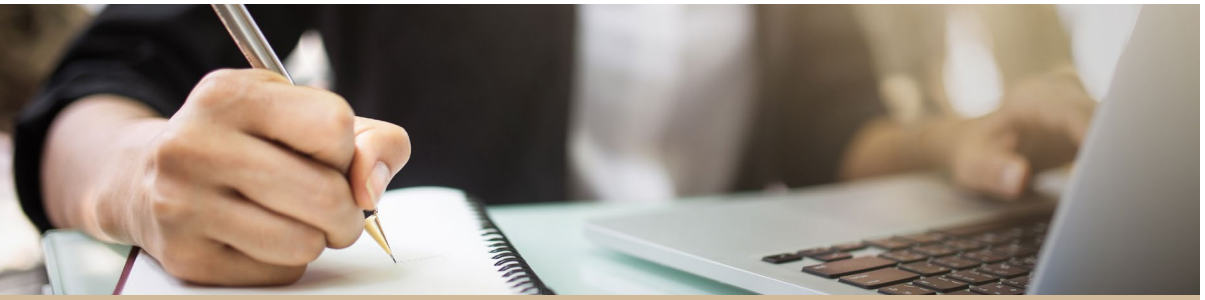
Internal validity is threatened by potential nonresponse bias. While bootstrapping and sample gender demographics reduce the threat of nonresponse bias, such bias must be recognized. Nonresponse bias threat would hold greater importance if the study found a statistically significant relationship. Follow-on research using secondary data will overcome risks associated with survey results.



This study focused on explicit knowledge gained through training and education without fully examining tacit knowledge gained through experience. Wateridge (1997) suggested that 60% of project management skill can be learned on the job, but formal training is required. Hao and Swierczek (2010) suggested that more training and certification is required to build PM skills. Other studies have found tacit knowledge gained through experience relates to positive project outcomes (Coleman, 2014; Sauer et al., 2007).

Implications for Practice

This exploratory study suggests organizational executives and chief information officers sponsor more research on the interactive effects of IT PM education and training in order to achieve the appropriate balance of soft and hard skills' education and training. Further study using secondary data will provide researchers the opportunity to do a deeper examination of educational differences by subdividing STEM and non-STEM education into more specific areas of undergraduate study. DoD leaders should exercise caution in enacting policy designating commercial PM certification as mandatory until more studies expand on this exploratory research. This study provided initial work to reduce the knowledge gap concerning the interactive effects of IT PM education and training.



Knowledge of IT PM competencies' impact on DoD IT project outcomes contributes to the ongoing dialogue regarding legislation and policy for PM education and training (Defense Acquisition University Structure Act, 1990; Program Management Improvement Accountability Act, 2016). Recent research recommends changing current IT PM education and training certification to adopt a new approach that balances hard and soft skills' competencies (Nazeer & Marnewick, 2018). Additionally, this research contributed to the body of knowledge on appropriate factors for selecting and training IT PMs (Ahsan et al., 2013; Mazur et al., 2014).

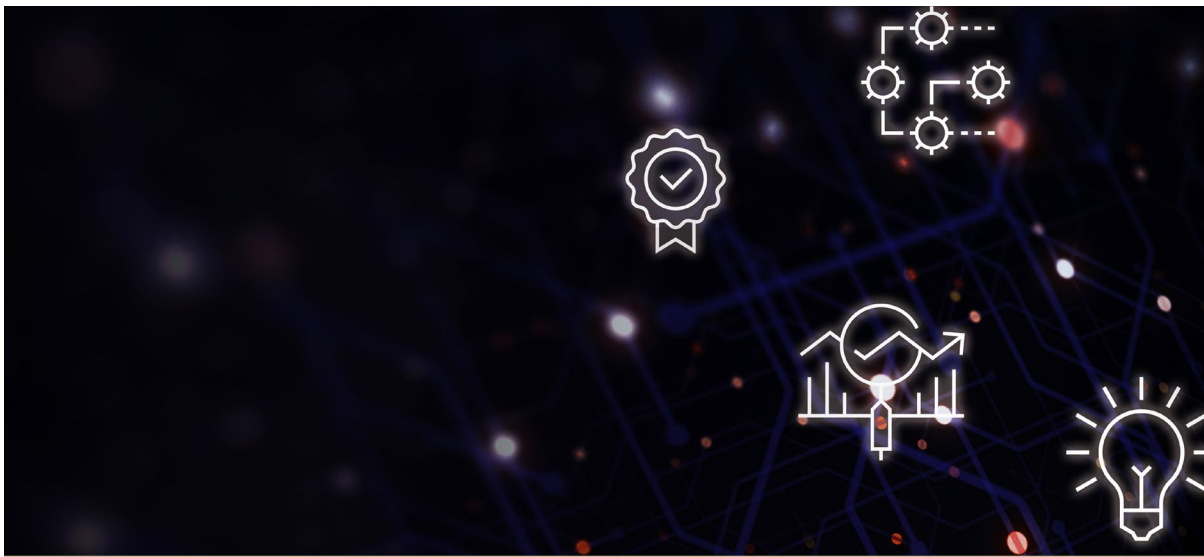
Recommendations for Further Research

This study began the exploration of interactive effects of PM competence critical success factors. While significant research exists on the critical success factors that contribute to PM competence, the interactive effects of the factors require more research. Research needs to be expanded across several PM competence factors in multiple contexts including various industries, in both public and private sectors. Udechukwu et al. (2015) and Pandya (2014) noted that in addition to technical education, management skills training was necessary for PMs. Niederman et al. (2016)

identified a trend in adding nontechnical skills training to information systems curricula. These studies did evaluate the impact of the combined training on project outcomes.

Defense acquisition executives could benefit from sponsoring continued academic research on IT PM education and training to inform future legislation and policy. The researcher recommends further research on DoD IT PM competencies' relationship to project efficiency using secondary data to overcome limitations associated with survey data. A follow-up study of the DoD IT PM education and training certification relationship to project efficiency using DoD secondary data would add validity to this exploratory study. The DoD collects significant data on IT program-and-project performance and associated PM education, training, and experience (DoD, 2015). Granting DoD researchers access to the available data would expand the statistical methods available for analysis, thus improving study validity. Also, the researcher recommends additional research on the overall approach to education and training requirements for IT PMs.

This is an exploratory study based on the survey respondents' perceptions of cost, schedule, and scope. Follow-on studies could overcome this limitation associated with surveys by using secondary data from DoD projects. Using secondary data from DoD projects would increase the sample size sufficiently to allow for the examination of different PM certifications and specific degrees beyond STEM and non-STEM. Such an examination could support or refute the contingency theory claim that context matters for project success factors.



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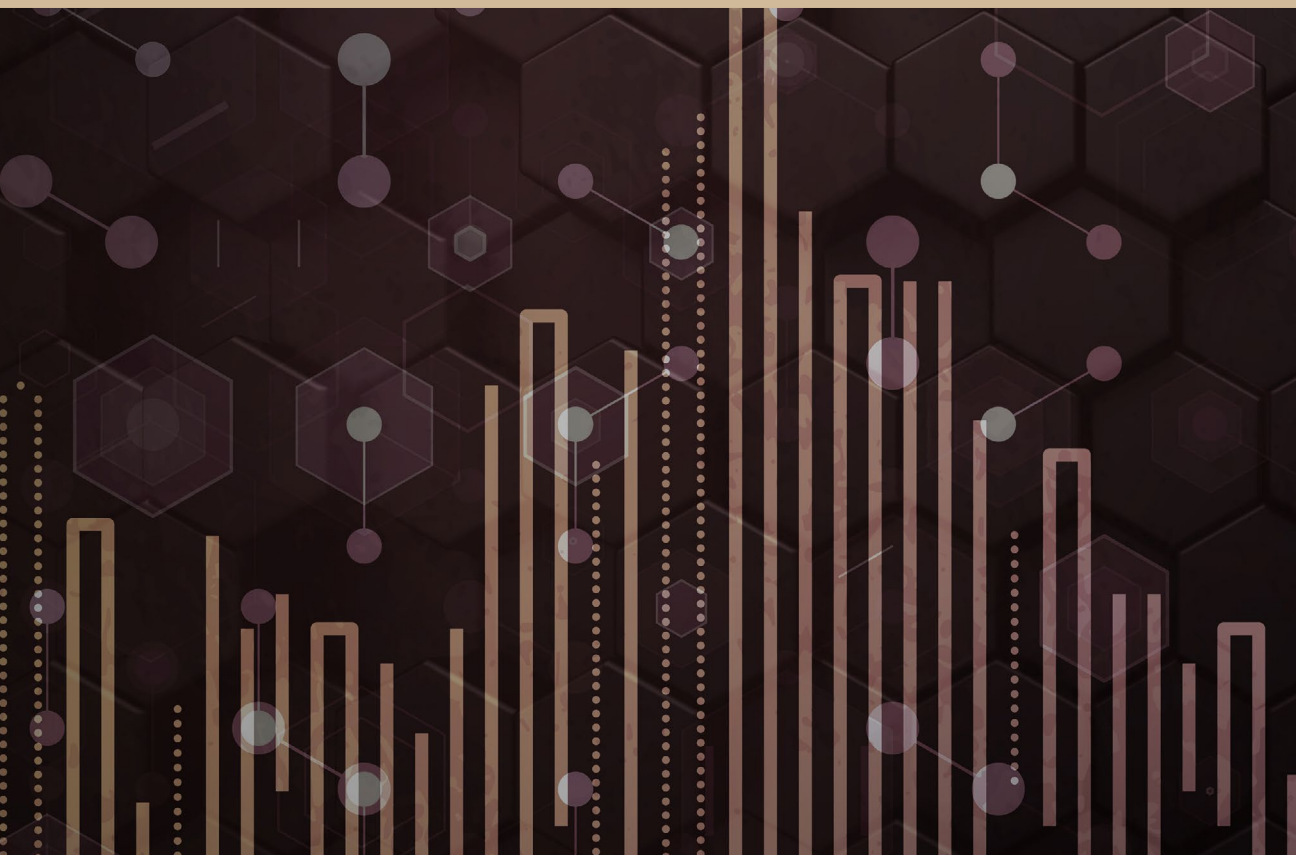
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Appendix

PROJECT SUCCESS ASSESSMENT QUESTIONNAIRE (PSAQ)

This survey captures project manager (PM) perceptions of project success to include scope, schedule, and cost. The PSAQ developed by Shenhar and Dvir (2007) contains 28 questions using a 5-point Likert scale. The instrument displayed consistent reliability and validity in several studies (Ahmed & bin Mohamad, 2016; Hagen & Park, 2013; Shenhar & Dvir, 2007). Respondents were asked to answer these questions based on the most recent Department of Defense (DoD) IT program/project managed. The researcher added demographic questions to create independent variable groups for the study. The final demographic question confirms that the survey respondent worked on DoD IT projects.

Demographic questions:

1. Several commercial project management certifications have been earned by project managers and program managers to include:
 - Certified Associate in Project Management (CAPM@)
 - Project Management Professional (PMP@)
 - Master Project Manager (MPM@)
 - Certified Project Manager (CPM)
 - other commercial PM certifications

Do you possess a commercial project management certification?

Yes (Please specify) _____

No

2. The U.S. Department of Education defines a science, technology, engineering, and mathematics (STEM) undergraduate degree as included in the following areas of study:
 - mathematics
 - physical sciences
 - biological/life sciences
 - computer and information sciences
 - engineering/technologies

Do you possess a STEM undergraduate degree?

Yes (Please specify) _____

No

3. What is your gender?

Male

Female

4. What was the largest IT project or program you managed?

DoD IT program or project with project value under \$100 million

DoD IT program or project with project value at or over \$100 million

Have not managed a DoD IT program or project

Author Biography

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joined the Defense Acquisition University faculty after serving 23 years in the U.S. Marine Corps and working in the defense industry. He currently serves as Executive Program Management faculty. Dr. Parker holds a bachelor's degree in Economics from Pennsylvania State University, an MBA from Old Dominion University, and a PhD in Information Technology from Capella University. He earned a Project Management Professional (PMP) certification and a certified scrum master certification from the Scrum Alliance. Dr. Parker also completed a postgraduate Executive Data Science certificate program from Johns Hopkins University.

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HOW TO BAIL OUT A DEFENSE CONTRACTOR:

CASES ON SECURING A SUPPLY CHAIN *IN EXTREMIS*



James M. Hasik

How can governments effectively bail out faltering defense contractors? While the idea may seem politically distasteful, any defense ministry with domestic suppliers may view the problem as supplier management *in extremis*. Reviewing nine prominent bailouts of defense contractors from the past 50 years, the author draws two conclusions. Providing long-term demand is very likely necessary and sufficient to maintain industry structures. Providing short-term infusions of cash may be necessary to maintain programs, but it is not always sufficient. If legislators and defense officials wish to consider either approach for short-term or long-term objectives, they should also consider the historical lessons of the financial and information asymmetries between government and industry, and the general uncertainty over how technologies will evolve.

DOI: <https://doi.org/10.22594/dau.20-858.28.02>

Keywords: *Supply Chain, Finance, Cashflow, Industrial Structure*

Overview: Credible Commitment Not to Commit?

In September 2011, as American military spending tightened, Deputy Assistant Secretary of Defense Brett Lambert delivered a warning to the Common Defense industry conference in Washington, DC (Fryer-Biggs, 2011). There would be “no bailouts.” The Pentagon’s industrial policy chief was insisting that contractors “should not anticipate substantial Pentagon financial assistance” in the event of financial difficulty. Lambert was earnest, but he was also an official from an administration that had recently and massively bailed out automotive manufacturers and banks. Observers reasonably wondered whether the secretary didst protest too much. The Obama Administration would never really face the question with defense contractors, but the question remained. However, the recent massive increases in governmental debt worldwide, incurred as a macroeconomic response to the COVID-19 pandemic, may severely curtail future military spending, putting pressure on the business of many contractors. Level-headed thinking about bailouts today seems warranted.

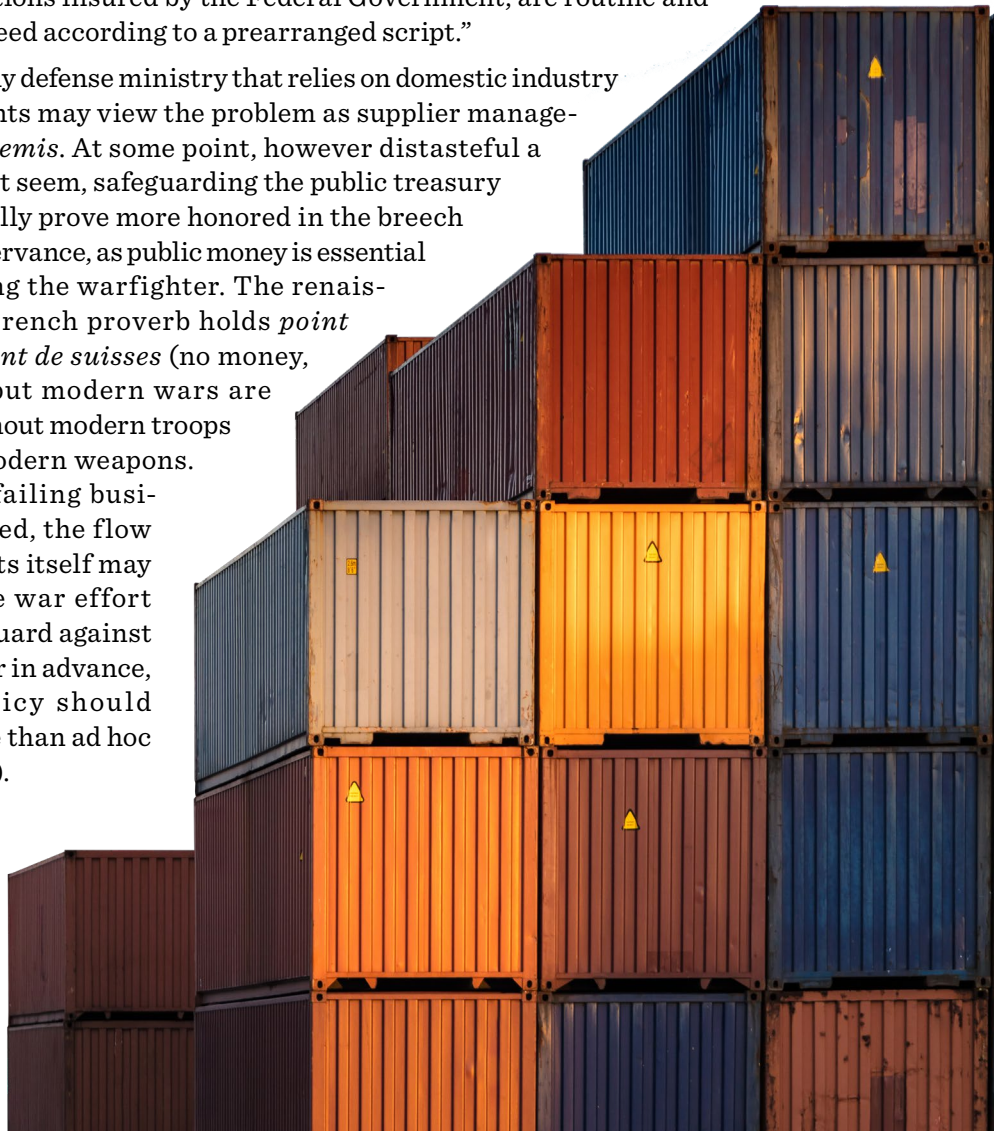
“ The recent massive increases in governmental debt worldwide, incurred as a macroeconomic response to the COVID-19 pandemic, may severely curtail future military spending, putting pressure on the business of many contractors

The question, of course, is hardly new. In 1994, during the earlier post-Cold War downturn, the Air Force had been sufficiently concerned about solvency in its supply chain to commission a study from RAND on how to forecast bankruptcies among its contractors (Bower & Garber, 1994). That same year, the Department of Defense (DoD) established an office, now known as Industrial Policy, and statutorily mandated in 10 U.S.C. 2508, “to monitor production capabilities, stockpiles and supply chain flows and prospective bottlenecks of critical sub-tier defense items” (Nelson, 2016). Since passage of the 2011 National Defense Authorization Act, the Industrial Policy office has also managed the overall Manufacturing Technology (Mantech) program, which since 1956 has separately provided longer term investments in manufacturing processes, techniques, equipment, and workforce training. Statutory authority for loans and loan guarantees is contained in Title III of the Defense Production Act of 1950, section 108(b), codified as

50 U.S.C. 2061. Statutory authority for broader assistance, such as unilateral increases or advanced progress payments, is contained in Public Law 85–804, and codified in 50 U.S.C. 1431–1435 (Mullen, 2002).

Outside these bureaucratic channels, special appropriations have been made as well. In the wake of Hurricane Katrina in 2005, Congress eventually provided just under \$100 million to repair Northrop Grumman’s shipyards in Louisiana and Mississippi (see discussion that follows). After various economic crises and natural disasters, companies do get bailed out. In the process, moral hazard naturally intercedes, for “it is essentially impossible for a bailout not to set a precedent for the future” (Poole, 2008). When special favors are granted, the negative-sum game of cronyism necessarily arises, for the losses by those tapped as payers substantially outweigh the gains of the favored payees (Henderson, 2012). Normal processes can thus be important for lending political legitimacy (Levitin, 2011). Painter (2009) cites a precedent for standards: Some bailouts, particularly those of “depository institutions insured by the Federal Government, are routine and usually proceed according to a prearranged script.”

Moreover, any defense ministry that relies on domestic industry for armaments may view the problem as supplier management *in extremis*. At some point, however distasteful a bailout might seem, safeguarding the public treasury will eventually prove more honored in the breach than the observance, as public money is essential to supporting the warfighter. The renaissance-era French proverb holds *point d’argent, point de suisses* (no money, no Swiss), but modern wars are not won without modern troops *and* their modern weapons. Unless the failing business is funded, the flow of armaments itself may fail, and the war effort as well. To guard against such disaster in advance, bailout policy should thus be more than ad hoc (Block, 1992).



Theory: Cash in the Short Run, Demand in the Long Run

In July 2017, the Trump Administration moved in towards more active management, announcing a comprehensive assessment of the entire defense industrial base. The Federal Government would more consciously develop an industrial policy calibrated towards reducing the risk of disruption; the assessment would particularly look for “supply chains with single points of failure or limited resiliency, especially at suppliers third-tier and lower” (Exec. Order No. 13,806, 2017). Thus, as in the past, the DoD would seek to save programs, preserve industrial structure, and avoid scandals—just with an expanded and perhaps more conscious plan.

“ In the long run, unsteady businesses need more than immediate cash. They need real demand that will sustain the delivery of more cash over time, to recapitalize their physical assets and sustain their balance sheets

The causes of failures of suppliers can be sorted into short- and long-term problems. In the long term, entire industries disappear without sustained demand. In armaments, that demand is often monopsonistic, so governments can find themselves entirely responsible for sustaining the business of firms that they hope they will not need to bail out. However, even with sustained demand, mismanagement within the firms can lead to liquidity problems in the short run. This may require immediate infusions of cash to save a business with otherwise strong, long-term prospects.

The consequences of failures of suppliers can also be sorted into short- and long-term effects. Almost immediately, programs may falter, and deliveries of products interrupted, as reconstituting corporate capabilities under another banner can take time, even if all the staff and supplier relationships can be preserved. For years to come, the industry producing the general type of product will be structurally altered, as one firm will be missing. Market entry may be possible, but perhaps with firms without lasting positive relationships with the government. Industrial evolution is not strictly to be feared, but the closeness of deeply embedded processes and shared goals partly explains the notable stability of defense industries, in the United States and around the world (Dombrowski & Gholz, 2006).

If the consequences can be sorted temporally, then perhaps remedies can be as well. In the short run, faltering businesses need cash. Income and assets are interesting, but cash pays the bills and thus maintains operations. In the long run, unsteady businesses need more than immediate cash. They need real demand that will sustain the delivery of more cash over time, to recapitalize their physical assets and sustain their balance sheets. Demand from enduring governmental customers signals to suppliers, potential joint venture or alliance partners, and other customers that the firm is a going concern. I thus argue that short-term infusions of cash can bail out contractors in the short run, and that sustained demand is necessary for that bailout to stick.

Model and Hypotheses: Binary Observations on Cases

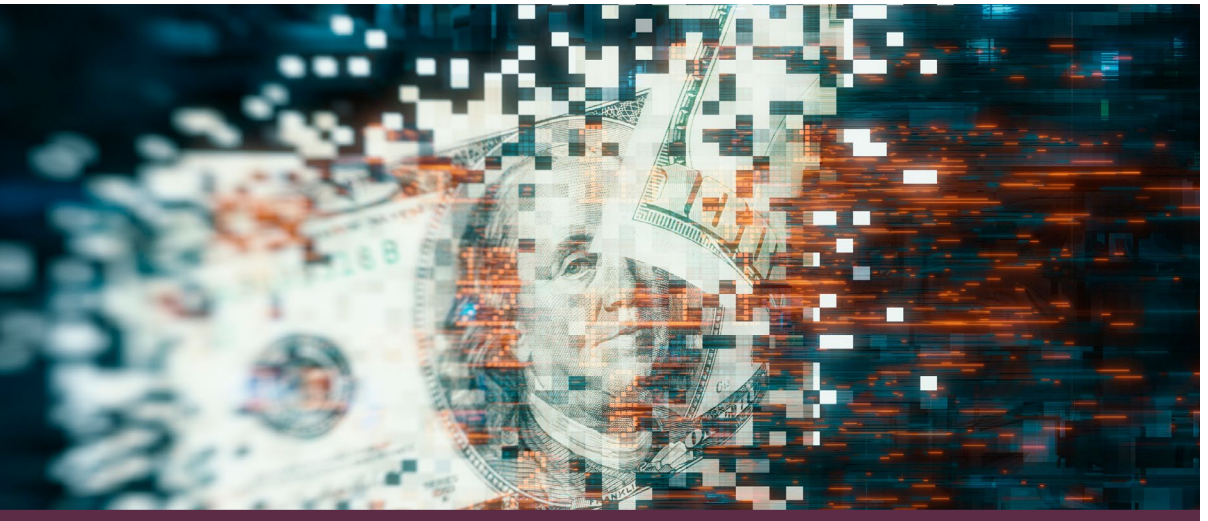
To model these theories, I identify two dependent variables and two independent variables, all binaries. *Short-Term Cash Provided* takes the value YES if the government or its agents arranges for a short-term infusion of cash into the company (and otherwise NO). *Long-Term Product Demand* takes the value YES if the Federal Government or another buyer is continuing to purchase the company's product or similar products in the future. *Short-Term Program Survival* takes the value YES if the government's program to purchase that product continues for at least 1 year. *Long-Term Industry Structure Sustained* takes the value YES if the number of firms in the industry producing that product does not decrease between the attempted bailout and the Federal Government's next effort to procure the product.



In reviewing cases, I identify six means by which the government attempted to bail out the companies in question: a price increase in the contract, a loan guarantee, a direct purchase of the product when the product is not strictly needed, advancing progress payments in the contract, other direct cash payments, and a long-term purchase agreement to increase investor confidence and secure financing. I map the first five to *Short-Term Cash Provided*, and long-term purchase agreements to *Long-Term Product Demand*, though I also admit other means by which long-term demand may be sustained, and perhaps by other customers. I then hypothesize, in keeping with my previous discussion, that the provision of short-term cash contributes to program survival, and that long-term product demand sustains industry structure:

H1: Short-Term Cash Provided → Short-Term Program Survival

H2: Long-Term Product Demand → Long-Term Industry
Structure Sustained



Cases: Nine Examples of Defense Contractor Bailouts

To test the models, and understand what is possible, I review nine of the more prominent bailouts of defense contractors of the past 50 years: four from the middle of the Cold War, two at the end of the Cold War, and three since that time. I have selected the cases largely based on their historical prominence and the availability of a certain richness of information about the processes and outcomes of the bailouts. Two address firms making primary materials, and seven address original equipment manufacturers

(OEMs), though I do not draw inferences from this difference. Their activities span four North American Industry Classification System (NAICS) codes: 336411, Aircraft Manufacturing; 325180, Other Basic Inorganic Chemical Manufacturing; 325220, Artificial and Synthetic Fibers and Filaments Manufacturing; and 336611, Ship Building and Repairing. For the analysis of the effects on industry structure, I further refine these administratively determined industries, to better compare the individual companies to direct competitors with similar products. I segment 336411 into Airlifter Manufacturing, Airliner Manufacturing, and Combat Jet Aircraft Manufacturing, as companies in these segments do not necessarily compete across those segments. I further refine 325180 into NH_4ClO_4 Manufacturing; 325220 into Long-Fiber Rayon Manufacturing; and 336611 into Naval Ship Building, for similar reasons. With each case I observe variables and code accordingly.

Lockheed and the C-5

In 1971, Lockheed extracted a \$500 million unilateral price increase from the U.S. Air Force to finish its work developing the C-5 Galaxy cargo aircraft. The company had beaten Boeing's offer of a military cargo version of the 747 by agreeing to a fixed-price development and delivery program. The contract was originally awarded under Defense Secretary Robert McNamara's Total Package Procurement concept, which would be excoriated by the FitzHugh Commission in 1969 (Boyne, 1998; Fitzgerald, 1972). Lockheed's second lot contract contained a complex pricing formula that would have made up its mounting losses, but the cash flow problems were so extreme that the company could not wait that long. The affair has been cited as evidence that defense contractors can shake down governments by citing the risk of their own financial leverage. Indeed, from the 1950s through the 1990s, U.S. contractors generally carried twice the debt load of comparably sized non-defense U.S. firms. This commitment to future debt service limited room for renegotiating procurement contracts, which paradoxically increased the value of the firms by increasing the *ex ante* costs of bankruptcy, and transferring those to the government (Spiegel, 1996). Regardless, Lockheed (now Lockheed Martin) remains in the airlifter manufacturing business today, continuing to produce the C-130 series of aircraft.

Coded Observations

Short-Term Cash Provided: YES

Long-Term Product Demand Sustained: YES

Short-Term Program Survival: YES

Long-Term Industry Structure Sustained: YES

Lockheed and the L-1011

Concurrent with the C-5 development, Lockheed was also urgently petitioning the government for \$250 million in loan guarantees to launch its L-1011 Tri Star airliner. The company assured the U.S. Congress that the project would break even at sales of 195 to 205 aircraft, but that given its financial distress, the money could not be obtained from commercial sources. The project was a wholly commercial affair, but the company was a valued military contractor in financial distress. The affair has since become a case study of informational asymmetries in industrial subsidy: Lockheed knew more about the project than the government, and was able to color its estimates quite effectively. A more critical analysis, which included the company's cost of capital, predicted break-even at roughly twice that number (Reinhardt, 1973). Indeed, by 1981, when the company decided to terminate production, Lockheed had amassed cumulative orders of 244 aircraft, but expected to lose roughly \$2.9 billion on the project overall (Ropelewski, 1981). Lockheed then exited the business of manufacturing commercial airliners.

Coded Observations

Short-Term Cash Provided: YES


Long-Term Product Demand Sustained: NO

Short-Term Program Survival: YES

Long-Term Industry Structure Sustained: NO

Grumman and the F-14

In March 1971, Grumman Aircraft notified the Navy Department that it wanted to renegotiate its fixed price development and production program for F-14 fighter jets. Grumman claimed to have lost \$1 million on each of the first 86 aircraft and was refusing to deliver any more without a price increase. A budget decision by Deputy Defense Secretary David Packard cut the program roughly in half, though at a much higher unit price. Grumman's rescue was facilitated not merely by the government of the United States, but also by that of Iran and a consortium of banks. The Shah ordered 80 F-14s, which improved the economics of the overall program, and seven U.S. banks and Melli Bank of Iran loaned the company \$250 million to maintain positive cash flow (Zumwalt, 1976). Some 40 years on, those "Persian Cats" continue to serve in the Islamic Republic of Iran Air Force, with lasting political consequence (Cenciotti, 2015). The F-14, however, was the last combat jet that Grumman would build for any customer. Its successor company, Northrop Grumman, today builds the RQ-4 Triton jet drone, and is designing the B-21 Raider jet stealth bomber. The corporate capabilities



for those efforts, however, came from the predecessor companies Teledyne Ryan and Northrop, respectively. More to the point, the 1994 merger of the Northrop and Grumman reduced the number of combat jet aircraft manufacturers in the United States by one.

Coded Observations

Short-Term Cash Provided: YES

Long-Term Product Demand Sustained: NO

Short-Term Program Survival: YES

Long-Term Industry Structure Sustained: NO

McDonnell Douglas and the KC-10

Between 1982 and 1990, the U.S. Air Force (USAF) purchased 60 KC-10 Extender aircraft from McDonnell Douglas. The aircraft were nearly off-the-shelf purchases, differing from their DC-10 airliner cousins only in the loading system, the size of the cargo door, the strength of the cargo floor, and (naturally) the boom and hoses (Werrell, 2003). The purchase was publicly justified as an insurance policy against unexpectedly severe wing corrosion in the KC-135 Stratotankers—an issue used 25 years later to justify the USAF's later faltering tanker-leasing deal with Boeing (see discussion that follows). One of the government's unspoken motivations, however, may have been saving the company's airliner production from closure before its MD-11 would be ready in 1990 (Arnold & Porter, 1991). The Air Force was committed to buying large cargo aircraft from U.S. sources, and Lockheed had just exited the market. The DC-10 was admittedly only a modest commercial success, with 446 eventually built (Martin & Hartley, 1995). However, the order did help the company sustain production, as the Air Force's procurements stretched over 8 years. While the USAF would not buy another commercial-derivative aircraft from McDonnell, it would eventually buy its C-17 (see discussion that follows). For its part, McDonnell Douglas would indeed go on to design and build the MD-11 airliner as the next installment in its product line.

Coded Observations

Short-Term Cash Provided: YES

Long-Term Product Demand Sustained: YES

Short-Term Program Survival: YES

Long-Term Industry Structure Sustained: YES

PEPCON and NH_4ClO_4

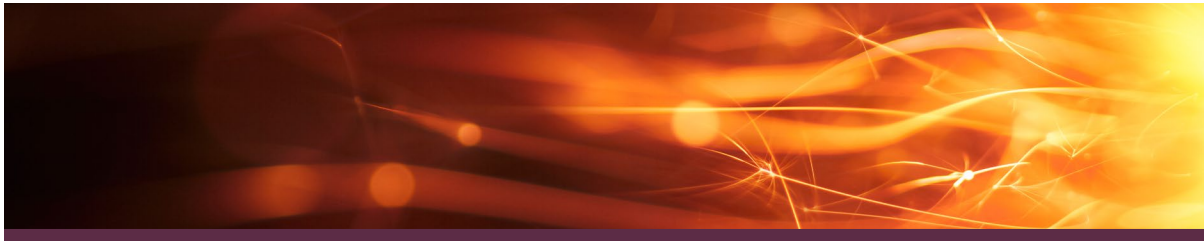
On May 4, 1988, an ammonium perchlorate (NH_4ClO_4) plant in Henderson, Nevada, exploded, killing two people and injuring several hundred. While the toxic cloud avoided nearby Las Vegas, the blast eliminated 20 million pounds of annual capacity for producing solid rocket fuel oxidizer—roughly half of that available in the United States. The plant was owned by Pacific Engineering and Production Company of Nevada (PEPCON), a unit of American Pacific Corporation. The other 20 million pounds of capacity was only two miles away at Kerr McGee's H_4ClO_4 plant. As the cause of the blast was undetermined, the latter company promptly shut down for safety inspections, at least temporarily halting U.S. production.

A new plant would cost \$50 to 60 million, and insurance coverage was incomplete. PEPCON immediately requested funding from the Federal Emergency Management Agency (FEMA) to assist with rebuilding. This was quickly denied. Under the Federal Disaster Relief Act, FEMA could only supply funds if state and local resources were likely to be exhausted (Disaster Relief Act, 1974). However, the State of Nevada, Clark County, and the City of Henderson all considered rebuilding to be PEPCON's problem. Failure to insure adequately was also not considered a governmental problem, particularly when the insurers were suing PEPCON over its safety practices (Linke, 1996).

All the same, this *was* a problem for the Federal Government, because 90% of U.S. perchlorate purchases were for the military and NASA. Solid rocket fuel demand was decreasing with the winding down of the Cold War, but the space agency was planning a robust return to Space Shuttle flights, after the



loss of the *Challenger* 2 years before. Each Space Shuttle stack equaled the propellant of about 273,000 Hellfire missiles (Butler, 2011). Demand was forecast to eventually fluctuate somewhere over 50 million pounds annually. The loss of the plant, however, was not universally alarming: on May 18, 1988, the National Security Council rejected the NASA Administrator's plea that the president declare a national emergency.



Instead, Robert Costello, the Under Secretary of Defense for Acquisition, chaired an Ammonium Perchlorate Advisory Group. Kerr McGee offered to build another NH_4ClO_4 plant far from Henderson, under the condition that the Federal Government provide a 4-year supply contract for the entirety of the output. PEPCON wanted a piece of this action as well, but with its own supply contract and a loan guarantee to facilitate private financing. Given the government's projections of its long-term demand, Costello's group chose to extend long-term purchase agreements to both companies, with PEPCON building a new plant in Utah and Kerr McGee remaining in Nevada.

In 2004, after a long history of environmental complaints (perchlorate in drinking water is thought to cause thyroid problems), Kerr McGee closed its plant and sold its remaining activities to American Pacific, which remains the sole American producer (Brean, 2004). The substance would not be formally regulated for some years thereafter, but the industrial question was settled (Vastag, 2011). For purposes of analysis, however, I conclude that the long-term purchasing agreement had a comparatively lasting effect: Kerr McGee did remain in the business for a further 16 years, during which NASA and the DoD purchased a great deal of NH_4ClO_4 from a duopoly, not a monopoly.

Coded Observations

Short-Term Cash Provided: YES

Long-Term Product Demand Sustained: YES

Short-Term Program Survival: YES

Long-Term Industry Structure Sustained: YES

Avtex Fibers and Long-Fiber Rayon

In early November 1988, Avtex Fibers of Front Royal, Virginia, ceased production. The company had been the sole domestic source of long-fiber rayon, a fourth-tier ingredient for the carbon-phenolic blankets in liquid-fired rocket nozzles. The Commonwealth had cited huge safety and environmental deficiencies at the plant, and the company lacked the estimated \$38 million to remedy the problems. This time, the National Security Council got involved quickly, and both NASA and the DoD extended long-term purchase agreements to Avtex to finance its cleanup and restart production. While the company was back in business in 3 months, it shut down permanently in early 1990 for the same reason. While the plant has been substantially remediated, it was for a time Virginia's largest Superfund site. Because the bailout proved unsuccessful within about a year-and-a-half, I conservatively code the short-term survival of the purchasing programs of the DoD's suppliers as NO. This case thus provides **disconfirming** evidence for the theory.

Today, however, rayon is the dominant precursor in only 1% of composite production. By early 2002, eight different U.S. firms were producing other composites suitable for rocket nozzles (DoD, 2002). Moreover, the rapid expansion of the industry for inputs into everything from aircraft wings to bicycles meant that defense contractors had a wide range of suppliers from which to choose. By 2006, the problem was not monopoly, but short-term shortage as producers were struggling to build enough capacity to chase *commercial* demand (Glader, 2006).

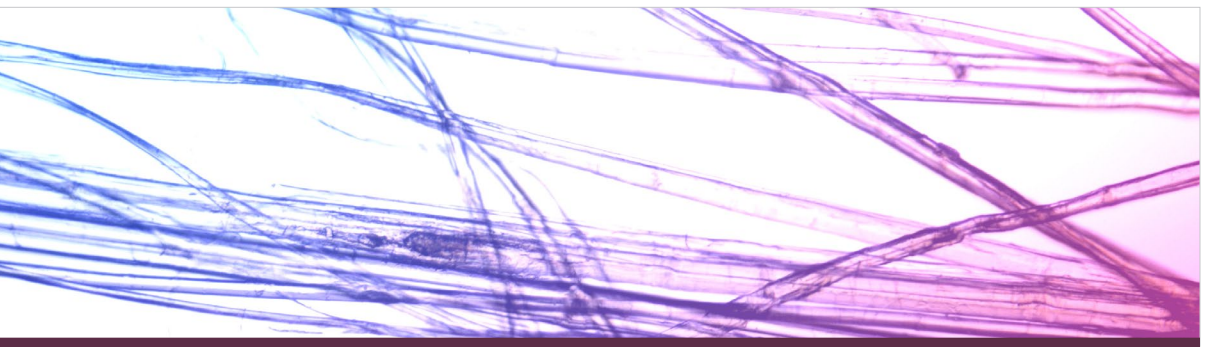
Coded Observations

Short-Term Cash Provided: YES

Long-Term Product Demand Sustained: NO

Short-Term Program Survival: NO

Long-Term Industry Structure Sustained: NO



McDonnell Douglas and the C-17

The early stages of the C-17 Globemaster III program featured frequent recriminations between the program office and the prime contractor, McDonnell Douglas. By September 1990, the relationship had grown so bad that the company and the government were exchanging alternative threats about stopping work or canceling the program. In response, Maj Gen Michael Butchko, the C-17 program director, met with senior management and arrived at an understanding. Against the advice of his accountants, the general ordered progress payments accelerated—an action clearly intended “to put some money into Douglas Aircraft Company because they have a financial problem” (Department of Defense Inspector General [DoD IG], 1993). Letters from outraged procurement officials eventually led to an investigation by the DoD IG. In January 1993, the IG recommended disciplinary action against five officials, including Butchko (Morrocco, 1993). In April of that year, Defense Secretary Les Aspin fired Butchko, and ordered that three of the remaining four be banned from again working in government procurement (Aspin, 1993). In a rebuttal to the secretary, the *Air Force* Inspector General insisted their actions lay “clearly within a range of acceptable managerial discretion”—they were merely aiming for a bailout (Heil, 1994; Kaczor, 1993, p. B2). For his part, Butchko went on to a long second career managing space launch operations. The Air Force, however, still has not purchased another new airlifter since the C-17, whose production ended in 2015. McDonnell Douglas was finally purchased by Boeing in 1997, so the number of potential domestic manufacturers of airlifters (and indeed airliners) decreased by one.

Coded Observations

Short-Term Cash Provided: YES

Long-Term Product Demand Sustained: NO

Short-Term Program Survival: YES

Long-Term Industry Structure Sustained: NO

Boeing and the KC-767

In 2002, the Air Force again raised an alarm about unexpectedly severe wing and engine pylon corrosion in the Service’s fleet of KC-135 aerial tankers. The Service considered several options, including an intensive program to rebuild the aircraft (which are very similar to 707 airliners), and the purchase of new A330 Multi-Role Tanker Transports (MRTTs) from Airbus. By early 2003, the USAF had rejected these options and settled on the acquisition of new 767 aerial tankers from Boeing. With additional controversy, the

Air Force decided to lease the tankers, with options to buy, in what would have been by far the largest lease of military equipment in history. It also would have constituted a non-competitive award in a competitive market.

Governmental transparency in the deal was particularly lacking. The USAF planned to lease the tankers from a special purpose entity (SPE), essentially a holding company that would be established to sell bonds backed by the value of the aircraft. The SPE would then procure those aircraft from Boeing and lease the aircraft to the USAF. Since the SPE (to be known as the KC-767 USAF Tanker Statutory Trust 2003-1) was to be wholly controlled by the USAF, the Air Force would be “leasing” the tankers to itself. Although the U.S. Federal Government does not consider itself subject to generally accepted accounting principles, this arrangement egregiously violated them. It was also a particularly bad financial deal, as the higher borrowing costs of the SPE would have cost the government a net penalty of roughly \$280 million.



What was transparent was the intent—saving the 767 production line (Crock et al., 2003). At the time, Boeing claimed to be in some commercial trouble, and the company was certainly falling behind rival Airbus in orders for new jets. The 767 in particular had won very few orders in preceding years and seemed outmatched in competitions against faster selling and more modern Airbus offerings. In August 2003, Boeing had a backlog of only 31 767s, while Airbus had a backlog of over 150 A330s (Bolkom, 2003). That October, Boeing announced that its 757 production line would close in late 2004, well before production would start on the replacement 7E7, later named the 787 Dreamliner (Boeing, 2003). Still, the company had determined that it could build 767s on its 747 production line at economic rates as low as one per month (Wallace, 2002).

At the time, this meant that the USAF could probably wait until at least early 2006 to decide whether to maintain the option to acquire 767s. Boeing could have chosen early, as it did with the 707 in 1991, to close the line against the USAF’s wishes, but the credibility of Airbus’s commitment then to a factory

in the United States made this an unlikely gambit. After some scandal, the government chose not to lease the tankers. After another failed procurement effort in 2007 and 2008, the Air Force tried a third time, with a second competition that stretched from 2009 into 2011. This final time, the government awarded the contract to Boeing for an updated tanker design, but one still based on the 767. In the meantime, several other air forces had purchased refueling tankers from Airbus, indicating long-term demand for that type of military aircraft. Boeing, of course, remains in the airliner and specifically the aerial tanker business today.

Coded Observations

Short-Term Cash Provided: NO

Long-Term Product Demand Sustained: YES

Short-Term Program Survival: NO

Long-Term Industry Structure Sustained: YES

Northrop Grumman Shipbuilding After Hurricane Katrina

In August 2005, Hurricane Katrina inflicted roughly \$1 billion in damage on Northrop Grumman's shipyards in New Orleans, Louisiana (Avondale) and Pascagoula, Mississippi (Ingalls). For its cooperation with state agencies in the aftermath of the storm, Mississippi Governor Haley Barbour called the company "another great corporate citizen" (Barbour, 2015). Much of the losses were to ships under construction, but for which responsibility had already been legally transferred to the Navy Department. The company also believed that its facilities were adequately insured, and so initially disclaimed interest in a federal bailout (Pae, 2005). But disagreements with its primary carrier, Factory Mutual Insurance Company, led to alternating lawsuits that were not fully resolved until 2013 (Anderson et al., 2010; Duroni, 2013).

Thus, early in 2006, Senator Trent Lott of Mississippi sponsored a narrowly approved amendment to pay Northrop to repair its own yards. The legislative language justified the eventual transfer of \$98 million for improving "the ability of shipbuilding facilities on the Gulf Coast to withstand damage from potential hurricanes or other natural disasters." Northrop was happy to take the money, even if it did not arrive quickly; contracts were not awarded until July 2007 (DID, 2007; Scully, 2006). Even so, there was never any serious financial distress. In 2005, Northrop Grumman's net income was \$1.4 billion, with cash flows from operations of \$2.6 billion. Of that, \$1.2 billion was used to repurchase the company's own shares—effectively returning the cash to its investors. The next year, net income was \$1.5 billion, and cash flows from operations were \$1.7 billion (Northrop Grumman, 2005,

TABLE. NINE BAILOUTS OF U.S. DEFENSE CONTRACTORS, 1971-2005

Case Description				Independent Variables—Observations		Dependent Variables—Predictions		Dependent Variables—Observations		Testing Theory				
Year	Company	Tier	Product	NAICS	Industry Segment	Means of Bailout	Short-term cash provided?	Long-term product demand sustained?	Short-Term Program Survival	Long-Term Industry Structure Sustained	Short-Term Program Survival	Long-Term Industry Structure Sustained	Providing short-term cash saves programs	Sustaining long-term demand maintains industry structure
1971	Lockheed	OEM	C-5A	336411	Airlifters	Price increase	YES	YES	YES	YES	YES	YES	CONFIRM	CONFIRM
1971	Lockheed	OEM	L-1011	336411	Airliners	Loan guarantee	YES	NO	YES	NO	YES	NO	CONFIRM	CONFIRM
1971	Grumman	OEM	F-14	336411	Fighter jets	Price increase, Loan guarantee	YES	NO	YES	NO	YES	NO	CONFIRM	CONFIRM
1982	McDonnell Douglas	OEM	KC-10	336411	Airliners	Product purchase	YES	YES	YES	YES	YES	YES	CONFIRM	CONFIRM
1988	PEPCON	Primary material	NH ₄ ClO ₄	325180	NH ₄ ClO ₄	LT purchase agreement	YES	YES	YES	YES	YES	YES	CONFIRM	CONFIRM
1988	Avtex	Primary material	Long fiber rayon	325220	Long fiber rayon	LT purchase agreement	YES	NO	YES	NO	YES	NO	DOES NOT	CONFIRM
1993	McDonnell Douglas	OEM	C-17	336411	Airlifters	Advanced progress payments	YES	NO	YES	NO	YES	NO	CONFIRM	CONFIRM
2002	Boeing	OEM	KC-767	336411	Airliners	LT purchase agreement	NO	YES	NO	YES	NO	YES	CONFIRM	CONFIRM
2005	Ingalls Shipbuilding	OEM	DDGs, LHDS	336611	Naval Shipbuilding	Cash payment	YES	YES	YES	YES	YES	YES	CONFIRM	CONFIRM

Note. OEM = Original Equipment Manufacturer

pp. 57–59; 2006, pp. 57–59). The shipyards were probably not earning their keep on the capital invested, but they were not hemorrhaging cash (Arnold et al., 2008). In short, Northrop got the bailout, but certainly did not need it to stay in business. For this reason, I code Long-Term Industry Structure Sustained as YES, but with an asterisk, commenting further below.

Coded Observations

Short-Term Cash Provided: YES

Long-Term Product Demand Sustained: YES

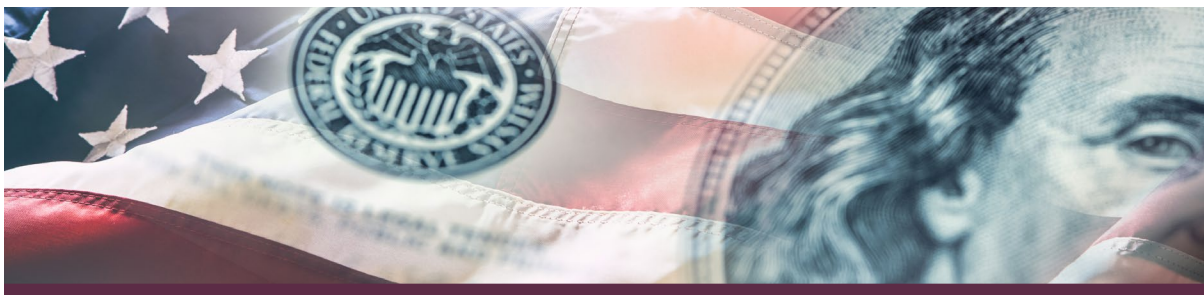
Short-Term Program Survival: YES*

Long-Term Industry Structure Sustained: YES

Observations: Cash Is King, Unless It Isn't

The table that follows summarizes the findings. The nine cases together provide strong evidence for the second hypothesis—that long-term governmental demand leads to sustained structures in defense industries. With a single disconfirming observation, they provide evidence of somewhat lesser strength for the first hypothesis—that short-term infusions of cash enable programs to survive.

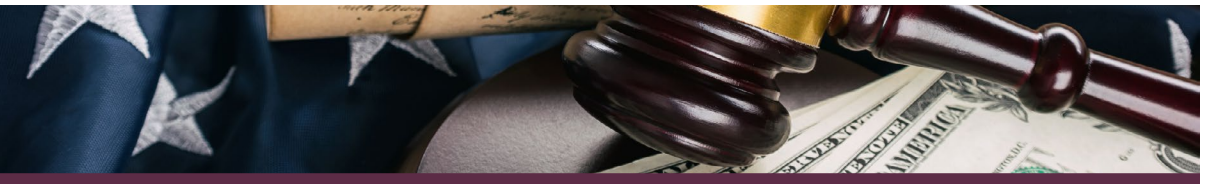
From these findings, I draw two conclusions. Providing short-term infusions of cash may be necessary to maintain programs, but it is not always sufficient. Programs—like those of the C-5A, the F-14, and the C-17—generally can be saved with influxes of cash, through price increases or accelerated progress payments. However, if the company in question is truly nonfunctional—as was the environmental disaster of Avtex—even large transfers of cash may be insufficient, and even in the short run. Industrial structure sometimes can be preserved when the government sustains its demand, at least long enough for other buyers to return to the market. The difficulty is that long-term agreements and long-term demand are not the same thing. Most monies are appropriated and authorized only annually, so many



governments cannot fully commit to enduring deals. Firms with better commercial prospects, or just owners with alternative uses of capital, sometimes *cannot be paid* to stay in declining military markets.

“ Long-term agreements and long-term demand are not the same thing. Most monies are appropriated and authorized only annually, so many governments cannot fully commit to enduring deals. ”

It is also important to note that in two cases—those of the C-17 and the KC-767—creative government financing of contractors’ production programs led to lengthy investigations. The C-17 program did get back on track, and a decade on, the 767 did become the basis of the USAF’s KC-46 tanker. Taking note of the Air Force IG’s response to Secretary Aspin, there remains some difference of opinion about the ethics of all this. Whatever the case, large scandals may be warded off by keeping payouts small (perhaps under \$100 million), so as not to trigger congressional fire alarms (McCubbins & Schwartz, 1984). And as with Northrop’s hurricane deal, when the Congress leads in appropriating the money, all is legally and finally forgiven.



Recommendations: Match the Duration of the Remedy to that of the Desired Effects

Bureaucrats and politicians often share an interest in preserving their programs, in both the short run and the long run. In some cases, long-range procurement or war plans may depend on preserving the structures of existing industries. Industrialists generally prefer to keep their firms running within those industries. Within this Iron Triangle of interests, all prefer keeping their jobs and avoiding scandal. So, what guidance can be gleaned from these cases? If legislators and defense officials wish to consider bailouts, they should also consider the embedded historical lessons of the financial and informational asymmetries between government and industry, and the general uncertainty over how technologies will evolve. Three general cautions should govern official reviews of requests for bailouts:

1. Do not allow the deal to become a shakedown. As in the Lockheed cases from the early 1970s, consider the financial asymmetries. Contractors may be flush with cash today, but should spending turn down, they may not always be. If the company has strong cash flows from other activities and contractual commitments to uphold, its poor planning may actually not be your problem.
2. As in those cases and others, consider the informational asymmetries. Contractors will always know more about their businesses than will the government. An independent audit of the situation may not uncover everything, but a contractor truly *in extremis* has no grounds to refuse. Is the whole company really failing, or is its management just failing its shareholders?
3. Question the assumption of essentiality. Map the military supply chain around the firm in question, and seek to understand firmly where the threatened business sits and how it functions. Estimate how long the gaps in production can be managed with stockpiles or just input inventories. Consult competitors and technology forecasters about the possibility of substitute products, foreign sources, and forthcoming developments. As in the Avtex case, that which is critical today could prove superfluous tomorrow. Yesterday's McDonnell Douglas factory in Long Beach may be supplanted by tomorrow's Airbus factory in Mobile. Betting on the uninvented is a precarious business, but industry is constantly searching and innovating.

“ If the company has strong cash flows from other activities and contractual commitments to uphold, its poor planning may actually not be your problem. ”

These cautions arguably should be incorporated in bailout guidance issued to bureaucrats in the Pentagon's Office of Industrial Policy and similar offices in other defense ministries. They may merit a separate chapter in the Pentagon's "5000" series of instructions because bailouts should be treated as exceptional and emergent events outside the normal flow of the business of defense. In such emergencies, level-headed thinking is easier with the guidance of a playbook.

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EFFECTIVE DECISION-MAKING BEHAVIORS FOR DEFENSE R&D: ACCOUNTING FOR DYNAMIC COMPETITION



Mark Calafut, Shahram Sarkani, and Thomas A. Mazzuchi

Research and Development (R&D) in the Department of Defense (DoD) is molded and shaped by competition. Competition is a complex and interactive process that is difficult to predict and has significant effects on the value of R&D investments over time. Initially promising investments may ultimately result in little value, due to the actions of others in a competitive environment. This article models the interaction of competition with R&D decision-making and introduces a simulation-based methodology to determine effective decision-making behaviors for the distinctive competition dynamics of DoD applications. The approach is built on the insight that R&D decision-making can be optimized for the resulting Post-Competition Value (PCV) of opportunities, rather than for their initial value. The authors demonstrate the value of this approach in three diverse applications across the DoD, including a case of defense industry companies, government laboratories, and non-profits. In all cases, optimized behaviors are identified that achieve significantly more average value than standard alternatives that do not account for competition. This creates an opportunity for DoD leaders to systematically account for competition in their decision-making and enhance the value of their R&D investments.

DOI: <https://doi.org/10.22594/dau.20-859.28.02>

Keywords: *Optimization, Simulation, Agent-Based Modeling (ABM), Evolutionary Algorithm*



Collectively, U.S. defense research and development (R&D) currently represents approximately \$104 billion in annual investment (Congressional Research Service, 2020). This R&D is critical to the DoD enterprise, contributing new technologies that drive the state-of-the-art and impact major acquisition programs. Across these activities, competition is ubiquitous. Competition occurs between companies seeking DoD contracts, as well as between government-funded and nonprofit laboratories pursuing scientific breakthroughs, and even between government research divisions ostensibly collaborating on larger programs. These organizations experience distinctive and varied competition dynamics that result from the interaction of complex factors, including the legal and regulatory environment, contract source selection processes, and internal and external organizational incentives. It is important to emphasize that in addition to its benefits, competition also poses significant challenges for these organizations. Competition dynamics are inherently difficult to predict and challenging to account for in organizational decision-making. Organizations that do not appropriately account for these factors risk making poor R&D investment decisions that leave significant value on the table.

In this article, we examine the interaction of competition and R&D decision-making in the DoD. We intend to provide practical guidance to DoD organizations on what decision-making behaviors are most effective for their circumstances. We use the term decision-making behavior to describe the method by which an organization determines if and when to invest in R&D opportunities. This includes both the metrics by which organizations evaluate opportunities and the process by which they select opportunities based on the metrics. First, we introduce an extensible methodology that models competition as a mathematical transfer function and simulates alternative decision-making behaviors in representative environments. This allows us to compare the value created by different behaviors and determine the most effective approach for an environment.

We then apply the methodology. U.S. defense R&D is conducted by a 'three-legged stool' of organizations, composed of nonprofits, government laboratories, and defense industry companies (The MITRE Corporation, 2015). In each case, the competitive environment is different. We apply our methodology to one application in each leg of the stool, considering decision-making by federally funded research and development centers (FFRDCs), the government laboratories of the U.S. Army Combat Capability Development Command (CCDC), and independent research and development (IR&D) conducted by defense industry companies.

Research Questions

The following research questions are inherently broad and cannot be fully addressed by any single analysis. In this article, we consider these questions from the perspective of optimization.

- Across Applications: Do competition-optimized decision-making behaviors outperform standard (noncompetition optimized) approaches in DoD competitive environments?
- Nonprofits: What decision-making behaviors are most effective for DoD-funded FFRDCs by resource level?
- Government: What decision-making behaviors are most effective for CCDC laboratories by resource level?
- Defense Industry Companies: What decision-making behaviors are most effective for IR&D by resource level?

Each of these questions includes a series of important subquestions. Are online or periodic decision-making behaviors preferred, or similarly, is decision timeliness or accuracy more important? Should decision-makers emphasize strategic considerations in the decision process? Should decision-makers seek or avoid high-risk technologies with high payoff?

“Competition dynamics are inherently difficult to predict and challenging to account for in organizational decision-making. Organizations that do not appropriately account for these factors risk making poor R&D investment decisions that leave significant value on the table.”

To assess these subquestions, we evaluate a range of candidate decision-making behaviors. We also use simulation to perform a comparative analysis that provides an empirically and statistically justified basis to select between potential decision-making behaviors in a competitive environment. This approach follows in a strong and growing tradition of using quantitative modeling as part of the engineering decision process (Galli, 2020) and as an important element of DoD acquisition, as highlighted in initiatives such as digital engineering (Bone et al., 2019). We argue that a modeling and simulation-based approach is particularly valuable to DoD decision-makers in competitive contexts. It is not clear a priori, which decision-making behavior will be most effective in any given context. Each

potential approach has debatable pros and cons that are often argued informally and qualitatively. We seek to contribute a new objective viewpoint that informs the decision process for DoD organizations.

Literature Review

This article focuses on the intersection of two important topics—competition dynamics in defense acquisition and the optimization of R&D decision-making. In the following section, we touch briefly on each of these broad and complex topics, as well as their interaction.

Competition Dynamics in the DoD

Competition is generally accepted as a desirable and beneficial element of the acquisition enterprise that can drive innovation and cost savings. Competition is both formally mandated in federal procurement by the Competition in Contracting Act of 1984, as well as encouraged by prominent government officials (Manuel, 2011). Research by Levenson (2014) has questioned this conventional wisdom and analyzed cases where competition may not be sufficiently valuable to the DoD to justify increased costs. Regardless, competition has remained a point of emphasis in the DoD. In past initiatives, such as Better Buying Power 3.0, DoD leadership has reasserted a commitment to competition, promoting increased competition and the maintenance of competitive environments (Kendall, 2015). Recent policy in DoD 5000.01 continues to promote competition with new points of emphasis, such as encouraging companies to adopt a modular open-system approach (MOSA) that enables expanded competition during technology refreshes (DoD, 2020b). These competition dynamics are often distinctive. Unlike many commercial markets, during acquisition, the government formally establishes its decision criteria, as described in Federal Acquisition Regulation (FAR) Subparts 15.3, 35.007(f), 35.008(a), and 35.008(b) (FAR, 2019). This regulation conspicuously and explicitly defines the form of competition. Furthermore, this form of competition interacts with the relative resource distribution of R&D organizations in the environment, which in the DoD context often involves a diverse mix of organizations.

Optimization of R&D Decision-Making and Portfolios

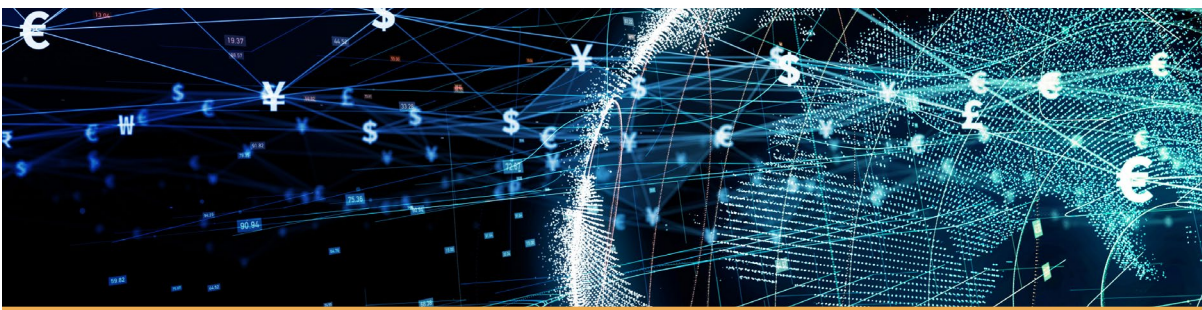
R&D represents an important and particularly difficult area for optimization. Literature abounds on the optimization of R&D portfolios, decision-making, and strategy. A common thread across this literature establishes several significant challenges. First, R&D decision-makers experience significant uncertainty. This includes uncertainty not only in the payoff of R&D opportunities, but also often in the risk and cost associated

with the opportunities (Browning, 2014; Liberatore & Pollack-Johnson, 2013). Additionally, R&D decision-makers make decisions without knowing the full decision space. Unlike many other decision-making problems, R&D decision-makers make investment decisions on a recurring basis, never knowing what new R&D opportunity may emerge in the upcoming months or years.

To address these challenges, the historical literature has considered large numbers of quantitative and qualitative methods. From the 1960s on, literature reviews have regularly documented dozens of new approaches (Baker, 1974; Cetron et al., 1967; Schmidt & Freeland, 1992). This research has continued in recent years, including efforts to manage uncertainty using real options (Santiago & Bifano, 2005), enhance decision-making through ranking (Bitman & Sharif, 2008) and profiling (Agresti & Harris, 2009), and improve budget allocation using integer programming (Eckhause et al., 2012). Some authors have advocated for greater accuracy and complexity in the decision-making process, while others argue for practicality and ease of use. The research area remains active, and recent work has considered the path dependence of R&D, including sequencing of investments (Van Bommel et al., 2014) and technology roadmaps (Lai et al., 2019), as well as unique portfolio optimization challenges faced by the DoD (Mun, 2020). The extent of this research evidences a core idea that R&D decision-making is a key source of value and competitive advantage.

Interaction of Competition and R&D Decision-Making

Competition inherently interacts with the R&D decision process in the creation of value. When considering competition, the value of R&D opportunities cannot be treated as static. This is effectively illustrated in the cases of both first-mover (Lieberman & Montgomery, 1988) and winner-take-all markets (Frank & Cook, 2013), such as those dominated by patents or network effects. In these markets, the initial value of an R&D opportunity appears similar for all research organizations. However, the final, resultant value to the successful organization is often large, while it may be negative



“ Unlike many other decision-making problems, R&D decision-makers make investment decisions on a recurring basis, never knowing what new R&D opportunity may emerge in the upcoming months or years. ”

or zero for other competitors. In addition to these forms, there are also other observed forms of competition, including cases of latecomer advantage with nearly the opposite practical effects (Markides & Sosa, 2013). Each of these forms of competition has been empirically observed and results from complex interactions between competing organizations and their environment.

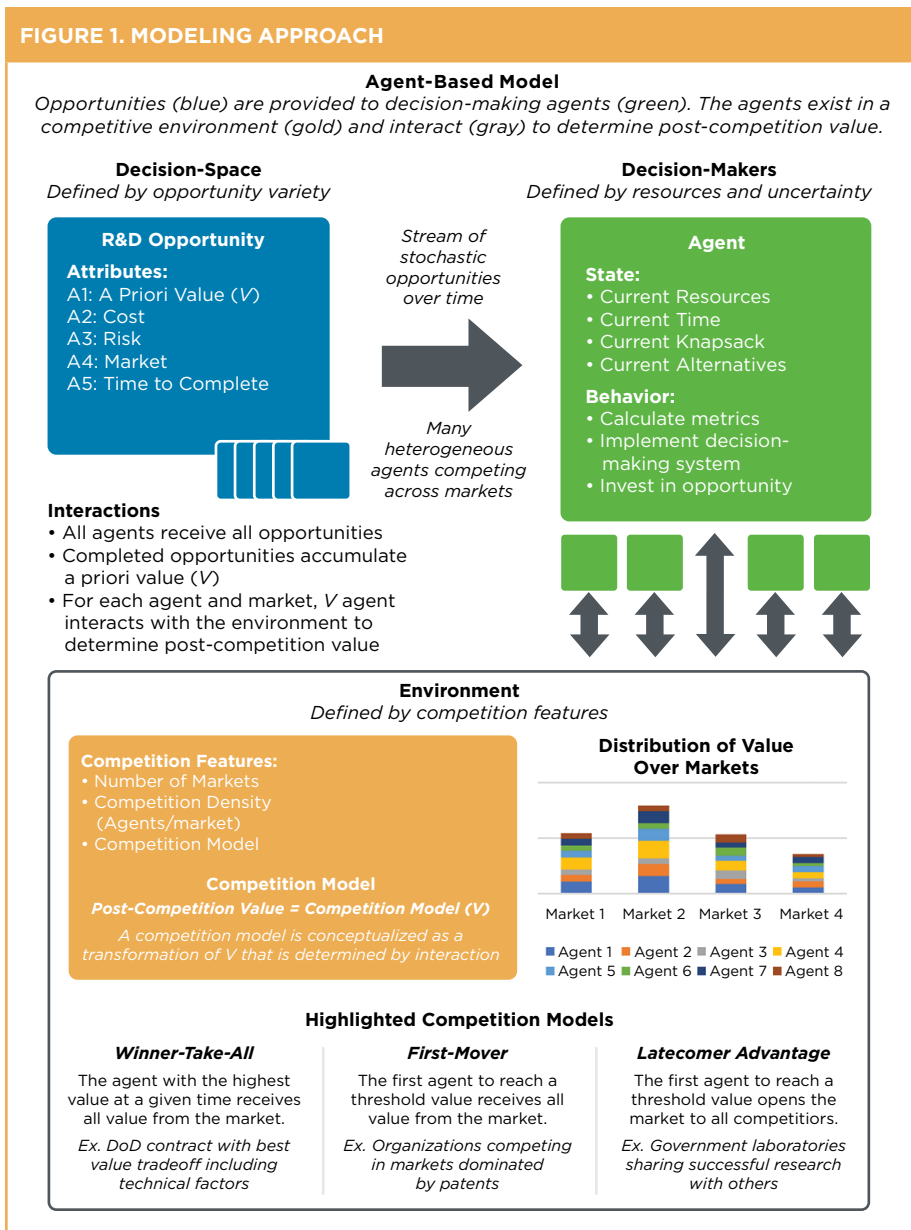
For these reasons, competition also has profound implications on the performance of decision-making behaviors. Recent research has established that when accounting for competition, behaviors optimized for competition significantly outperform alternatives (Calafut et al., 2020). Although prior work has determined the general impact of competition on R&D decision-making, it did not optimize behaviors for specific applications. This is essential for DoD organizations, which regularly experience distinctive and application-specific forms of competition. In this article, we adopt the mathematical framework introduced by Calafut et al. and extend their approach by adding a new application-specific optimization methodology, enabling analysis of the competition dynamics encountered in the DoD (2020).

Model Fundamentals

Model Description

In Figure 1, we provide an overall description of the model. The key elements of agent-based models are the agents, their interactions, and the environment (Wilenski & Rand, 2015). The model begins with a population of R&D decision-making agents, representing DoD technology organizations. Each agent has access to its own resources and makes independent decisions. The agents receive and evaluate randomly generated R&D opportunities with uncertainty across multiple markets.¹ Thus, at the level of an individual agent, the model takes the classic formulation of an online and stochastic knapsack problem, in which a decision-maker attempts to select the most valuable opportunities, as they arrive, for its given resource constraint. The knapsack problem has numerous variations, which have been documented extensively (Kellerer et al., 2004; Martello & Toth, 1990).

FIGURE 1. MODELING APPROACH



Environment
Defined by competition features

Competition Features:

- Number of Markets
- Competition Density (Agents/market)
- Competition Model

Competition Model

Post-Competition Value = Competition Model (V)

A competition model is conceptualized as a transformation of V that is determined by interaction

Distribution of Value Over Markets

Highlighted Competition Models

<p style="text-align: center;">Winner-Take-All</p> <p>The agent with the highest value at a given time receives all value from the market.</p> <p><i>Ex. DoD contract with best value tradeoff including technical factors</i></p>	<p style="text-align: center;">First-Mover</p> <p>The first agent to reach a threshold value receives all value from the market.</p> <p><i>Ex. Organizations competing in markets dominated by patents</i></p>	<p style="text-align: center;">Latecomer Advantage</p> <p>The first agent to reach a threshold value opens the market to all competitors.</p> <p><i>Ex. Government laboratories sharing successful research with others</i></p>
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The agents assess opportunities based on metrics. Their metrics include three traditional capital budgeting metrics, which are calculated from the estimated attributes of opportunities: net present value (NPV), return on investment (ROI), and an approximated payback period (PP). They also

utilize a risk distance metric, allowing agents to target opportunities with a specified level of risk, as well as a market distance metric, allowing agents to target specific markets. The agents weight these metrics based on their preferences and calculate a weighted sum that reflects their total estimate of an opportunity’s quality.

TABLE 1. CANDIDATE DECISION-MAKING BEHAVIORS		
Category	Name	Description
Baseline • Simple static decision-making • Selection based on financial metrics • Baseline for comparison	Static Online System (SOS)	Immediate decision-making It accepts or rejects each opportunity as it arrives by comparing a weighted estimate of opportunity quality to an acceptance threshold. <i>Ex. An organization that accepts or rejects opportunities as it identifies them.</i>
	Static Periodic System (SPS)	Standard periodic reviews It conducts periodic reviews to select opportunities, using linear programming to rank opportunities based on weighted estimates of their quality. <i>Ex. An organization that uses periodic reviews to select opportunities.</i>
Adaptive • Adapts decision-making • Selection based on financial metrics • Improves robustness to varied conditions	Adaptive Online System (AOS)	Adapt the acceptance threshold It adapts its behavior by varying its acceptance threshold. It states as selective, and if few opportunities are chosen, gradually decreases threshold. <i>Ex. An organization that intentionally varies its selectivity.</i>
	Adaptive Periodic System (APS)	Adapt the time between reviews It adapts its behavior by varying the time between its reviews. When opportunity variability is low, it waits for a shorter time and vice versa. <i>Ex. An organization that initiates reviews based on event-driven criteria.</i>
Diversified • Implements policy to pursue diversified opportunities • Operates independently of others and the environment	Multi-Perspective Selection System (MPSS)	Bottom-up diversification It divides its budget into multiple subperspectives. Each perspective independently selects opportunities and implements its own preferences. <i>Ex. An organization with distributed decision-making across divisions.</i>
	Diversified Selection System (DSS)	Top-down diversification It pursues a risk balanced set of opportunities by varying its risk preferences towards a target. <i>Ex. An organization that uses top-down management tools to balance risk.</i>
Strategic • Implements policy to pursue target markets • Considers other and environment • Specifies 50% of weight preference to target markets	Emerging (Emerging)	Pursue immature markets It targets the least mature markets. <i>Ex. An organization that targets a specific class of markets.</i>
	Dominate (Dominate)	Focus on best markets It targets markets it currently leads or is closest to leading. <i>Ex. An organization that targets its best markets.</i>
	Avoid (Avoid)	Stay away from competitors It targets markets with the least investment from others. <i>Ex. An organization that attempts to avoid competition.</i>



Each agent employs a decision-making behavior to accept or reject opportunities. Table 1 introduces nine candidate behaviors, each representing a potentially viable strategy under different circumstances. The behaviors are not meant to capture every possible solution but instead to establish a diverse mix of reasonable alternatives, providing, in effect, several theories of the case for evaluation. We do not intend to create new decision-making behaviors. Instead, the behaviors are designed to be conceptually representative of decision-making behaviors used in practice. Surveys of R&D organizations show that the most popular R&D management behaviors are financial methods (77.3% of organizations), business strategy methods (64.8% of organizations), and bubble diagrams (40.6% of organizations) (Cooper et al., 1999). The behaviors in the Baseline and Adaptive categories attempt to maximize the expected financial return of opportunities, representing the class of financial methods. The behaviors in the Strategic category pursue an overarching strategic objective, representing the class of business strategy methods. The behaviors in the Diversified category focus on pursuit of a balanced collection of opportunities, representing the class of bubble diagrams. We implement these behaviors in the model as systems, structured decision-making methodologies, with associated parameters and weight preferences. By assessing the performance of agents implementing different behaviors, we can infer their fundamental effectiveness in a competitive environment.

Following the successful completion of an R&D opportunity, the opportunity generates a priori value for the agent in its specified market. A priori value accumulates over time and reflects the technical state of the field. Although the a priori value of an opportunity is fixed, its resulting value is the dynamic product of interaction between the agent and the environment. We refer to this resulting value as post-competition value (PCV). In effect,

we model competition as a mathematical transfer function that determines the PCV of a competitive market for each competitor based on its a priori value (V) and the environment. Finally, as in the real-world, value is subject to a discount rate (d). The resulting objective valuation (o) of an opportunity with PCV received at a time (t_p) in the future is:

$$o_i = PCV_i (1+d)^{-t_i}$$

In this analysis, we specify discount rate to 0.07, based on guidance from the Federal Government (Office of Management and Budget, 2019). Decision-making agents seek to maximize this objective value.



Points of Emphasis and Qualifications

In designing an Agent-Based Model (ABM), it is essential to consider the purpose of the model (Macal & North, 2010). For our research questions and objective, the appropriate approach is a normative ABM focused closely on the decision-making process and the interaction of decision-making and competition. We intentionally do not replicate real-world elements that are not relevant to our questions and objective. This is in contrast to alternative, extremely descriptive ABMs. For example, our model considers different decision-making behaviors, but not different organizational processes or differences in R&D execution. These factors would only obscure the impact of decision-making. Similarly, all R&D opportunities are provided to all decision-makers and all decision-makers assess opportunities with the same degree of uncertainty. This approach directly measures the increase in value attributable to decision-making, enabling comparison between behaviors on a level playing field.

“ Our model considers different decision-making behaviors, but not different organizational processes or differences in R&D execution. These factors would only obscure the impact of decision-making.

It is also important to document the underlying assumptions in the model. The model assumes that several decision-making agents are in the environment and that markets are potentially profitable. Additionally, the agents are assumed to interact in a generally independent fashion as they pursue their goals. These assumptions are valid in a wide range of real-world circumstances and are traditional assumptions made in economic analysis. However, in certain circumstances, they do not apply. For example, when only two decision-makers are in an environment, agents primarily act with each other. In these cases, game theoretic considerations, such as adversarial action, secrecy, and signaling, should be emphasized. Other recent work has focused on game theoretic considerations in DoD acquisition (Rosen et al., 2019). Finally, this work models decision-making systematically. Other research, such as the school of naturalistic decision-making, instead focuses on the human element of the decision process. In practice, both approaches are valuable and provide complementary perspectives.

Optimization Methodology

This section describes the process by which a user can determine an effective decision-making behavior for a DoD application of interest. This is an optimization process. Its optimization objective is to maximize average objective value, as measured by median market share. Therefore, this process determines a decision-making behavior or behaviors, which are effective in generating value. We implement the optimization algorithm and model in a programming environment, with all code developed in MATLAB 2019a.

Constructing an Application Model

To perform an optimization, the user constructs an application model that reflects the competitive environment. An application model is defined by its competition features and environmental parameters. The user defines the competition features as follows.

1. *Competition Model*: Consider the dynamics of the application and connect the dynamics to an empirically observed form of competition. Define the PCV function.
2. *Resource Conditions*: Identify competitors in the environment. Collect or estimate their resource level from real-world data.
3. *Fields or Markets*: Determine the number of areas under competition.

These are the most important parameters of the model. The combination of these parameters defines the competition dynamics. For example, the number of competitors relative to the number of markets defines the competition density.

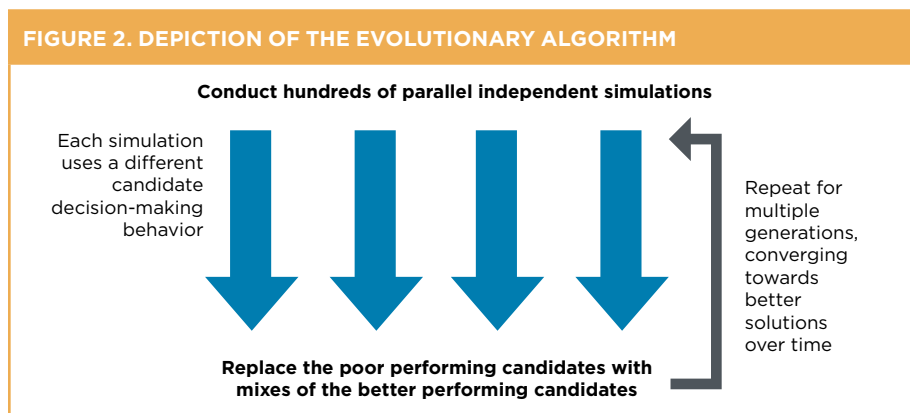
Then the user specifies the environmental parameters.² These are secondary parameters that are not application-specific. We generally recommend that they are set to a standardized moderate level. We specify them to moderate levels in this analysis.



Optimization Algorithm

Optimization is performed using an evolutionary algorithm. An evolutionary algorithm is appropriate in this context because the evolutionary fitness of a behavior can be directly measured based on its objective value. The evolutionary algorithm initiates by creating many independent instances of the application model and assigns the target organization a different candidate decision-making behavior in each instance. This

parallelized process flow is depicted in Figure 2. In a typical optimization, 108 total candidates are generated with 12 variants of each decision-making system across randomized parameters and weight preferences. This establishes a broad initial population of candidates. The remaining agents in each environment are the target organization's competitors. To ensure competitor diversity, the competitors are also assigned a mix of behaviors, including behaviors that are anticipated to be effective and randomized behaviors.



The evolutionary algorithm executes over multiple generations. During a generation, each candidate is simulated separately in its own environment. The use of multiple separate instances of the simulation allows for independent assessment of the candidates and enables side-by-side comparison of their results. The only factor that changes between each simulation is the target organization's decision-making behavior. Each independent simulation executes for a 10-year time horizon in monthly time steps. This is composed of a 5-year decision period and a 5-year resolution period, which allows time-related aspects to stabilize. In a typical optimization, ~500 independent simulations are completed for each candidate, resulting in ~54,000 total simulations per generation. This helps to both reduce expected uncertainty in the result due to randomness, as well as improve robustness by exposing the candidate to a wide mix of competitor behavior.

At the completion of each generation, the algorithm updates the population of candidates. The performance of each candidate is assessed based on the median market share, and poor performing candidates are eliminated. Replacements are generated by probabilistically selecting parents based on their performance and utilizing a mixing algorithm to create replacements that combine the attributes of the parents. Some replacements are

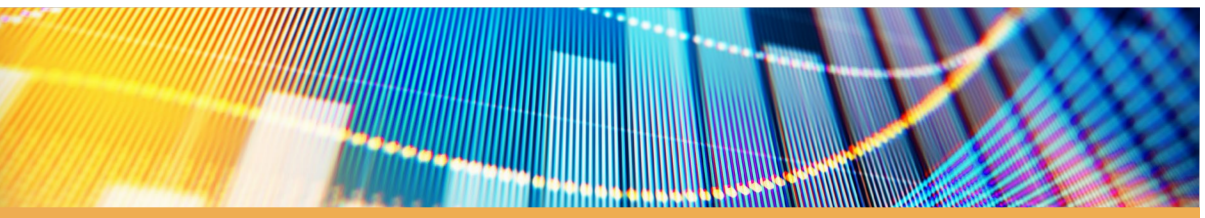
randomly modified through a mutation process to inject new diversity. This process continues for multiple generations until the algorithm converges to an effective solution.

“ The evolutionary algorithm executes over multiple generations. During a generation, each candidate is simulated separately in its own environment. ”

In each of the following applications, the competitor population is composed of baseline behaviors. Evolutionary simulations are executed with a removal rate of 30% per generation and a mutation rate of 20%. It is important to note that this optimization covers a broad search space, and an evolutionary approach cannot be guaranteed to converge to a globally optimal result. However, in practice a competition-optimized behavior, even if not globally optimal, often shows dramatic improvement over alternative behaviors.

Points of Comparison

After completing an optimization, the competition-optimized candidate is compared to alternative decision-making behaviors. This provides context on the effectiveness of the candidate behavior and the degree of improvement that is attributable to the optimization. Three alternatives are used for comparison. The first two are standard behaviors, which represent a traditional or standard approach of maximizing decision-making value without accounting for competition. It is reasonable to argue that decision-makers can ignore competition and assume that effective decision-making in general will translate to effective decision-making in any context. We represent this approach by optimizing the baseline systems—the Static Online and Static Periodic—within the model for static (noncompetitive) conditions, creating highly effective decision-making behaviors when not accounting for competition dynamics. The third alternative is the mixed competitor population that is generated by the optimization algorithm, representing a diverse set of behaviors. Statistical analysis is performed between alternatives using the Kruskal-Wallis test, with family statistical significance at 0.05.



FFRDC Application

In the following sections, we apply the optimization methodology to R&D conducted by organizations across the DoD enterprise. We begin first with analysis of FFRDCs. As detailed in FAR 35.017, FFRDCs hold a special relationship with the U.S. Government, operating independently and in the public interest. They are not expected to compete directly with industry but instead to spearhead new research initiatives that address long-term, fundamental objectives (FAR, 2019). The government maintains detailed data on the status of FFRDCs and their R&D expenditures (National Center for Science and Engineering Statistics, 2018). In 2018, there were 46 FFRDCs executing a total of approximately \$21 billion in total funding. Of these, 12 are R&D FFRDCs that received at least \$10 million in funding from the DoD. We focus our analysis on these 12 organizations, performing analysis at the level of each individual center.

Model Definition

1. *Competition Model:* FFRDCs focus on long-term research and the goal for these organizations is to advance the technical state of the art. In this context, the federal government commonly measures productivity through patents received and invention disclosures (The Technology Partnerships Office, 2013). These dynamics fundamentally represent first-mover competition, in which the first organization to reach an objective receives the rewards (Lieberman & Montgomery, 1988).

We define this model mathematically through a PCV function. All markets begin closed and provide no value. When a first decision-maker reaches a breakthrough threshold in a market, the market is opened, and the decision-maker receives all value (M) from the market. In an environment with (N) decision-makers, where each decision-maker's time to threshold is given as (t), this is represented as follows for each open market:

$$PCV_i = \begin{cases} \frac{M}{n} & \text{if } \left(\sum_{j=1}^N t_j \geq t_i \right) = N \\ 0 & \text{otherwise} \end{cases}$$

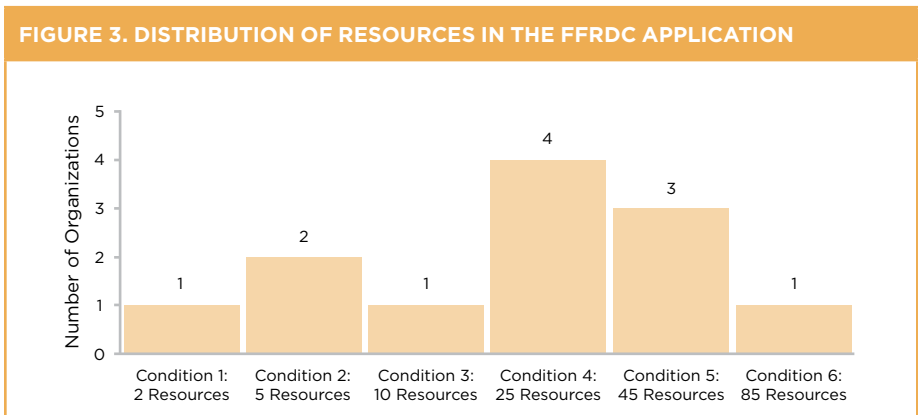
$$\text{where } : n = \left(\sum_{j=1}^N t_j = t_i \right)$$

Although first-mover competition can also occur organically, in this case, it occurs due to government policy and incentives.



2. *Resource Conditions:* We utilize the 2018 expenditure data from the National Center for Science and Engineering Statistics to define the resources for the FFRDCs. The data cover a wide distribution of \$2,967 million for the first organization, Sandia National Laboratories, to \$68 million for the smallest organization. This distribution influences the competition dynamics in the environment. We process the budget data by assigning the organizations to resource bins using a log histogram. We apply the scaled mean resource value of each bin to all organizations within the bin. This preserves the representative characteristics of the underlying data and focuses our analysis on six conditions, representing the major resource levels in the distribution. The resulting distribution of modeled resources is shown in Figure 3.
3. *Fields or Markets:* We specify 11 areas for competition.³ There are 11 modernization areas for U.S. defense R&D (Department of Defense, n.d.).

For the resource levels in the environment, these conditions result in the generation of ~170 new opportunities on average per year. Each candidate is simulated 495 times per generation.

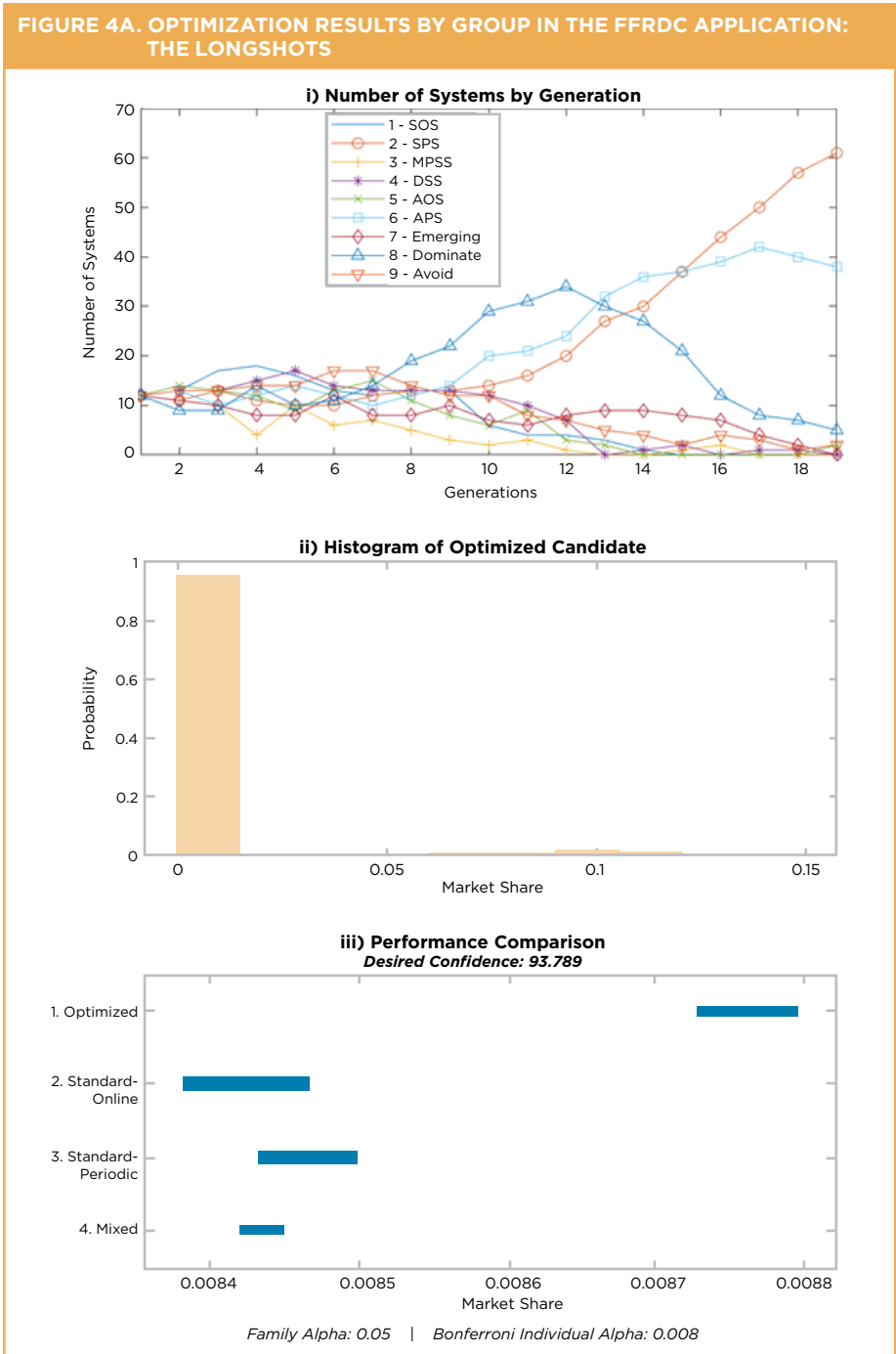


Results

The optimization results are stratified by resource level into three characteristic groups. We refer to the low-resource group as the Longshots (Conditions 1–3), the intermediate-resource group as the Contenders (Conditions 4–5), and the high-resource group as the Frontrunners (Condition 6). In Figures 4a, 4b, and 4c, we provide an exemplar result for each group to depict its fundamental characteristics. In Table 2, we display a performance comparison of the alternative behaviors, based on statistical analysis of 24,000 simulations. The results are presented as median market share with associated statistics.

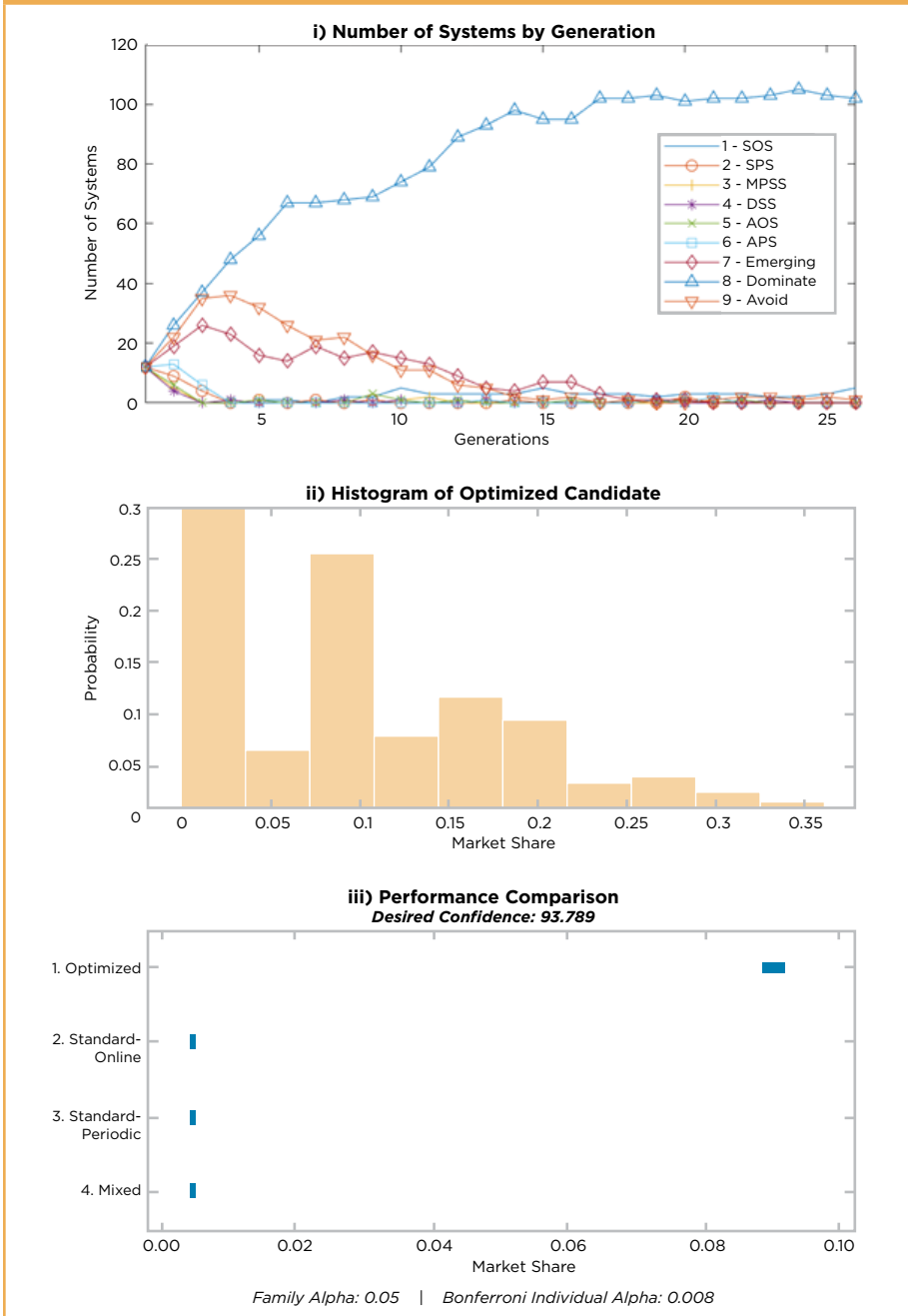
TABLE 2. PERFORMANCE COMPARISON IN THE FFRDC APPLICATION						
Comparison by Resource Condition		1) Optimized	2) Standard Online	3) Standard Periodic	4) Mixed Competitors	Description of Preferred Approach
Condition 1: 2 Resources (0.58% Total)	Result	0.0092572	0.0091225	0.0090665	0.0090808	The Longshots: Static Periodic System • Annual Reviews (12 Month) • Capital-Budgeting Metrics: 50% • Risk Seeking: 25% • Area Target 1 Market: 25%
	Z-Value	-	2.7521	5.0686	6.0763	
	P-Value	-	0.0059	0.0000	0.0000	
Condition 2: 5 Resources (1.46% Total)	Result	0.0087657	0.0084247	0.0084612	0.0084318	
	Z-Value	-	12.307	11.987	16.314	
	P-Value	-	0.0000	0.0000	0.0000	
Condition 3: 10 Resources (2.92% Total)	Result	0.0079409	0.0073638	0.0074453	0.0073815	
	Z-Value	-	15.028	14.562	20.560	
	P-Value	-	0.0000	0.0000	0.0000	
Condition 4: 25 Resources (7.31% Total)	Result	0.090424	0.0042889	0.0043712	0.0043002	The Contenders: Dominate System • High Threshold (2x Ex. Value) • Capital-Budgeting Metrics: 50% • Area Target 3-4 Markets: 50%
	Z-Value	-	71.622	70.467	97.190	
	P-Value	-	0.0000	0.0000	0.0000	
Condition 5: 45 Resources (13.16% Total)	Result	0.27280	0.089024	0.0005943	0.037425	
	Z-Value	-	57.673	94.094	100.212	
	P-Value	-	0.0000	0.0000	0.0000	
Condition 6: 85 Resources (24.85% Total)	Result	0.87918	0.86804	0.37203	0.74454	The Frontrunners: Static Online System • Low Threshold (0.8x Ex. Value) • Capital-Budgeting Metrics: 100%
	Z-Value	-	2.6969	69.310	39.593	
	P-Value	-	0.0078	0.0000	0.0000	



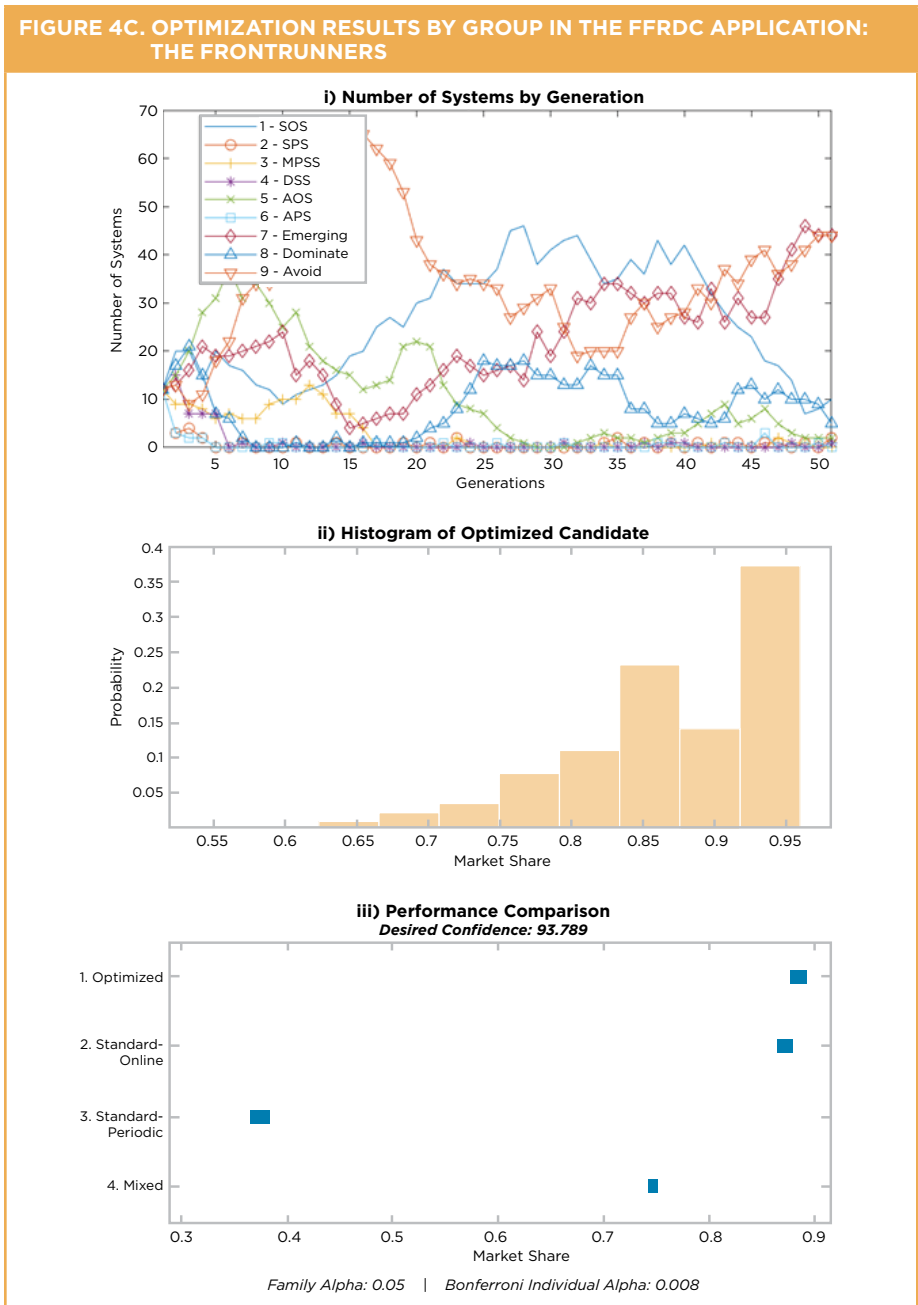


Note. AOS = Adaptive Online System; APS = Adaptive Periodic System; DSS = Diversified Selection System; MPSS = Multi-Perspective Selection System; SOS = Static Online System

FIGURE 4B. OPTIMIZATION RESULTS BY GROUP IN THE FFRDC APPLICATION: THE CONTENDERS



Note. AOS = Adaptive Online System; APS = Adaptive Periodic System; DSS = Diversified Selection System; MPSS = Multi-Perspective Selection System; SOS = Static Online System



Note. The optimized behavior is the SOS. Although the population converges to strategic systems, their weight preferences evolved from an area-focus of 50% to 0%. With an area-focus of 0% their behavior is identical to the SOS. AOS = Adaptive Online System; APS = Adaptive Periodic System; DSS = Diversified Selection System; MPSS = Multi-Perspective Selection System; SOS = Static Online System; SPS = Static Periodic System.

Discussion

At all resource levels, the competition-optimized behavior outperforms all alternatives at the 0.05 family statistical significance level. The optimized behavior varies as follows by resource group.

The Longshots group includes organizations with less than 3% of the total resources in the competitive landscape, representing the bottom 30% of organizations in the resource distribution. The results for these organizations are presented in Figure 4a. In a first-mover context, the Longshots are at a fundamental disadvantage and must do everything they can to improve performance at the margins. Their optimized behavior is periodic decision-making with annual decision reviews. Their optimized weight preferences are risk-seeking (25%) and area-focus on a single market (25%), with the remaining emphasis on traditional capital budgeting metrics (50%). This behavior blends periodic decision-making with a Dominate strategy that targets high-risk technologies. The use of periodic reviews maximizes the accuracy of the organization's own decision-making and reduces the resource burden required throughout each year, conserving resources until a decision review occurs.



The Contenders group includes organizations with ~3-15% of the total resources in the environment, representing the middle 60% of organizations in the resource distribution. The results for these organizations are presented in Figure 4b. In a first-mover context, the Contenders can capture one or more markets through effective decision-making. Their optimized behavior is the Dominate strategy, which focuses investment on the most viable markets. Their optimized weight preferences are area-focus on a small number of markets (50%), with the remaining emphasis on traditional capital budgeting metrics (50%). They should also be selective, adopting an acceptance threshold of 2x the value of an average opportunity. The success of this behavior indicates that in this intermediate-resource group, organizations can directly compete with rivals and even larger competitors by strategically focusing their investment, despite the inherent



risk of overemphasizing a limited number of areas. In this group, the gains attributable to decision-making can be very substantial, with the competition-optimized behavior achieving more than double the average value of each alternative.

The Frontrunners group includes organizations with >15% of the total resources in the competitive landscape, representing the top 10% of organizations in the resource distribution. The results for these organizations are presented in Figure 4c. In a first-mover context, the Frontrunners regularly capture many markets. Their optimized behavior is online decision-making with an aggressive acceptance threshold (0.8x the value of an average opportunity). Their optimized weight preferences focus on traditional capital budgeting metrics (100%). The success of this behavior indicates that in this high-resource group, organizations generate more value when they compete aggressively over a range of markets. They also benefit from focusing on their own behavior, rather than the actions of competitors or strategic concerns. In this group, the result varies greatly with the decision-making behavior and decision-makers risk leaving significant value on the table by utilizing a slower periodic behavior (37.2% median market share) as opposed to the optimized behavior (87.9% median market share).

CCDC Application

Next, we consider government organizations, focusing on the U.S. Army Combat Capabilities Development Command (CCDC). CCDC is the organic R&D capability for the U.S. Army. There are seven R&D organizations within the CCDC (U.S. Army CCDC, 2019). We focus our analysis on these organizations and perform analysis at the level of each individual research center.

Model Definition

1. *Competition Model*: Government organizations experience varied and complex forms of competition. From the overarching CCDC perspective, the CCDC subordinate centers are

ostensibly collaborative but also have individual incentives and goals. On one hand, they are managed and assessed independently. On the other, they do not maintain trade secrets or individual intellectual property and are required to share results with each other when new research avenues are opened. This allows centers to conduct follow-on applied research based on the work of others, often after the most challenging elements are already addressed. In this way, the practical incentives for government research centers can be fundamentally different from FFRDCs. To capture their competition dynamics, we select a model of latecomer advantage (Markides & Sosa, 2013).

We define this model mathematically through a PCV function. Markets begin closed. When a first decision-maker reaches the threshold value in a market, the market is opened to everyone. All competitors are provided sufficient bonus value (B) to reach the threshold. Competition then proceeds according to a proportional model that distributes post-competition value between organizations based on their relative contribution. This is represented as follows for each open market:

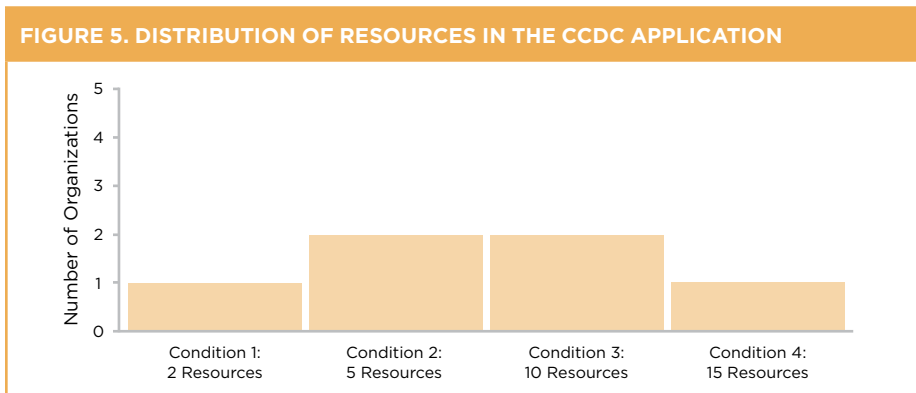
$$PCV_i = (M) \left(\frac{U_i}{\sum_{j=1}^N U_j} \right)$$

where: ΔU , $U_i = V_i + B_i$

This model favors applied research, allowing an organization to benefit from the foundational work of others. It also allows an R&D center to appear collaborative, even when primarily free-riding on others.

“Subordinate centers are ostensibly collaborative but also have individual incentives and goals. On one hand, they are managed and assessed independently. On the other, they do not maintain trade secrets or individual intellectual property and are required to share results with each other when new research avenues are opened.”

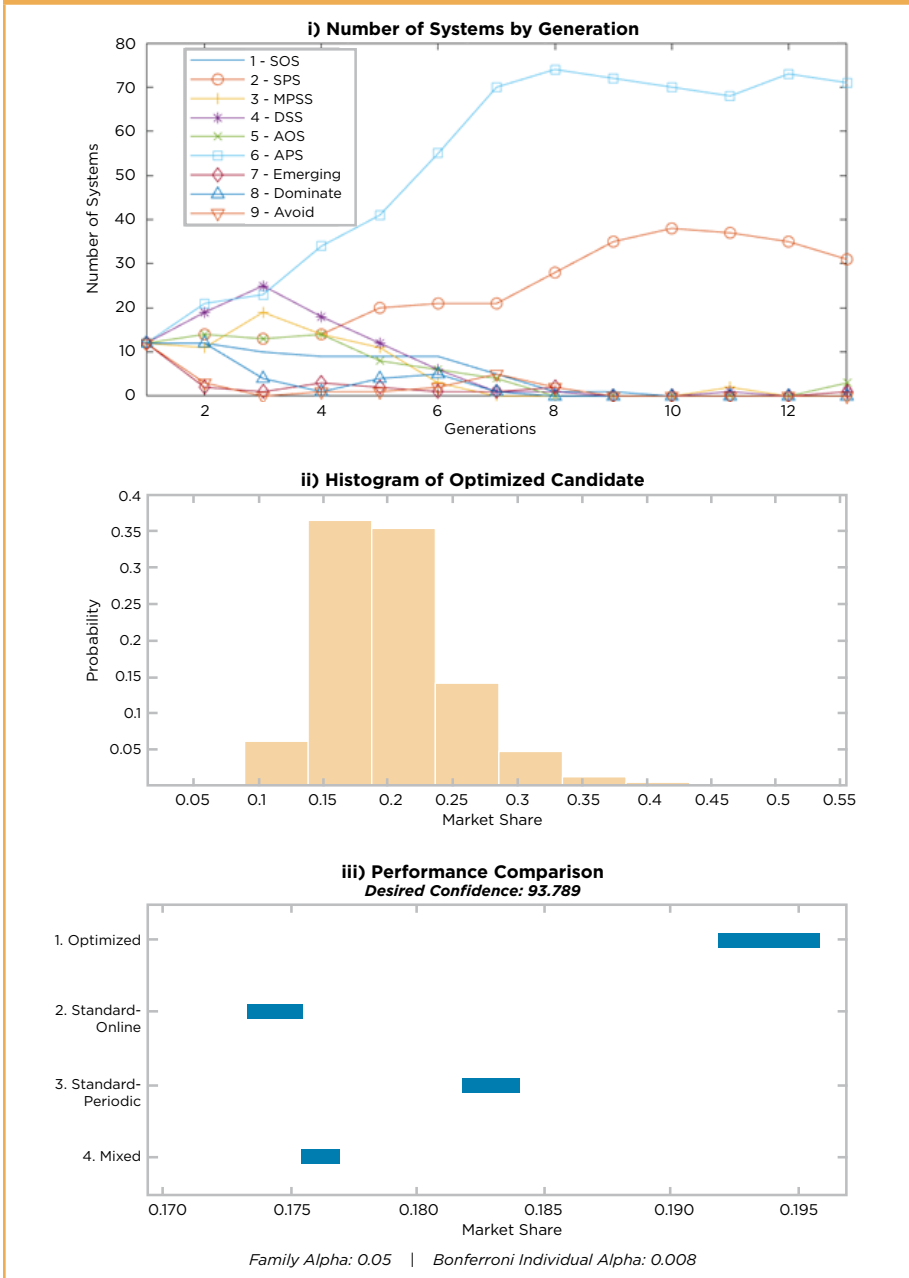
2. *Resource Conditions:* Each CCDC center receives a federal appropriation of Science and Technology (S&T) funding (Warren et al., 2020). We utilize the S&T budgets of each center from Fiscal Year (FY) 17 as the basis of resource definition. We eliminate the smallest center from the analysis, which practically is represented by the other low-resource cases. The resulting data cover a broad distribution of \$609 million for the first organization, Army Research Laboratory, to \$81 million for the smallest organization. We process the budget data, using the same method described in the FFRDC application. This results in four analysis conditions that represent the major resource levels in the distribution, as shown in Figure 5.
3. *Fields or Markets:* As in the FFRDC application, we specify 11 areas for competition.³ For the resource levels in the environment, these conditions result in the generation of ~35 new opportunities on average per year. Each candidate is simulated 500 times per generation.



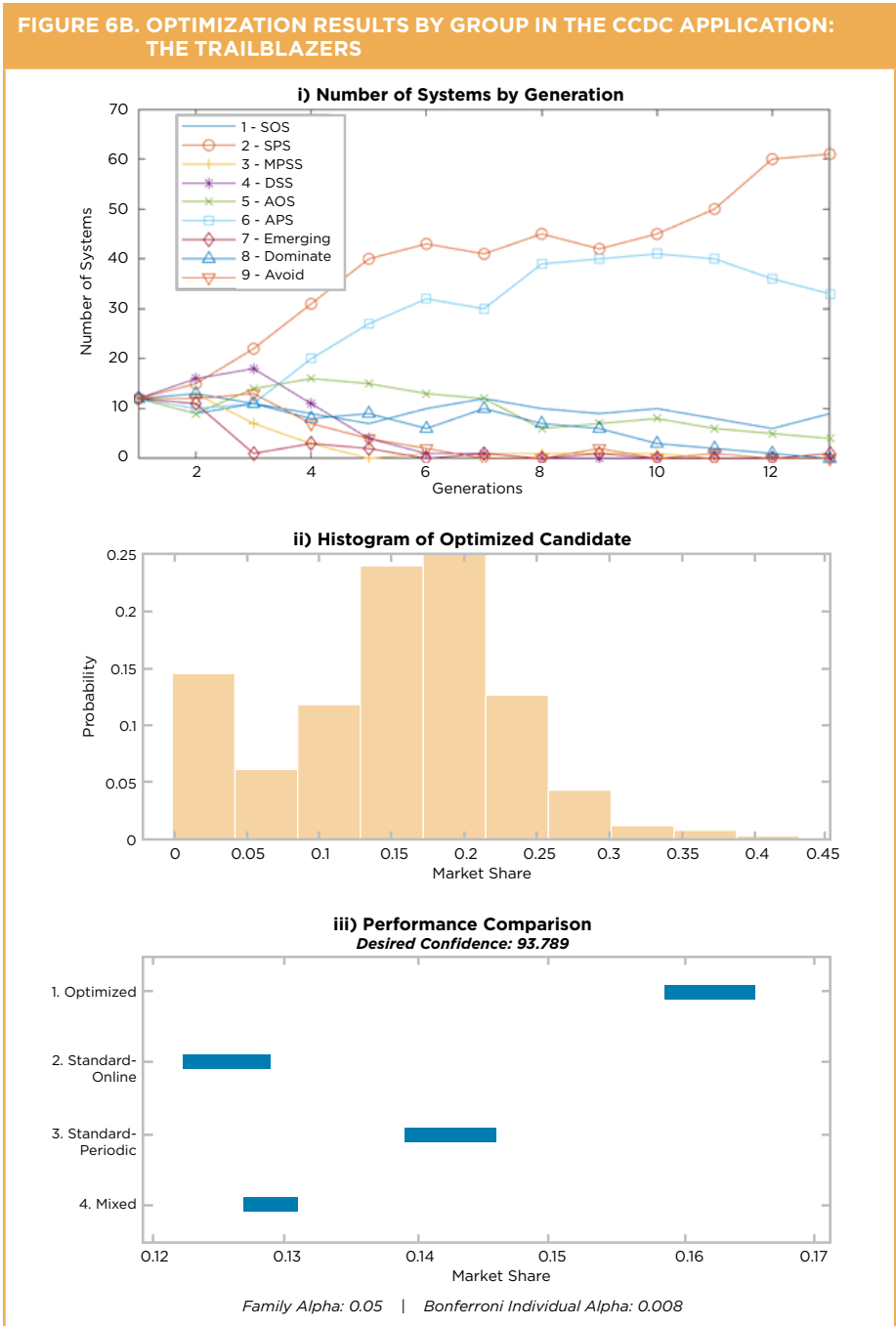
Results

As in the FFRDC application, the optimization results are stratified by resource level into characteristic groups. We refer to the low-resource group as the Free Riders (Conditions 1-2) and the high-resource group as the Trailblazers (Condition 3-4). In Figures 6a and 6b, we provide an exemplar result for each group to represent its fundamental characteristics. In Table 3, we display a performance comparison of the alternative behaviors, based on statistical analysis of 12,000 simulations. The results are presented as median market share with associated statistics.

FIGURE 6A. OPTIMIZATION RESULTS BY GROUP IN THE CCDC APPLICATION: THE FREE RIDERS



Note. AOS = Adaptive Online System; APS = Adaptive Periodic System; DSS = Diversified Selection System; MPSS = Multi-Perspective Selection System; SOS = Static Online System; SPS = Static Periodic System



Note. AOS = Adaptive Online System; APS = Adaptive Periodic System; DSS = Diversified Selection System; MPSS = Multi-Perspective Selection System; SOS = Static Online System; SPS = Static Periodic System

TABLE 3. PERFORMANCE COMPARISON IN THE CCDC APPLICATION

Comparison by Resource Condition		1) Optimized	2) Standard Online	3) Standard Periodic	4) Mixed Competitors	Description of Preferred Behavior
Condition 1: 2 Resources (4.26% Total)	Result	0.20145	0.18478	0.19102	0.185367	The Free Riders: Static Periodic System • Annual Reviews (12 Month) • Capital-Budgeting Metrics: 50% • Risk Seeking: 50%
	Z-Value	-	10.569	7.1450	12.726	
	P-Value	-	0.0000	0.0000	0.0000	
Condition 2: 5 Resources (10.64% Total)	Result	0.19375	0.17431	0.18279	0.17618	
	Z-Value	-	21.396	9.9183	23.331	
	P-Value	-	0.0000	0.0000	0.0000	
Condition 3: 10 Resources (21.28% Total)	Result	0.17841	0.14125	0.16284	0.14873	The Trailblazers: Static Periodic System • Annual Reviews (12 Month) • Capital-Budgeting Metrics: 75% • Risk Seeking: 25%
	Z-Value	-	39.467	14.929	38.263	
	P-Value	-	0.0000	0.0000	0.0000	
Condition 4: 15 Resources (31.91% Total)	Result	0.16205	0.12593	0.14254	0.12853	
	Z-Value	-	17.192	10.211	19.434	
	P-Value	-	0.0000	0.0000	0.0000	

Discussion

At all resource levels, the competition-optimized behavior outperforms all alternatives at the 0.05 family statistical significance level. The optimized behavior varies as follows by resource group.

The Free Riders group includes organizations with < 15% of the total resources in the competitive landscape, representing the bottom 50% of organizations in the resource distribution. The results for these organizations are presented in Figure 6a. The Free Riders are at a fundamental advantage and can efficiently generate value with limited investment. Their optimized behavior is periodic decision-making with annual decision reviews. Their optimized weight preferences are risk-seeking (50%) balanced with traditional capital budgeting metrics (50%). The use of periodic reviews emphasizes accuracy at the expense of timeliness, allowing the decision-maker to capitalize on the investments of others.

In contrast, the Trailblazers group includes organizations with ≥ 15% of the total resources in the environment, representing the top 50% of organizations in the resource distribution. The results for these organizations are presented in Figure 6b. The optimized behavior for this group is periodic decision-making with annual decision reviews and weight preferences that emphasize traditional capital budgeting metrics (75%) with mild risk-seeking (25%). Interestingly, in both resource groups for the CCDC application, risk-seeking behavior is preferred. Risk-seeking benefits Trailblazers by emphasizing potential high-reward opportunities in emerging markets that can allow them to significantly exceed threshold and achieve a



persistent competitive advantage. Risk-seeking also benefits Free Riders, by helping them to outcompete not only disadvantaged first-movers, but also the numerous other latecomers. Or put differently, due to their limited resources, Free Riders must accept risk to be successful even when receiving a latecomer advantage. Additionally, in both groups, periodic decision-making is preferred. Like Free Riders, Trailblazers prefer to free ride and gain latecomer benefits when possible. However, limited established markets and also limited investment opportunities are available in the established markets. The Trailblazers, due to their high available resources, are forced to accept more opportunities in emerging markets and over time conduct most of the foundational research that opens new markets. Notably, these results imply that government organizations are currently incentivized towards slow and deliberative decision-making, even if that behavior is not preferred at higher organizational levels.

IR&D Application

Finally, we consider R&D conducted by defense industry companies, focusing on IR&D. IR&D has been an important component of the U.S. defense research enterprise for decades (Alexander et al., 1989). There are hundreds of companies performing IR&D, and IR&D is highly complex due to its scale. We perform analysis at the level of each individual company.

Model Definition

1. *Competition Model:* IR&D is independent research conducted by defense industry companies without direct government funding or oversight, with a primary objective of securing future government contracts (Manos, 2004). Their competition dynamics are thus driven by DoD acquisition processes. This

includes both Broad Agency Announcements (BAA) through FAR 35.016, often for early stage R&D, and acquisition source selection through FAR Subpart 15.3, often for late stage R&D (2019). Across cases, companies with a technology edge have the advantage in winning a government contract. During BAAs, the government evaluates technical proposals through scientific review. During source selection, the government establishes selection criteria and defines best-value. Source selection best-value spans a continuum described in FAR 15.101, from the highest technically rated offeror to the lowest-price technically acceptable offeror, including intermediate cases of tradeoff (2019). Across the continuum, technical factors are relevant to R&D acquisition.

We model these dynamics as Winner-Take-All Competition (Frank & Cook, 2013). We define this model mathematically through a PCV function. For each market area, the decision-maker with the highest value, at the time of source selection, receives all value from the market. This is represented as follows:

$$PCV_i = \begin{cases} \frac{M}{n} & \text{if } \left(\sum_{j=1}^N V_i \geq V_j \right) = N \\ 0 & \text{otherwise} \end{cases}$$

where: $n = \left(\sum_{j=1}^N V_i = V_j \right)$

By achieving a technology edge, an organization can capture a contract. However, unlike in the first-mover model, this is subject to reversal in future contracts, as competitors can invest and recapture the advantage.

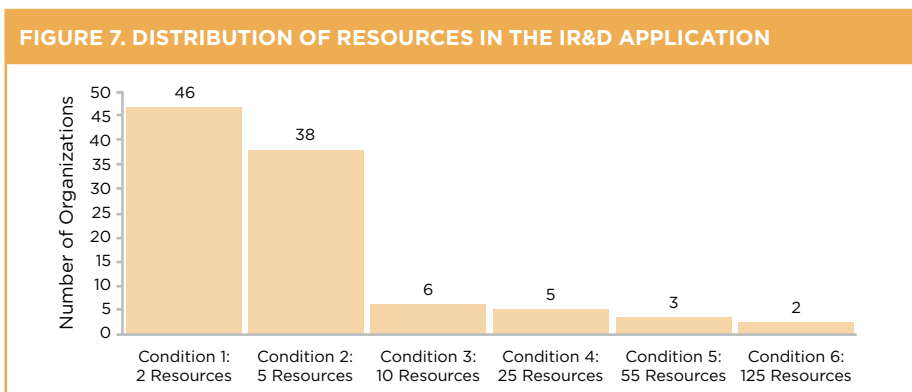
2. *Resource Conditions*: In 2018, there were hundreds of defense industry companies performing IR&D recognized by the U.S. Department of Defense. We utilize available sales data for U.S. Defense contractors (Federal Procurement Data System, 2018). For practical reasons, we limit this analysis to the top 100 companies by sales. This reflects all organizations with annual sales of approximately \$350 million or more in 2018. It covers a dramatic span in sales from ~\$38.9 billion for the 1st organization, Lockheed Martin, to ~\$348 million for the 100th organization, AAR Corp. We use two methods to estimate the ratio of IR&D to DoD sales. First, we determine the



median ratio over two decades from historical data, yielding an estimate of 0.037 (Alexander et al., 1989). Second, we calculate a point value for 2018 using the DoD approximation of IR&D incurred and the total sales of the largest U.S. Defense contractors, yielding an estimate of 0.0385 (DoD, 2020a). With both methods in concurrence, we use the historical estimate to approximate the IR&D budget for each organization. We then process the budget data, using the same method described in the prior applications. This results in six analysis conditions that represent the major resource levels in the distribution, as shown in Figure 7.

3. *Fields or Markets:* As in the prior applications, we specify 11 areas for competition.³

For the resource levels in the environment, these conditions result in the generation of ~250 new opportunities on average per year. Each candidate is simulated 495 times per generation.

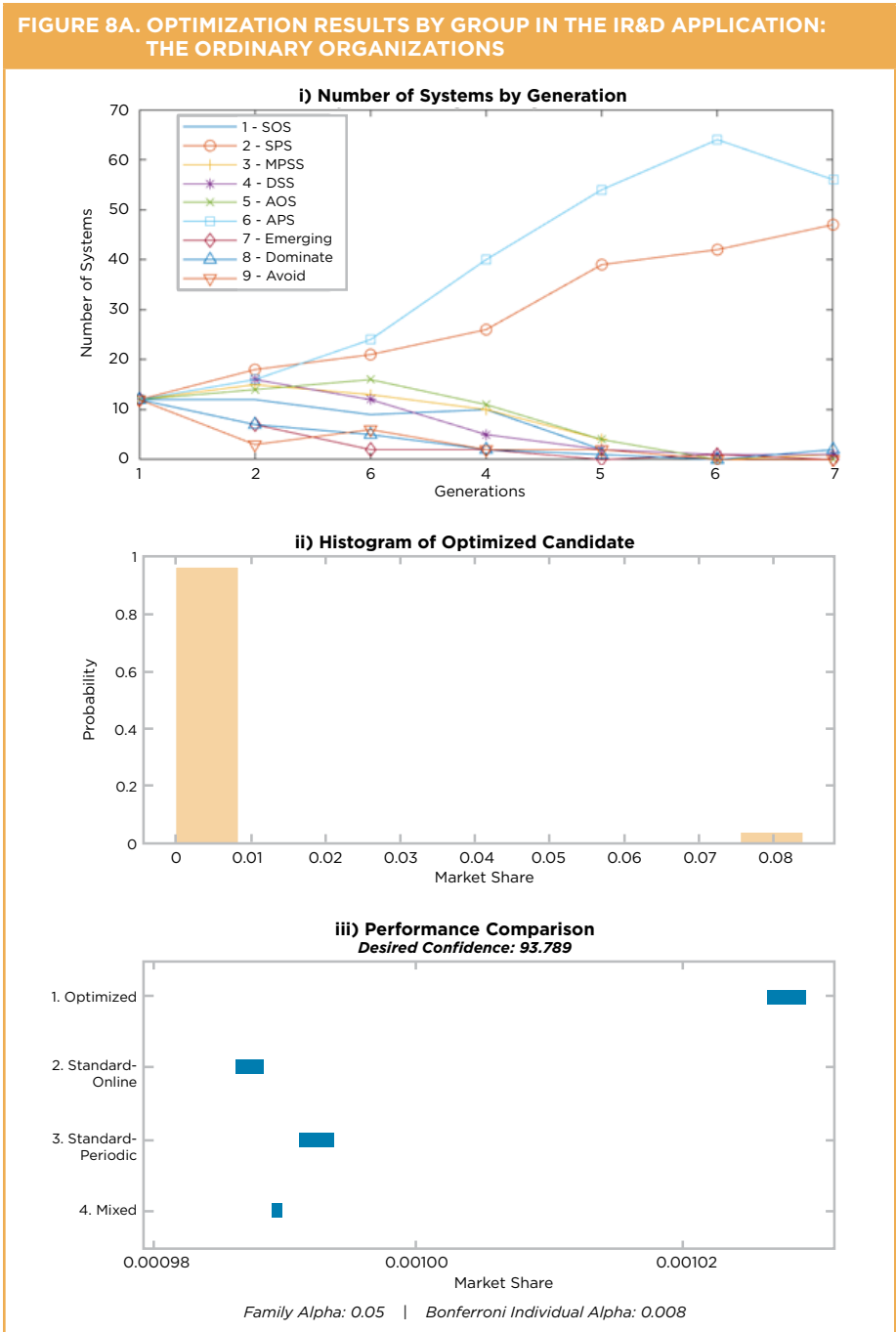


Results

As in the prior applications, the results are stratified by resource level into characteristic groups. We refer to the low-resource group as the Ordinary Organizations (Conditions 1-3), the intermediate-resource group as the Strong-Possibilities (Conditions 4-5), and the high-resource group as the Market Leaders (Condition 6). In Figures 8a, 8b, and 8c, we provide an exemplar result for each group to represent its fundamental characteristics. In Table 4, we display a performance comparison of the alternative behaviors, based on statistical analysis of 50,000 simulations. The results are presented as median market share with associated statistics.

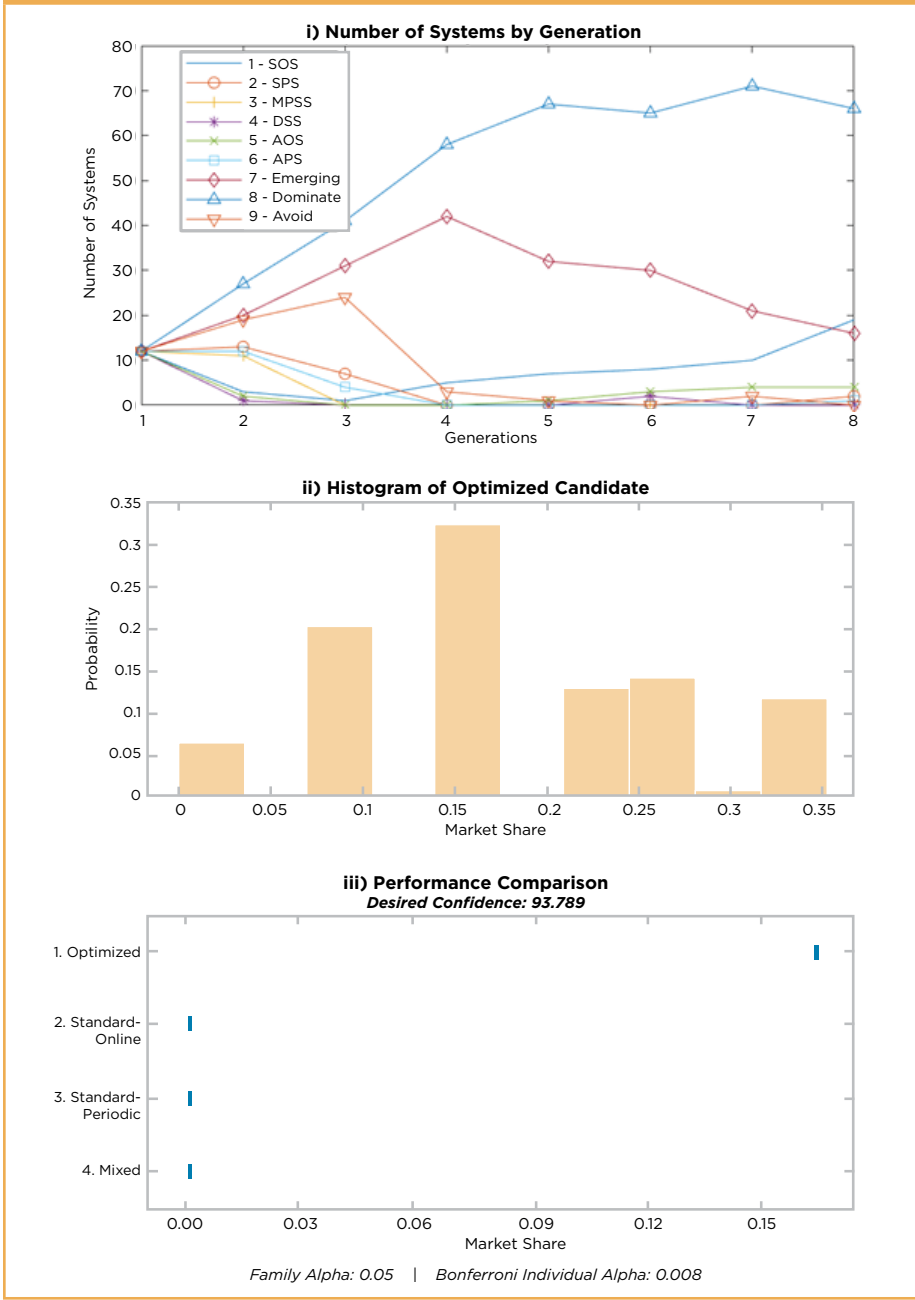
TABLE 4. PERFORMANCE COMPARISON IN THE IR&D APPLICATION							
Comparison by Resource Condition		1) Optimized	2) Standard Online	3) Standard Periodic	4) Mixed Competitors	Description of Preferred Behavior	
Condition 1: 2 Resources (0.23% Total)	Result	0.0011676	0.0011632	0.0011649	0.0011638	The Ordinary Organizations: Static Periodic System • Annual Reviews (12 Month) • Capital-Budgeting Metrics: 50% • Risk Seeking: 25% • Area Target 1 Market: 25%	
	Z-Value	-	22.074	13.139	27.159		
	P-Value	-	0.0000	0.0000	0.0000		
Condition 2: 5 Resources (0.57% Total)	Result	0.0011135	0.0010969	0.0011006	0.0010982		
	Z-Value	-	68.879	52.314	89.079		
	P-Value	-	0.0000	0.0000	0.0000		
Condition 3: 10 Resources (1.13% Total)	Result	0.0010279	0.0009869	0.0009923	0.0009890		
	Z-Value	-	52.816	43.035	68.666		
	P-Value	-	0.0000	0.0000	0.0000		
Condition 4: 25 Resources (2.83% Total)	Result	0.082263	0.0006597	0.0006756	0.0006660	The Strong-Possibilities: Dominate System • High Threshold (2x Ex. Value) • Capital-Budgeting Metrics: 50% • Area Target 1-4 Markets: 50%	
	Z-Value	-	71.038	47.384	85.229		
	P-Value	-	0.0000	0.0000	0.0000		
Condition 5: 55 Resources (6.24% Total)	Result	0.16452	0.0000000	0.0000638	0.0000114		
	Z-Value	-	62.108	27.024	66.362		
	P-Value	-	0.0000	0.0000	0.0000		
Condition 6: 125 Resources (14.17% Total)	Result	0.64926	0.57337	0.16316	0.41117		The Market Leaders: Adaptive Online System • Low Threshold (0.75x Ex. Value) • Capital-Budgeting Metrics: 100%
	Z-Value	-	2.6610	44.536	25.560		
	P-Value	-	0.0078	0.0000	0.0000		

IR&D has been an important component of the U.S. defense research enterprise for decades.

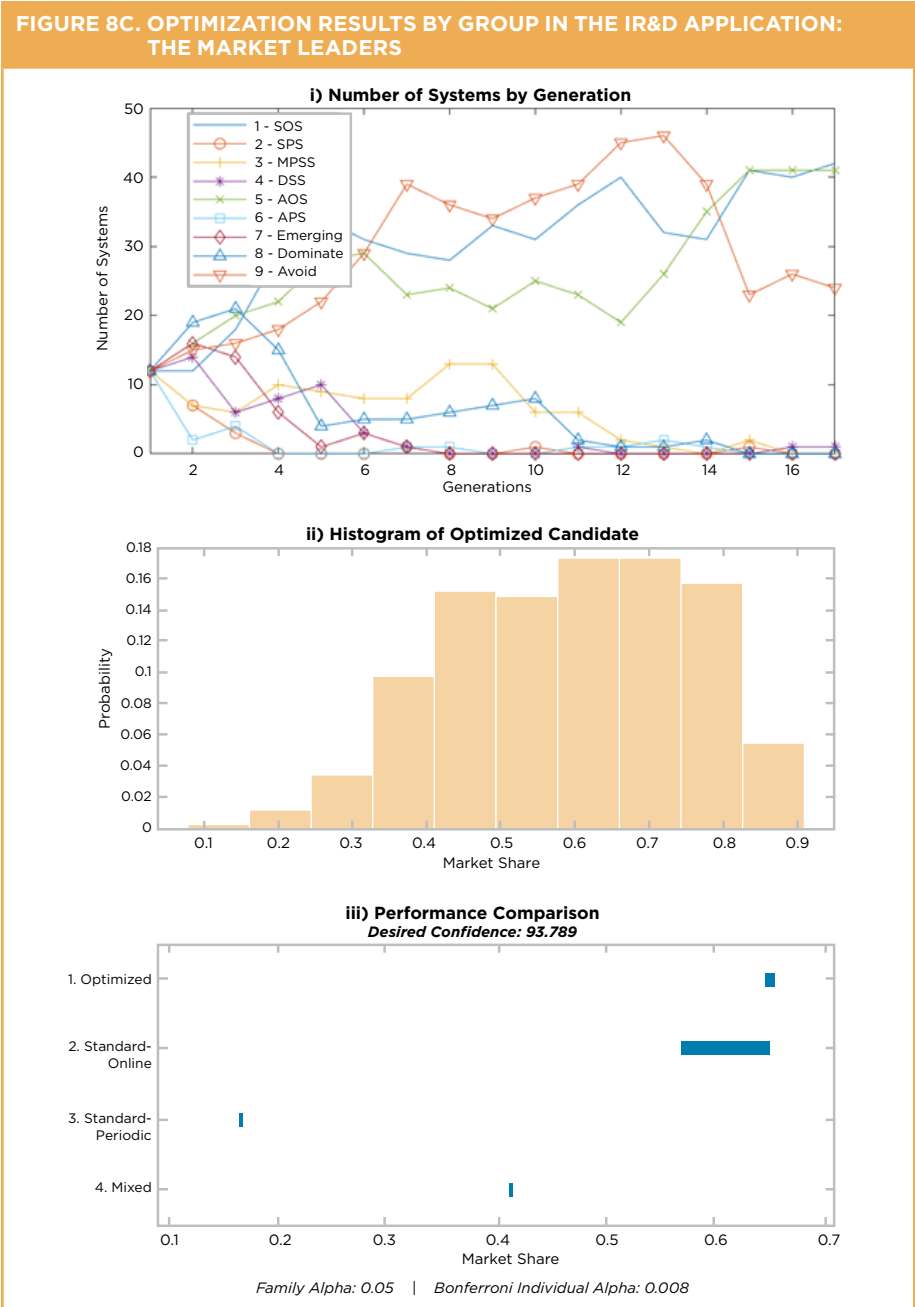


Note. AOS = Adaptive Online System; APS = Adaptive Periodic System; DSS = Diversified Selection System; MPSS = Multi-Perspective Selection System; SOS = Static Online System; SPS = Static Periodic System

FIGURE 8B. OPTIMIZATION RESULTS BY GROUP IN THE IR&D APPLICATION: THE STRONG-POSSIBILITIES



Note. AOS = Adaptive Online System; APS = Adaptive Periodic System; DSS = Diversified Selection System; MPSS = Multi-Perspective Selection System; SOS = Static Online System; SPS = Static Periodic System



Note. The optimized behavior is the AOS or SOS. Although the population also converges to Emerging, its weight preferences evolved from an area-focus of 50% to 0%. With an area-focus of 0%, its behavior is identical to the SOS. AOS = Adaptive Online System; APS = Adaptive Periodic System; DSS = Diversified Selection System; MPSS = Multi-Perspective Selection System; SOS = Static Online System; SPS = Static Periodic System.

Discussion

At all resource levels, the competition-optimized behavior outperforms all alternatives at the 0.05 family statistical significance level. The optimized behavior varies as follows by resource group.

The Ordinary Organizations group includes organizations with less than 2% of the total resources in the competitive landscape, representing the bottom 90% of organizations in the resource distribution. The results for these organizations are presented in Figure 8a. Despite their prevalence, the Ordinary Organizations are disadvantaged because of the presence of larger and better funded rivals. Their optimized behavior is periodic decision-making with annual decision reviews. Their optimized weight preferences are risk-seeking (25%) and area-focus on a single market (25%), with the remaining emphasis on traditional capital budgeting metrics (50%). This behavior accurately targets high-risk, high-reward opportunities in a single market, reduces resources required throughout the year, and achieves a small but consistent improvement in average value over all alternatives.

The Strong-Possibilities group includes organizations with ~2-10% of the total resources in the environment, representing the middle 8% of organizations in the resource distribution. The results for these organizations are presented in Figure 8b. Their optimized behavior is a selective Dominate strategy, which focuses investment on the most viable markets. Their optimized weight preferences are area-focus on a small number of markets (50%) with the remaining emphasis on traditional capital budgeting metrics (50%). The Strong-Possibilities are well-positioned among many poorly funded Ordinary Organizations and can regularly capture one to two markets. However, they are also disadvantaged as compared to organizations in the high-resource group. This manifests itself in a distinctive choppy histogram, and it is critical that the Strong-Possibilities maintain a strategic focus on a small number of markets. In this group, the gains attributable to decision-making are substantial, as competition-optimized behaviors consistently capture at least one market, while alternative behaviors rarely capture any markets.

The Market Leaders group includes organizations with >10% of the total resources in the environment, representing the top 2% of organizations in the resource distribution. The results for these organizations are presented in Figure 8c. The few organizations in this group regularly capture most of the markets. Their optimized behavior is adaptive online decision-making with an aggressive acceptance threshold (0.75x the value of an average opportunity). Their optimized weight preferences focus on traditional capital budgeting metrics (100%). This behavior accepts promising opportunities regardless of market area, spreading out investment, and adapts

to become increasingly aggressive if few opportunities are selected. It also does not consider risk in decision-making or the strategies of rivals. The success of the frontrunners demonstrates that defense industry companies derive inherent competitive benefit from scale. These benefits operate in addition to traditional economies of scale and may encourage consolidation in the defense industry.

Interestingly, the results for this application share fundamental similarities to the results for the FFRDC application. The optimized behavior for the Ordinary Organizations, Strong-Possibilities, and Market Leaders correspond to the optimized behavior for the Longshots, Contenders, and Frontrunners. However, in the IR&D case, the composition of those groups is substantially different. The Ordinary Organizations group makes up 90% of the organizations, while the comparable group in the FFRDC application makes up only 30% of the organizations. Similarly, the Strong-Possibilities and Market Leaders groups are much smaller by percentage than their corresponding groups in the FFRDC application. This analysis not only identifies a competition-optimized behavior for these organizations, but also shows how the dividing line between preferred behaviors shifts in different applications.



Conclusions

Significant value is available to DoD R&D organizations that effectively account for competition in their decision-making. Across applications, behaviors that are optimized for competition consistently and significantly outperform standard alternatives. The results further show that no single decision-making behavior is superior. Different behaviors perform best in different competitive contexts. We illustrate this in summary Table 5. Sometimes, strategic concerns dominate. In other cases, it is more important to emphasize timeliness or decision accuracy. For decision-makers in each of our application areas, the results provide actionable recommendations on what behaviors are effective. Decision-makers can review their current behaviors, including their metrics and decision processes, and adjust them to make their R&D investments more valuable.

TABLE 5. SUMMARY OF PREFERRED DECISION-MAKING BEHAVIORS

Application	Group	Preferred Behavior
FFRDC	Longshots (Bottom 30%)	Periodic decision-making with annual decision reviews Preferences: Seek High-Risk Technologies (25%), Focus on single market (25%), Capital-Budgeting Metrics (50%)
	Contenders (Middle 60%)	Dominate strategy with selective threshold Preferences: Focus on a small number of markets (50%), Capital-Budgeting Metrics (50%)
	Frontrunners (Top 10%)	Online decision-making with an aggressive threshold Preferences: Capital-Budgeting Metrics (100%)
CCDC	Free Riders (Bottom 50%)	Periodic decision-making with annual decision reviews Preferences: Seek High-Risk Technologies (50%), Capital-Budgeting Metrics (50%)
	Trailblazers (Top 50%)	Periodic decision-making with annual decision reviews Preferences: Seek High-Risk Technologies (25%), Capital-Budgeting Metrics (75%)
IR&D	Ordinary Organizations (Bottom 90%)	Periodic decision-making with annual decision reviews Preferences: Seek High-Risk Technologies (25%), Focus on single market (25%), Capital-Budgeting Metrics (50%)
	Strong-Possibilities (Middle 8%)	Dominate strategy with selective threshold Preferences: Focus on a small number of markets (50%), Capital-Budgeting Metrics (50%)
	Market Leaders (Top 2%)	Adaptive online decision-making with aggressive threshold Preferences: Capital-Budgeting Metrics (100%)

It is also important to emphasize that this methodology is extendable to new applications. It provides an objective, repeatable, and quantitative means to determine an effective decision-making behavior for a DoD application of interest. Decision-makers determine the competition dynamics of a target application, specify an appropriate PCV formula, and perform simulations to identify an optimized behavior. Our software model is designed to support this, allowing for different competition models, resource conditions, decision behaviors, statistical distributions, and measures of value. This flexibility also enables sensitivity analysis. If the parameters of an application are in question, they can be simulated over a range. This bounds uncertainty for the decision-maker.

In future work, this methodology can be extended to extrapolate how in-process or proposed changes to government policy will drive R&D organizations to change their behavior. For example, recent government efforts have expanded the use of non-FAR-based Other Transaction Authority (OTA) agreements to reach nontraditional defense contractors. This methodology can be used to characterize the impact of this change on the competitive landscape, determining its impact on R&D incentives. In this way, it can serve as a new tool in the toolkit of government leaders as they make decisions on complex and multifaceted policy topics.

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Endnotes

¹The opportunity attributes are stochastic parameters. The ABM framework is designed to support multiple statistical distributions in the generation of these random parameters. Generally, the statistical distribution is treated as a variable that is specified by the modeler. In this analysis, we take a standard approach in defining these distributions. Opportunity arrival rate is treated as Poisson and is defined by the expected arrival rate. Market is treated as uniformly distributed, resulting in, on average, an equal number of opportunities in all markets. Other opportunity and uncertainty parameters are treated as normally distributed and are defined by the standard deviation.

²The environmental parameters are opportunity variety and decision-maker uncertainty. Opportunity variety and decision-maker uncertainty are shorthand terms. Opportunity variety brings together similar levels of opportunity arrival rate and variability in the opportunity parameters. A low-variety scenario thus provides few opportunities to choose from, as well as little variability between the options. In contrast, a high-variety scenario provides many opportunities and a great degree of variability. Decision-maker uncertainty is defined by the estimation error parameter for each opportunity attribute. These are secondary parameters. It is generally the case that these parameters do not significantly influence the result, unless specified to extreme values. For this reason, we recommend that opportunity variety and decision-maker uncertainty be set qualitatively to standard levels of low, moderate, or high. Throughout this article, we select moderate levels. Moderate levels reflect intermediate values of the parameters, with standard deviation parameters specified at 50% of the expected value of an average opportunity. For completeness, in each of our applications, we also performed limited sensitivity analysis at alternate values of opportunity variety and uncertainty. This confirmed that our conclusions are not sensitive to reasonable changes in these parameters. For new applications, we recommend similar sensitivity analysis if there is uncertainty in any input parameters.

³In Model Definition, we have specified the model parameters that are most determinative of the result. Some competition models also have additional parameters that must be specified. These parameters are relative parameters that do not determine the result, but must be specified to acceptable values that allow the competition dynamics to be observed. For example, a threshold value that defines a competitive outcome is not objectively low or high, but only low or high in the context of the simulation length and resources available. If this threshold value is reasonably achievable

during the simulation, the competition dynamics can be observed, and the results are meaningful. In contrast, if the threshold is extremely high, it will never be achieved by any competitors in a simulation. In cases such as these, it is typically obvious that the parameters have not been set appropriately. In each application, the relevant additional parameters are specified as follows. In the FFRDC application, it is necessary to specify a first-mover breakthrough threshold. We specify this threshold as equal to 10 average-valued opportunities. In the case of the CCDC application, it is necessary to specify a latecomer threshold. We specify this threshold as equal to five average-valued opportunities. In each case, these thresholds are acceptable because during a 10-year simulation, given the resources of the organizations involved, some competitors will reach the threshold, enabling the competition dynamics to be observed in one or more markets. In the Independent Research and Development (IR&D) application, it is necessary to specify the number of competitive acquisitions per market area. We specify one acquisition per market, occurring after 5 years. In this case, simulating one acquisition reduces the computational complexity of the simulation, as compared to simulating multiple acquisitions, while still capturing the competition dynamics. In future applications, we recommend similarly setting any additional model parameters to low values within an observed acceptable range, managing computational complexity, while allowing competition dynamics to be analyzed.

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Featured Book

12 Seconds of Silence: How a Team of Inventors, Tinkerers, and Spies Took Down a Nazi Superweapon

Author: Jamie Holmes

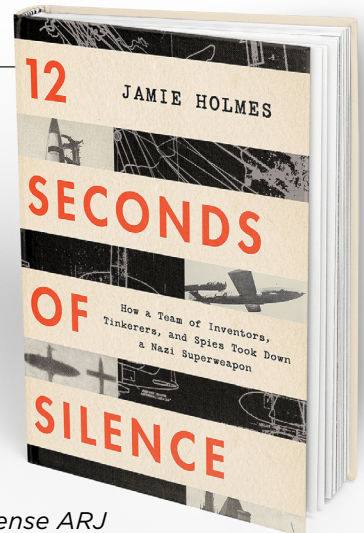
Publisher: Houghton Mifflin Harcourt

Copyright Date: 2020

Hard/Softcover/Digital: Hardcover,
416 pages

ISBN-13: 9781328460127

Reviewed by: Emily Beliles, Assistant Editor, *Defense ARJ*



Review:

Jamie Holmes' *12 Seconds of Silence* is the untold story of the scientists of Section T and the race to develop the proximity fuse (or fuze). At the dawn of World War II, with few resources dedicated to military research and woefully underfunded Army and Navy research laboratories, America found itself unprepared to keep up with rapidly developing German technology. Holmes notes that, "In 1938, the Army devoted only 1.5 percent of its budget to research" (p. 32). Just 18 months before the U.S. would enter the war, President Franklin D. Roosevelt established the National Defense Research Committee (later Office of Scientific Research and Development [OSRD]), marking the U.S. Government's first serious investment in scientific research and partnering university research labs, the DoD, and industry executives in a united effort. Section T, a branch of OSRD, was led by Merle Tuve and tasked with developing a "smart" fuse that would detonate in proximity to approaching aircraft rather than on a preset timer.

This thrilling story documents how the team at Section T met this challenge against all odds. While the huge German research base at Peenemunde, with over 17,000 workers, was developing the V-1 flying bomb to bombard London, Section T was developing the smart fuse that would take them down. Working out of an old car garage in Maryland with a backyard in rural Virginia for a testing ground, the scientists of Section T accomplished this task in just 2 years and not a moment too soon.

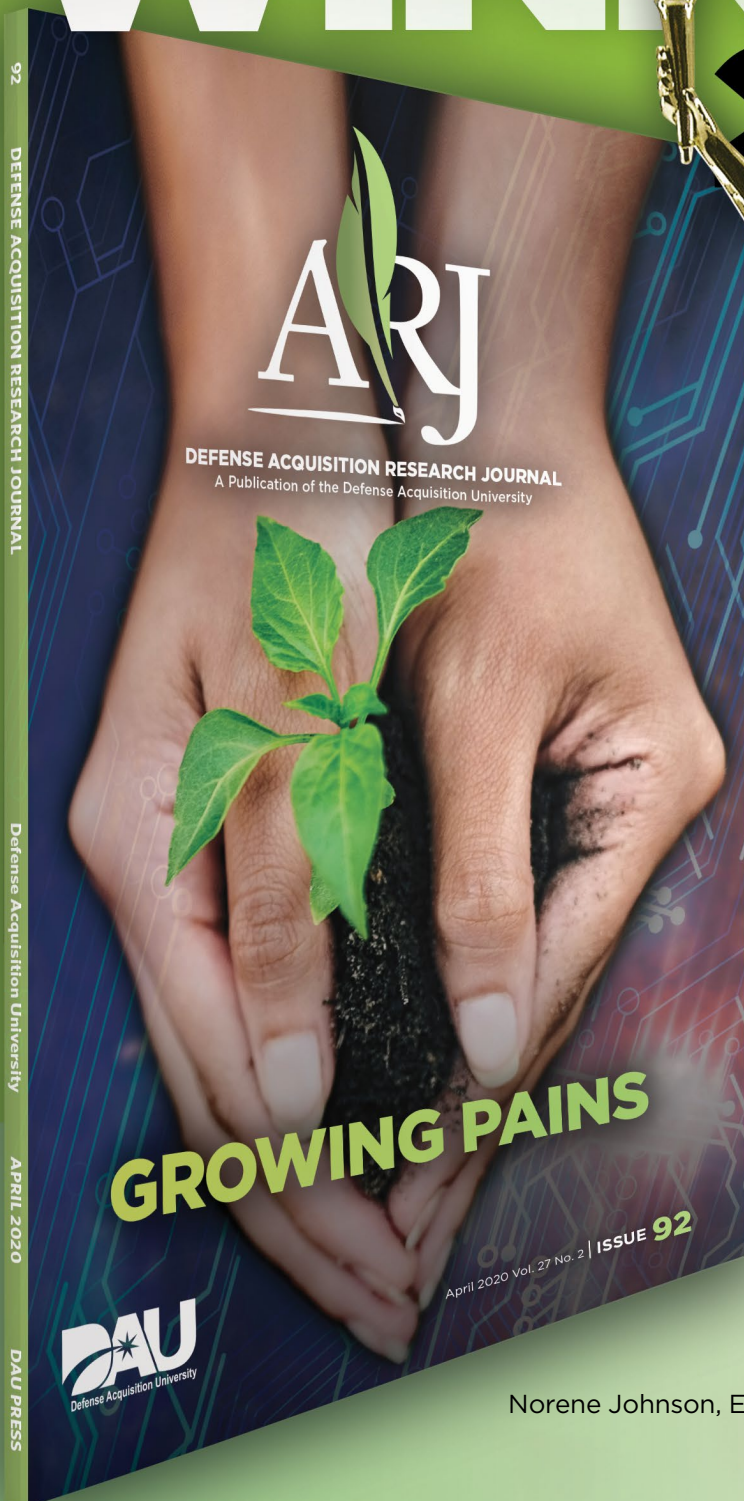
On June 13, 1944, shortly after D-Day, the first V-1 struck London, marking the dawn of a new type of aerial warfare. The British anti-aircraft gunners and the Royal Air Force pilots were no match for the high speeds of the V-1. Nearly 3,000 Londoners died from the V-1 attacks in the first 3 weeks. As the V-1 terrorized London, Section T rushed to fit the smart fuse to British shells in just 2 months. Aimed by batteries largely staffed by women, nicknamed "ack-ack girls," the smart fuse was able to take down V-1s with near 100% accuracy. On naval ships, it helped turn the tide in the Pacific, and when employed later as an antipersonnel weapon, the smart fuse, in the words of General George Patton, "won the Battle of the Bulge for us" (p. 268). Eventually, even the atomic bombs dropped over Hiroshima were armed with a Section T smart fuse.

Holmes' historical account of these events makes for a captivating read for individuals from every background. The story is particularly relevant to the Defense Acquisition Workforce in highlighting the connection between rapidly advancing technology and war strategy.

Section T “helped infuse scientific analysis directly into military tactics” (p. 162), cementing the vital role of scientific research in the Department of Defense. The development of the smart fuse is also a key example of the critical necessity of delivering capabilities faster and focusing on the needs of the Warfighter. As Merle Tuve said, “Our moral responsibility goes all the way to the final battle use of this unit; its failure there is our failure” (p. 135). Although OSRD and Section T were dissolved in 1947, the innovative collaboration between the DoD and leaders in science and industry paved the way for the thriving science and technology ecosystem that persists within the military today. Readers will thoroughly enjoy *12 Seconds of Silence* and this exciting story of the scientists of Section T.

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DevSecOps Practices for an Agile and Secure IT Service Management

Mounia Zaydi & Bouchaib Nassereddine

Summary:

Without appropriate consideration of security best practices, the continuous delivery of Information Technology (IT) services facilitated by Development Operations (DevOps) is risky. On the other hand, Security Operations (SecOps) offers the possibility to reduce security risks if security is integrated into the continuous delivery pipeline according to best practices. The purpose of this paper is to investigate how Development Security Operations (DevSecOps) culture can be applied in IT Service Management (ITSM). We interviewed representatives of five Middle East and North Africa (MENA) organizations that are adopting SecOps in their ITSM daily activities. We note that the majority of respondents expressed the potential of common DevSecOps such as automated monitoring to improve ITSM. The findings of this study imply that organizations need a framework for understanding the DevSecOps culture before they can adopt these practices in their ITSM. Likewise, this study explores the main DevSecOps practices relevant to efficient ITSM.

APA Citation:

Zaydi, M., & Nassereddine, B. (2020). DevSecOps practices for an agile and secure IT service management. *Journal of Management Information and Decision Sciences*, 23(2), 1-16. <https://search.proquest.com/docview/2424965737?accountid=40390>

Kessel Run: An Analysis of the Air Force's Internal Software Development Organization

Jenny Aroune, Robert Hollister & Nathan Taylor

Summary:

The current method of acquiring custom, innovative software through traditional contracting methods is an outdated practice. These traditional methods are time-consuming, and could be improved with the Air Force's Kessel Run, an internal software development organization. With the Air Force's Kessel Run, the time from software inception to operation can go from years to days. Unfortunately, neither most of the Air Force nor the rest of the Department of Defense (DoD) has yet to catch up to the forward thinking of those involved in the creation of Kessel Run. Most of the Air Force and the DoD are still outsourcing for most of their innovative acquisitions, whether it be research and design or product (software) development. This case study offers insight to the new organization and identifies the potential to apply the concepts learned during its creation to benefit other DoD organizations when considering insourcing as opposed to the traditional outsourcing acquisition approach.

APA Citation:

Aroune, J., Hollister, R., & Taylor, N. (2019). *Kessel Run: An analysis of the Air Force's internal software development organization* [Master's thesis]. Naval Postgraduate School. https://calhoun.nps.edu/bitstream/handle/10945/63995/19Dec_Aroune_Hollister_Taylor.pdf?sequence=1&isAllowed=y

From Waterfall to OASIS: Navy Command's Excursion through Kessel Run Brings DevSecOps to Marine Corps

Steve Ghiringhelli

Summary:

A Naval Information Warfare Center (NIWC) Atlantic enterprise engineering team recently began deploying in earnest its paradigm-shifting methodology for developing software. Modeled after the U.S. Air Force's

"Kessel Run," the newly accredited Operational Application and Service Innovation Site (OASIS) enables NIWC Atlantic's Expeditionary Warfare (ExW) Department to provide "DevSecOps"—development, security, and operations—to the U.S. Marine Corps for the first time. DevSecOps is a commercial best practice that has revolutionized the software industry and only recently made inroads in the U.S. military.

APA Citation:

Ghiringhelli, S. (2020). From waterfall to OASIS: Navy command's excursion through Kessel Run brings DevSecOps to Marine Corps. *Washington: Federal Information & News Dispatch, LLC*. <https://search.proquest.com/docview/2391512279?accountid=40390>

DevSecOps Puts Security at the Heart of Program Development

Henry S. Kenyon

Summary:

The Department of Defense is rethinking how it approaches software and systems development in its technology programs by using more flexible methods to streamline the process and to improve cybersecurity from the start. Because traditional DoD program development processes don't have the speed and flexibility to keep up with rapid technological changes or fast-paced modern adversaries, new methodologies are being considered. DevSecOps versus Agile Development methodologies that emphasize iterative development cycles and feedback to find and correct errors throughout the software building process have become more common in federal government technology programs. While DevSecOps does build on some Agile Development principles, such as the continuous integration and delivery of software systems in cycles, its key emphasis from the beginning of the process is to integrate security features: DoD Applications and Changing Culture DevSecOps fits into the DoD's modernization strategy to upgrade legacy systems and incorporate new capabilities such as machine learning or artificial intelligence into its mission.

APA Citation:

Kenyon, H. S. (2020). DevSecOps puts security at the heart of program development. *Signal*, 74(9), 42-43. <https://search.proquest.com/docview/2406319202?accountid=40390>

DoD Enterprise DevSecOps Reference Design: Version 1.0

Thomas Lam & Nicholas Chaillan

Summary:

Legacy software acquisition and development practices in the DoD do not provide the agility to deploy new software “at the speed of operations.” In addition, security is often an afterthought, not built in from the beginning of the life cycle of the application and underlying infrastructure. DevSecOps is the industry best practice for rapid, secure software development. DevSecOps is an organizational software engineering culture and practice that aims at unifying software development (Dev), security (Sec) and operations (Ops). The main characteristic of DevSecOps is to automate, monitor, and apply security at all phases of the software life cycle: plan, develop, build, test, release, deliver, deploy, operate, and monitor. In DevSecOps, testing and security are shifted to the left through automated unit, functional, integration, and security testing—this is a key DevSecOps differentiator since security and functional capabilities are tested and built simultaneously.

APA Citation:

Lam, T., & Chaillan, N. (2019). DoD enterprise DevSecOps reference design: Version 1.0. Department of Defense. https://dodcio.defense.gov/Portals/0/Documents/DoD%20Enterprise%20DevSecOps%20Reference%20Design%20v1.0_Public%20Release.pdf?ver=2019-09-26-115824-583



Developmental Test and Requirements: Best Practices of Successful Information Systems Using Agile Methods.

Jeremy D. Kramer & Torrey J. Wagner

Summary:

This article provides insights into the current state of developmental testing (DT) and requirements management in Department of Defense information systems employing Agile Development. The authors describe the study methodology and provide an overview of Agile Development and testing. Insights are described for requirements, detailed planning, test execution, and reporting. This work articulates best practices related to DT and requirements management strategies for programs employing modernized Software Development Life Cycle practices.

APA Citation:

Kramer, J. D., & Wagner, T. J. (2019). Developmental test and requirements: Best practices of successful information systems using agile methods. *Defense Acquisition Research Journal*, 26(2), 128-150. <https://doi.org/10.22594/dau.19-819.26.02>





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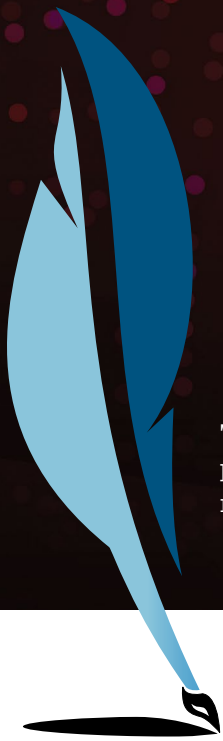
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Research involves the creation of new knowledge. This generally requires either original analysis of material from primary sources, including program documents, policy papers, memoranda, surveys, interviews, etc.; or analysis of new data collected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

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



We encourage prospective writers to coauthor, adding depth to manuscripts. We recommend that junior researchers select a mentor who has been previously published or has expertise in the manuscript's subject. Authors should be familiar with the style and format of previous *Defense ARJs* and adhere to the use of endnotes versus footnotes, formatting of reference lists, and the use of designated style guides. It is also the responsibility of the corresponding author to furnish any required government agency/employer clearances with each submission.

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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.

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- determine if the study can be replicated, and
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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.

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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/>.

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Each case history should contain the following components:

- Introduction
- Background
- Characters
- Situation/problem
- Analysis
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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.

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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.



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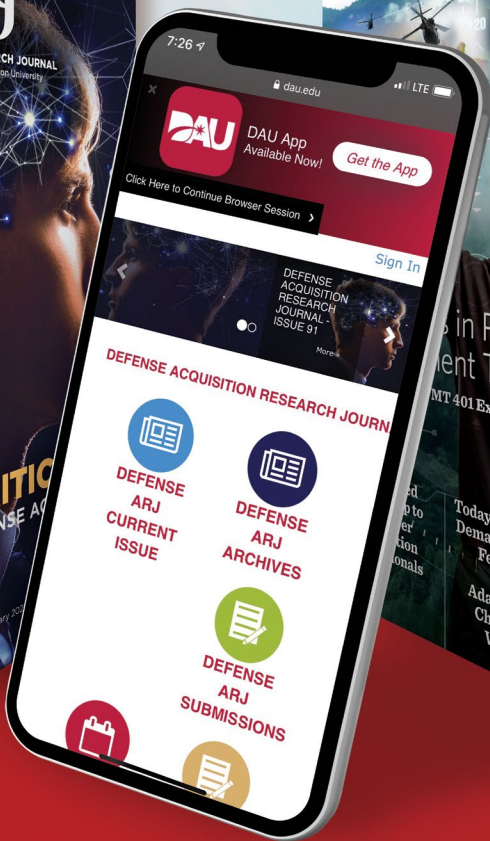
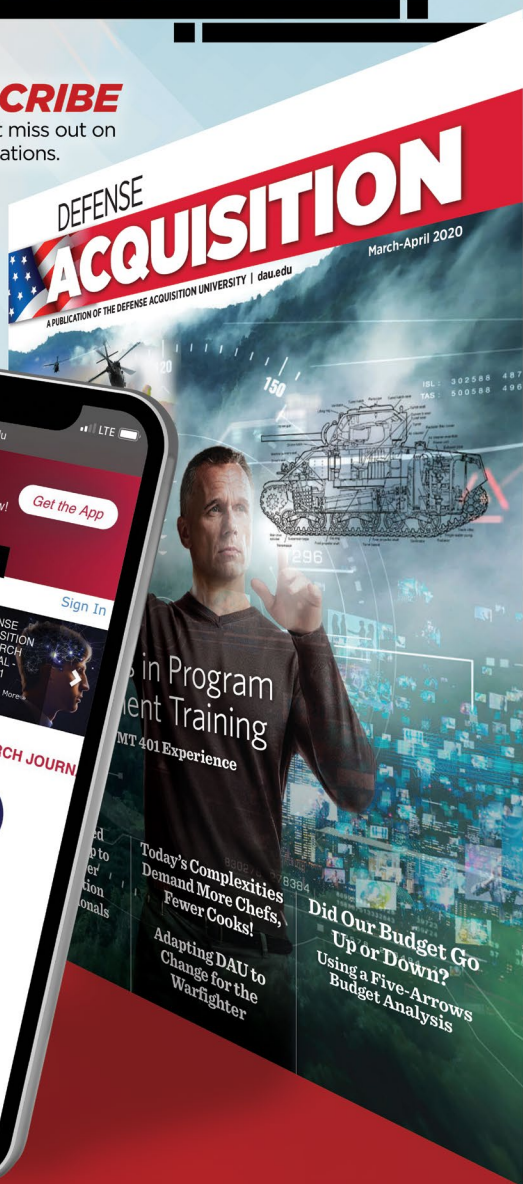
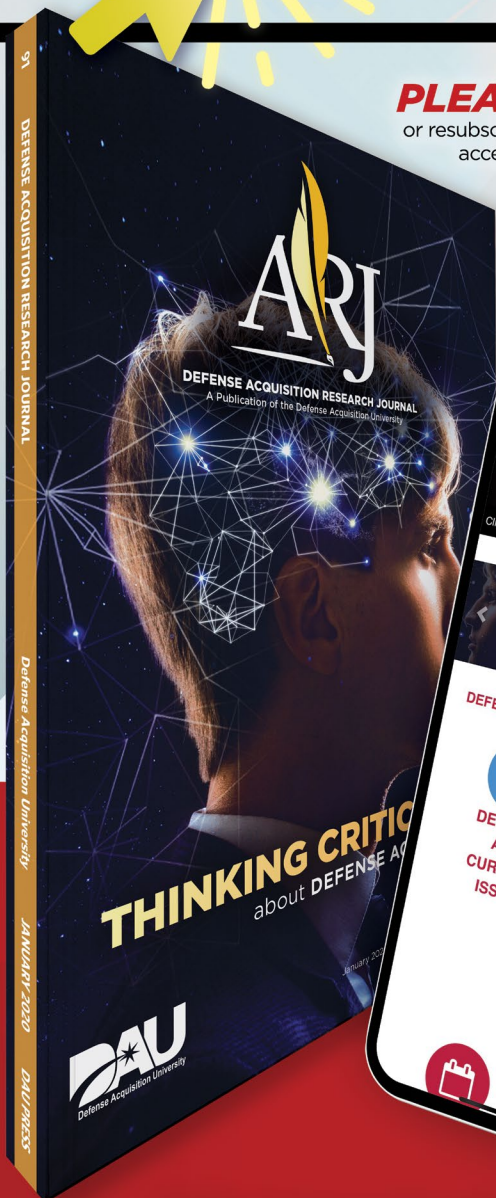
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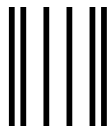
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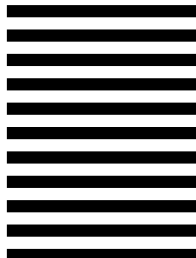
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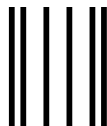
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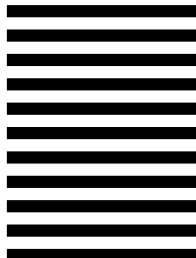


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