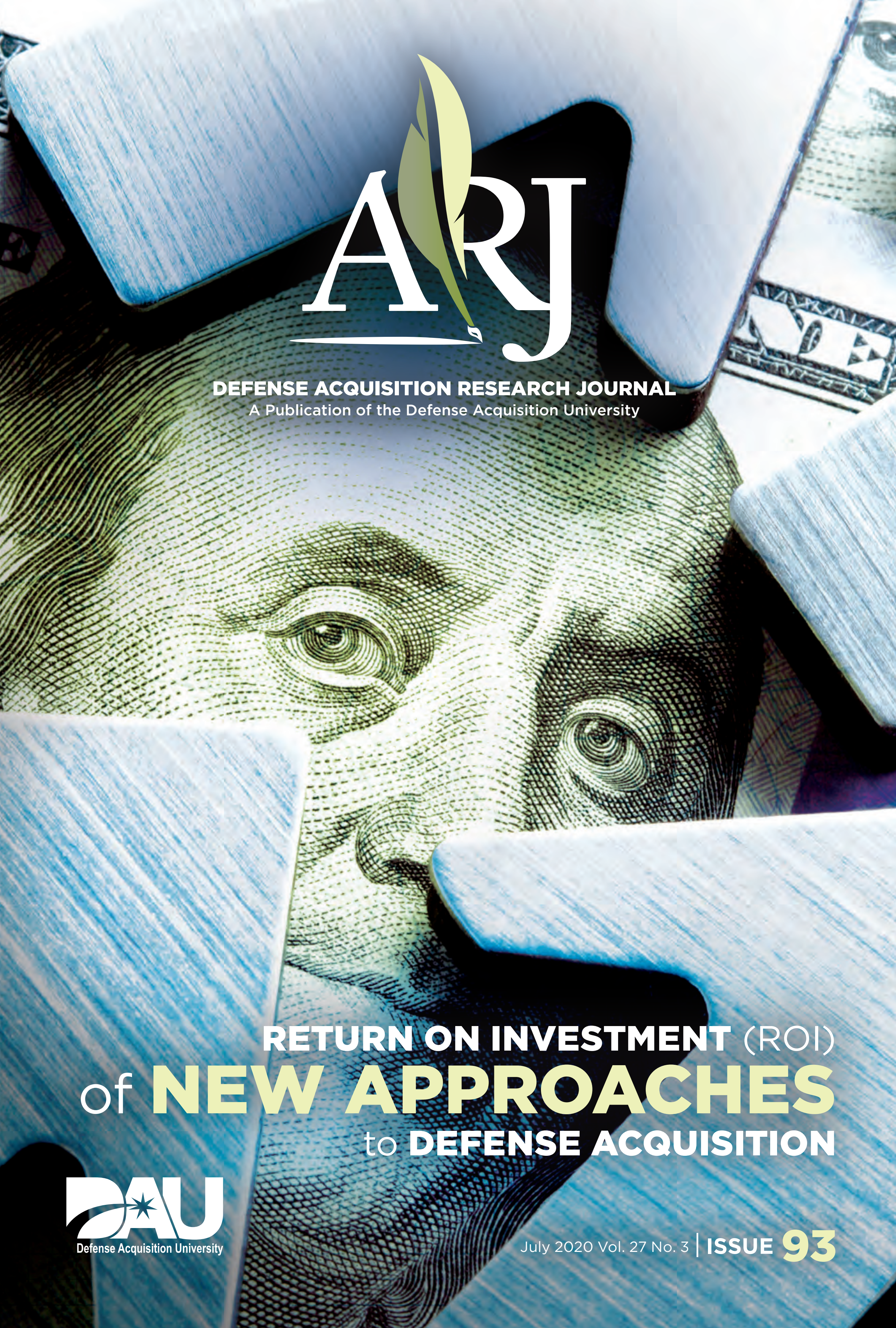

ARJ

DEFENSE ACQUISITION RESEARCH JOURNAL

A Publication of the Defense Acquisition University

RETURN ON INVESTMENT (ROI) of NEW APPROACHES to DEFENSE ACQUISITION

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A Model for Exogenous Learning on Department of Defense Procurement Programs

Patricia F. Bronson

This article presents a numerical optimization model for projecting exogenous learning on DoD procurement programs. The optimization is based on an assessment of the expected return on investments, and simulated results reflect characteristics of Patriot Advanced Capability-3 (PAC-3) and F-22 Raptor Fighter Aircraft procurement programs.

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FROM THE CHAIRMAN AND EXECUTIVE EDITOR

Dr. Larrie D. Ferreiro

This edition of the *Defense Acquisition Research Journal* is devoted to the Return on Investment (ROI) of new approaches to defense acquisition. The first article, "Increasing Value and Savings in Shipbuilding With Innovative Technologies" by David N. Ford and Tom Housel, describes the potential value and savings of adopting Three-Dimensional Laser Scanning (3DLS), Additive Manufacturing (AM), and Product Life-cycle Management (PLM). Simulation and modeling using knowledge value added demonstrates an innovative investment analysis approach and the potential for large savings and increased value.

The second article, "Studying Acquisition Strategy Formulation of Incremental Development Approaches" by Robert F. Mortlock, studies the challenges that acquisition professionals have in formulating the Department of Defense's preferred acquisition approach—incremental development—and provides acquisition policy reform recommendations. The research involves surveys of acquisition professionals to formulate the components of a recommended acquisition strategy based on typical programmatic decision inputs such as requirements, technology maturity, risk, urgency, and funding.

The third article, "A Model for Exogenous Learning on Department of Defense Procurement Programs" by Patricia F. Bronson, presents a numerical optimization model for projecting exogenous learning on DoD procurement programs. It is based on an assessment of the expected returns on investments using simulations of the Patriot Advanced Capability-3 (PAC-3) and F-22 Raptor Fighter Aircraft procurement programs.

This issue's Current Research Resources in Defense Acquisition focuses on Intellectual Property and Data Rights in Government Procurement.

The featured book reading in this issue's Defense Acquisition Professional Reading List is *Seapower States* by Andrew Lambert, reviewed by Dr. Mary Redshaw.

Dr. James Moreland has departed the *Defense ARJ* Editorial Board. We thank him for his service and wish him well.

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

DAU CENTER FOR DEFENSE ACQUISITION

RESEARCH AGENDA 2020

This Research Agenda is intended to make researchers aware of the topics that are, or should be, of particular concern to the 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. They are also encouraged to contact the Point(s) of Contact (POC), who may be able to provide general guidance as to current areas of interest, potential sources of information, etc. Contact information for the POCs is available on the DAU Research website at ***https://www.dau.edu/library/research/p/Research-Areas***.

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 successfully 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 what acquisition leaders might do to 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, e.g., 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 between DoD and complex, custom-built commercial products (e.g., offshore oil platforms).
- Compare program cost performance in various market sectors: highly competitive (multiple offerors), limited (two 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.

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 effect 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 services 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 Undefinitized Contract Actions have an effect on contractor pricing and willingness, or lack of willingness to provide support during proposal analysis?
- For multi-award, 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 from aligning 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/simulations 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 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 the professionalization 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 implement 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 with 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 made 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 adaption 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 be a process that produces 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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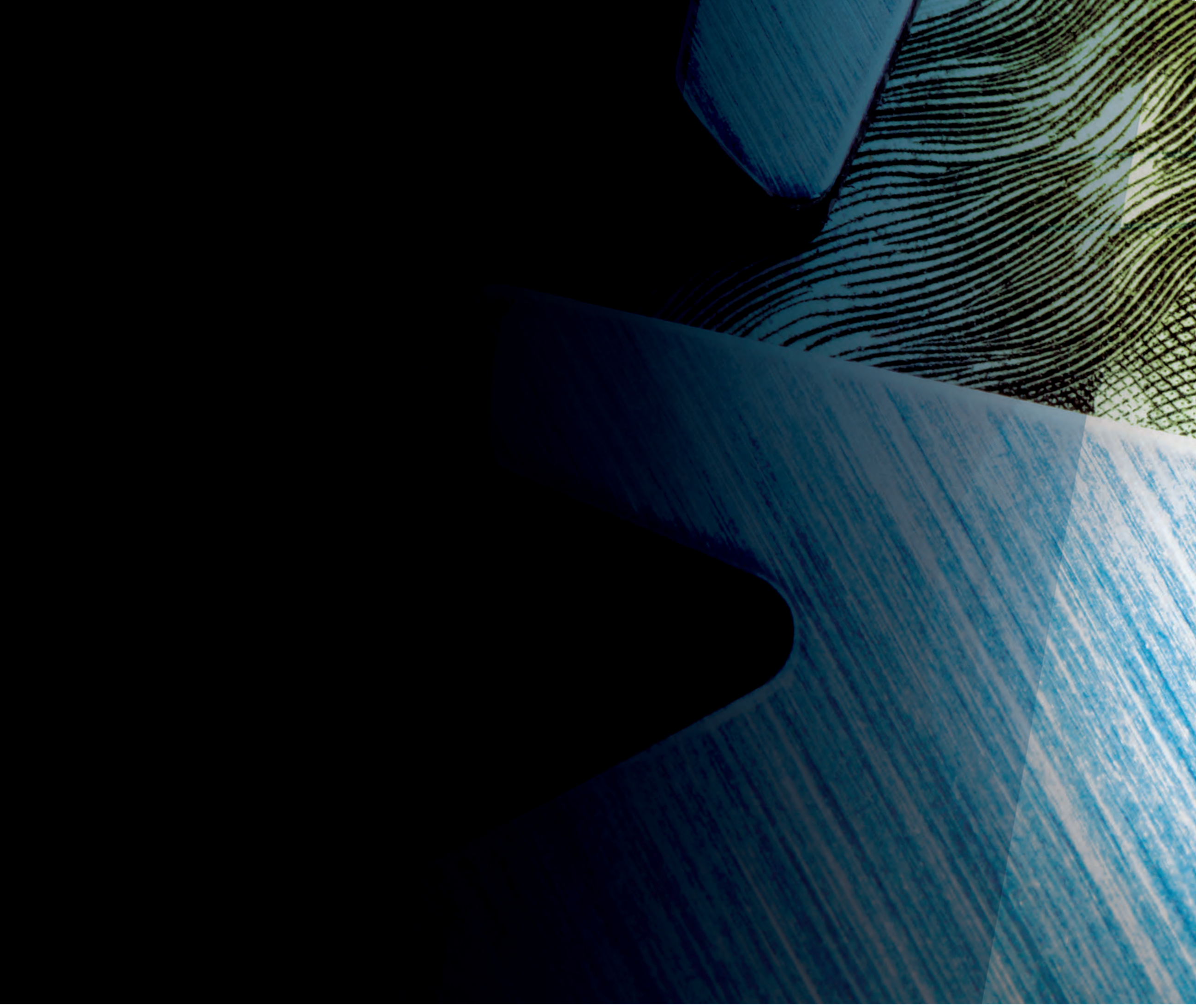
For submissions, please contact the *Defense ARJ* managing editor at ***DefenseARJ@dau.edu*** and visit the *Defense ARJ* Submissions page at ***https://www.dau.edu/library/arj/p/Defense-ARJ-Submissions***.



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INCREASING VALUE and SAVINGS in SHIPBUILDING WITH INNOVATIVE TECHNOLOGIES

David N. Ford and Tom Housel

Image designed by Michael Bubar-Krukowski

To effectively and efficiently build and fund the projected larger fleet, the U.S. Navy must reduce costs while meeting mission needs by leveraging the full benefits of new technologies. Three-Dimensional Laser Scanning (3DLS), additive manufacturing (AM), and product life-cycle management (PLM) may be able to provide such benefits. The current work tests this hypothesis by estimating potential cost savings and return on investment (ROI) to assess the impacts of these commercially available technologies on naval shipbuilding. Results indicate that very large savings and increased value are possible by adopting and using these technologies. The conclusions enumerate insights about how technology can increase value and reduce costs in shipbuilding.

DOI: *https://doi.org/10.22594/dau.19-842.27.03*
Keywords: *Knowledge Value Added (KVA), Simulation, Three-Dimensional Laser Scanning (3DLS), additive manufacturing (AM), Product Life-cycle Management (PLM)*

The U.S. Navy seeks to become a battle force of 335 ships over the next 30 years (Office of the Chief of Naval Operations, 2018), which is an increase from today's battle force of 289 ships. In a report submitted to Congress in February 2018, the Navy's 2019 shipbuilding plan covering fiscal years (FY) 2020 to 2050 forecasts that the plan would cost $106.45 billion through FY 2023, an average of about $21.3 billion per year. Budget pressures require the Navy to simultaneously pursue cost savings while improving valuable capabilities.

Innovative and Commercially Available Technologies

Adopting and using new technologies in shipbuilding is a potentially effective way to meet these goals. Three innovative and commercially available technologies (i.e., Three-Dimensional Laser Scanning [3DLS], additive manufacturing [AM], and Product Life-cycle Management [PLM]) may generate large savings in naval shipbuilding without degrading capabilities, thereby improving naval shipbuilding. Estimating the benefits of these technologies is a necessary part of assessing their value in naval shipbuilding. These three technologies were chosen as the basis for this study based on prior research in the manufacturing sectors (Ford & Housel, 2013; Ford et al., 2016; Housel et al., 2019; Housel et al., 2015).

Three-Dimensional Laser Scanning

Laser scanners use infrared laser technology to produce exceedingly detailed three-dimensional images of complex environments and geometries in only a few minutes. The resulting images are rendered by software into three-dimensional point clouds that can be used to design improvements, verify construction, and improve other operations. 3DLS technology has been used to achieve significant cost savings, optimize maintenance schedules, increase quality, improve safety, and reduce rework. Commercial applications range from maritime and space applications to manufacturing and production with applications in law enforcement for crime scene documentation, architectural and civil engineering as the basis for Building Information Modeling (BIM), factory and plant maintenance for equipment installation, and surveying to capture and calculate volumes.

The National Shipbuilding Research Program (NSRP, 2005, pp. 139–144; 2007) funded two Ship Check Data Capture projects in 2005 and 2006 to develop a process that captures as-built measurement data in digital/electronic format during a ship check. The two projects grew out of a need to process the as-built measurement data into 3D computer-aided design (CAD) models using available commercial-off-the-shelf (COTS) modeling technologies, and to provide a process for the development of 3D CAD models. The FY 2006 follow-on project refined the ship check process to better align it with the U.S. shipbuilding and repair industry using COTS technology. Performance improvement metrics were developed and tracked to compare the "as-is" practice with anticipated project results. Estimated cost savings of 37% and time savings of 39% compared to traditional ship checks using tape measures were realized (NSRP, 2005, 2007).

The Naval Undersea Warfare Center (NUWC) began using laser scanning to reverse engineer components with complex geometries to enable competitive bidding in 2007. In the past, the Navy did not have sufficient documentation from the original equipment manufacturer (OEM) to competitively procure replacement components, which resulted in purchasing very expensive replacements from the OEM. The Navy saved $250,000 by purchasing parts produced with laser scanning through competitive bidding. In addition, the time required to reverse engineer a typical component, including both measurement and modeling time, was reduced from 100 hours to 42 hours with a laser scanner. These programs revealed that 3DLS can improve shipbuilding-related operations by reducing or eliminating return visits to sites for missed measurements and by providing more accurate and complete as-built data that can improve design and reduce rework, thereby increasing cost avoidance.

Additive Manufacturing

AM is the "process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" (American Society for Testing & Materials, 2013). It differs radically from subtractive processes (e.g., machining) by building a 3D object by gradually adding successive layers of material. AM fabricates objects directly from 3D CAD models. The 3D model is disaggregated into multiple horizontal layers, each of which is produced by the machine and added to the preceding layers. AM is often referred to as "3D printing."

Very large improvement in manufacturing performance is possible with AM. For example, Lockheed Martin estimates that some complex satellite components can be produced 48 percent cheaper and 43 percent faster with AM, and production costs could be reduced by as much as 80 percent. Boeing has installed environmental control system ducting made by AM for its commercial and military aircraft for many years; tens of thousands of AM parts are flying on 16 different military and commercial production aircraft (Wohlers, 2020). Ford Motor Co. uses AM in several areas, including the tooling used to create production parts and to build intake manifold prototypes that can be tested for up to 100,000-mile cycles. With traditional manufacturing methods, it would take 4 months and cost $500,000 to build, while an AM manifold prototype costs $3,000 to build over 4 days.

"The 3D model is disaggregated into multiple horizontal layers, each of which is produced by the machine and added to the preceding layers. AM is often referred to as "3D printing."

Office of Naval Research studies have shown that an AM technology (Electron Beam Direct Manufacturing) process has the potential to reduce per-part manufacturing costs by 35–60% compared to costs to manufacture complex-shaped parts with traditional manufacturing approaches (Office of Naval Research, 2016). Product lead time might also be reduced by as much as 80%. The U.S. Army deployed in July 2012 its first mobile 3D printing laboratory in Afghanistan inside a shipping container that is capable of being carried by helicopter. The Navy has also used AM in shipbuilding. The Metalworking Center conducted the "Additive Manufacturing for Shipbuilding Applications" project to demonstrate the cost and time benefits of AM to support the construction of Navy platforms. Ingalls Shipbuilding has estimated a minimum acquisition cost savings of $800,000 per year by utilizing AM for the construction of Destroyer Designated Guided (DDG), Landing Helicopter Assault (LHA), and Landing Platform/Dock (LPD) Navy platforms (Navy Metalworking Center, 2015).

Product Life-cycle Management

PLM is an "integrated, information-driven approach comprised of people, processes/practices, and technology for all aspects of a product's life, from its design through manufacture, deployment, and maintenance—culminating in the product's removal from service and final disposal"

(Grieves, 2009, p. 3). By trading product information for wasted time, energy, and material across the entire organization and into the supply chain, PLM drives the next generation of "lean thinking" (SPAR 3D, 2006). PLM has been used by the automotive, aerospace, and other industries that build very large, very complex products and systems. It was designed to provide stakeholders with current views of every product throughout its life cycle to facilitate decision making and corrective actions, if necessary.

Problem Description

The problem is that traditional shipbuilding is a large and complex process, resulting in many cost and value deficiencies. This is a problem because, as budgets for shipbuilding and maintenance shrink, the number of ships available for service also shrinks.

The three technologies that are the focus of the current study—3DLS, AM, and PLM—have been applied in other industries, resulting in reduced costs and increased efficiencies in manufacturing. Therefore, the three technologies also have the potential to significantly reduce naval shipbuilding and maintenance costs. However, estimates of potential benefits are needed to assess whether, and to what extent, the technologies improve naval shipbuilding. Prior research indicated that using these technologies can save hundreds of millions of dollars in ship maintenance, suggesting that large savings in shipbuilding are also possible (Ford & Housel, 2013; Ford et al., 2016; Ford et al., 2012). To estimate benefits and thereby evaluate the usefulness of these technologies for shipbuilding, a methodology is needed that can provide quantitative estimates to assess the potential return on investment (ROI) and cost savings of using these information technologies in naval shipbuilding processes.

Investment evaluation tools are widely available, including cost/benefit ratios, ROI, and internal rate of return estimates. However, these tools require monetized benefits (i.e., revenue or revenue surrogate, in quantified common units of value) to evaluate the relative attractiveness of investment alternatives. Investment alternative evaluations for operations, such as naval shipbuilding and maintenance, are particularly challenging due to the lack of monetary revenues from these naval operations.

Research questions addressed in this research include the following:

- How can investments in potential improvements in nonrevenue operations such as naval shipbuilding and maintenance be evaluated?
- Does the scale of potential savings and increased value from the adoption of 3DLS, AM, and PLM in shipbuilding justify the adoption and use of these technologies?

Methodology and Procedures

To address this challenge we combined system dynamics modeling with the Knowledge Value Added (KVA) method of evaluation, which quantifies benefits in a proxy for revenue that can be used in ROI evaluations. ROI is a basic productivity ratio with profit generated from revenues (i.e., revenue minus cost) in the numerator and cost to generate the revenue in the denominator.

"The system dynamics perspective focuses on how the internal structure of a system impacts system behavior and thereby performance over time.

The investigation first built a process-focused simulation model of naval shipbuilding using the system dynamic modeling methodology. This model was tested and calibrated to a specific naval shipbuilding program. The operational impacts of the three innovative technologies on naval shipbuilding were described quantitatively and the results used to estimate their impacts on shipbuilding processes under different technology adoption strategies. These estimates were used in the simulation model to forecast the process impacts of the technology adoption strategies. The KVA simulation approach was then used to model the ROI of shipbuilding with and without the three technologies. The results were used to estimate the value added by adopting the technologies as well as shipbuilding costs and potential cost savings.

The system dynamics modeling methodology applies a control theory perspective to the design and management of complex human systems. System dynamics combines servo-mechanism thinking with computer simulation to analyze systems. It is one of several established and successful approaches to systems analysis and design (Flood & Jackson, 1991; Jackson, 2003; Lane & Jackson, 1995). Forrester (1961) developed the methodology's philosophy and Sterman (2000) specified the modeling process with examples and described numerous applications. The system dynamics perspective focuses on how the internal structure of a system impacts system behavior and thereby performance over time. The approach is unique in its integrated use of stocks and flows, causal feedback, and time delays to model and explain processes, resources, information, and management policies. The methodology's ability to model many diverse system components (e.g., work, people, money, value), processes (e.g., design, technology development, production, operations, quality assurance), and managerial decision making and actions (e.g., forecasting and resource allocation) makes system dynamics useful for modeling and investigating military operations, including naval shipbuilding.

System dynamics has been applied to military systems, including planning and strategy (Bakken & Vamraak, 2003; Duczynski, 2000; McLucas et al., 2006; Melhuish et al., 2009), workforce management (Bell & Liphard, 1978), technology (Bakken, 2004), command and control (Bakken & Gilljam, 2003; Bakken et al., 2004), operations (Bakken et al., 2004; Coyle & Gardiner, 1991), logistics (Watts & Wolstenholme, 1990); acquisition (Bartolomei, 2001; Ford & Dillard, 2008, 2009a, 2009b; Homer & Somers, 1988), and large system programs (Cooper, 1980; Lyneis et al., 2001). Coyle (1996) provided a survey of applications of system dynamics to military issues.

KVA describes outputs of all asset types (e.g., human, machine, information technology) in quantitative common units of output that reflect the knowledge in an organization. This provides a basis for combining and comparing the outputs of diverse operations. For example, the purpose of a military process may be to gather signal intelligence or plan for a ship alteration. KVA would describe the outputs of both processes in common units of knowledge, thus making their productivity performance comparable. KVA measures the value provided by analyzing an organization, process, or function at the process level. By capturing the value of knowledge embedded in an organization's core processes, KVA identifies the relative cost and value of various processes, products, or services. Describing processes in common units also permits revenue estimates to be generated that can be compared to market-based values, thereby enabling the use of standard financial analyses for nonprofits such as the U.S. military.

The KVA method has been applied to numerous military core processes across the Services (e.g., Ford et al., 2012; Housel et al., 2019). KVA research has more recently provided a means for simplifying real options valuation analysis for DoD processes. This research enables a more standard basis for comparing performance across diverse core processes.

Modeling Shipbuilding Technology ROI and Cost Savings

The description of the generic shipbuilding process in the 2013 GAO report, "Naval Shipbuilding: Opportunities Exist to Improve Practices Affecting Quality," was used as the basis for modeling the shipbuilding process. The four primary shipbuilding phases (pre-contracting, contract award, design and planning, and construction) were expanded into the following phases based on the report's process descriptions:

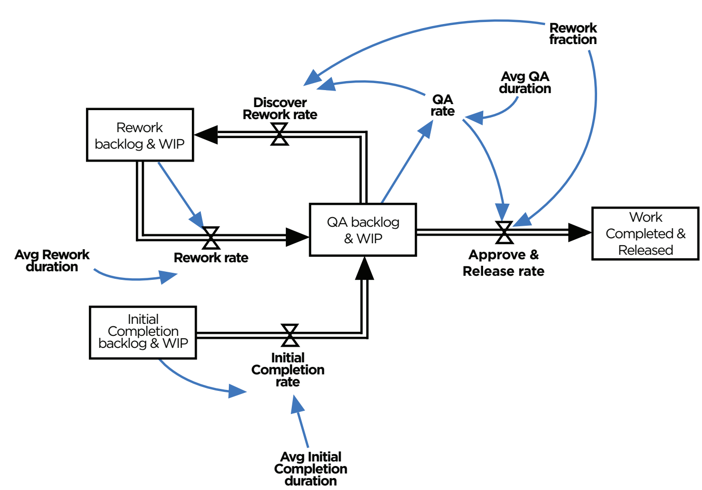
- **Concept design:** The Navy determines the necessary requirements and desired capabilities and develops an acquisition strategy.
- **Detailed engineering design:** Ship designers develop all aspects of the ship's structure and routing of major distributive systems, such as electrical or piping, throughout the ship.
- **Pre-construction planning:** Contractor plans production flow and develops drawings that, once approved by the Navy, will be used by the shipyard workers to build the ship.

- **Block fabrication:** Ship fabrication begins as large steel or aluminum plates are cut and welded to form the basic building units for a ship.
- **Assembly and outfitting of blocks:** Piping, brackets for machinery or cabling, and ladders, among other things, are installed.
- **Keel laying and block erection:** Blocks are welded to form larger sections that comprise the ship's structure. The contractor assembles these grand blocks to form the keel.
- **Pre-delivery final outfitting:** The remainder of the machinery and equipment is installed.
- **System testing and commissioning:** Parts, materials, and machinery, such as engines, pumps, and associated control instrumentation used in the ship, are tested by the manufacturer. Installation and connection of these components create subsystems.
- **Sea trials:** The ship embarks on a series of dockside and at-sea tests where the overall quality and performance of the ship is evaluated.
- **Post-delivery final outfitting:** Crews board the ship and begin training, and mission systems are installed.
- **Post-delivery tests and trials:** Operational tests are conducted on the ship's combat and mission-critical systems.
- **Post shakedown availability:** Planned maintenance prior to the maiden voyage is performed to install class-wide upgrades or ship improvements, perform maintenance, and correct new or previously identified construction deficiencies.

Based on previous modeling by Ford and Sterman (1998, 2003a, 2003b) and Ford et al. (2004), each shipbuilding phase described above was assumed to have three basic operations: initial completion (IC), quality assurance (QA), and rework (RW). Each operation moves work in steps through each phase. Initial Completion moves work from the Initial Completion Backlog and Work in Progress (WIP) to the Quality Assurance Backlog and WIP. The QA operation either discovers required rework or approves and releases the work to a downstream phase. This moves work from the QA backlog and WIP to either the Rework Backlog and WIP (if rework is discovered) or to the stock of Work Completed and Released. Performing RW moves work from the Rework Backlog and WIP back to the QA backlog and WIP, where it is inspected again (Figure).

Each phase operation rate (IC, QA, or RW) is driven and constrained by the amount of work waiting to be completed by that operation and the average time required to complete the operation. Operation durations include process and resource constraints and are assumed to be constant throughout the shipbuilding phase. The rate at which work, within a phase, is inspected (the QA rate) is disaggregated into the fraction of inspections that discover required rework and the complement that are approved and released. Progress through each shipbuilding phase in the model also depends on the completion of work in the preceding (upstream) phase and constrains progress in its downstream phase. Although some overlapping of phases is possible, for simplicity it was assumed that the phases occur sequentially.

FIGURE. SIMULATING SHIPBUILDING: DRIVERS AND CONSTRAINTS ON SHIPBUILDING OPERATIONS IN A SINGLE PHASE



Estimates of values for model parameters are not available for a single ship or class of ships. Therefore, the baseline, or as-is, conditions, were modeled using parameter values from the literature—field data previously collected by part of a research study (Kenney, 2013)—and modeler estimates. Calibration was partially based on the *Arleigh Burke* (DDG51) destroyer. Birkler et al. (2005) reported on the labor required to build a U.S. Navy destroyer. The baseline as-is model was used to model the impact of three technologies (3DLS, AM, PLM) on shipbuilding economics.[1]

Potential Applications of Advanced Technologies to Navy Shipbuilding

3DLS, AM, and PLM can impact naval shipbuilding in many ways, including:

- **Integrated Ship Development:** PLM can combine requirements, design, production, quality assurance/quality control (QA/QC), training, and coordination with users through a single, integrated software system that links all the ship components through the development process. This reduces rework.
- **Design and construction document management:** PLM provides a single, integrated set of design documents that are maintained and integrally linked across disciplines and time. This can reduce rework through improved coordination and reduces durations of finding information required to perform shipbuilding operations.
- **Prototype generation:** AM creates fast and more frequent prototypes, increasing the number of design iterations and decreasing the duration of those iterations. The improvement in the final products reduces the fraction of work that fails inspections and must be reworked.
- **Final parts manufacturing:** AM reduces the time required to generate parts, reducing rework, labor, and material costs. These benefits are increased by using PLM.
- **Manufacturing inspection:** 3DLS of as-built parts is electronically compared to the 3D designs to confirm compliance with designs or identify anomalies to be investigated or corrected. This reduces the time required to inspect manufactured parts and reduces labor costs. These benefits are increased by the use of PLM.
- **Construction inspection:** 3DLS images of as-built conditions are electronically compared to the 3D designs of those spaces to confirm compliance of construction with designs. This reduces labor costs. Benefits are increased by using PLM.

Several of the technology applications above are already in regular use in industry or fully developed for use in practice. For example, radio-frequency identification (RFID) is frequently used to control construction material flows (CoreRFID, n.d.). Damen Industries' ability to develop animated electronic construction instructions (Ford et al., 2012) and construction inspection by comparing laser scans of as-built conditions to design documents has been demonstrated (Taylor, 2015) and is in use in commercial settings. The Appendix to this article specifies the values assumed in the current study.

Model Use and Results

The system dynamics model was first used to simulate the processing rates of the as-is (without the technologies) scenario. Work was measured in uniform-size packages of phase products. The "market" value of a hypothetical ship was assumed to be the estimated total price to the U.S. Navy of the *Arleigh Burke* (DDG51) destroyer—approximately $1.2 billion (NavSource Naval History, 2019).[2] Other values were taken from previous KVA models of naval operations and modeler estimates. Applying KVA, this total value was allocated among the 12 shipbuilding phases based on the total KVA (i.e., calibrated in units of learning time for a common reference point learner) of each phase.

The use of the three technologies was simulated in the to-be scenario. First, shipbuilding operations without the three technologies were simulated for the as-is conditions in the system dynamics model. Then the potential impacts of the use of the three technologies in the shipbuilding phases were quantified in the form of fractional reductions in the rework fractions and operation durations. The reductions in the rework fractions reflect the improvements in quality (e.g., finding more errors earlier) due to adopting the technologies that result in fewer operations being required due to less rework. The reductions in the operation durations reflect the faster processing of operations by using the technologies. These fractional reductions are primarily modeler estimates based on actual reductions as described in the literature and were kept conservative to increase the likelihood of underestimating the benefits of the technologies.

The experience of very large improvements in operations in multiple industries related to shipbuilding supports the estimates, as do the savings experienced by the Navy. Example reductions from practice include:

- operation durations decreasing from 100 to 42 hours
- the Navy reducing operation durations 39% using 3DLS
- operation durations decreasing to 4 days instead of 4 months
- time savings of 43% using AM

See Housel et al. (2015) for additional support of rework and duration reductions. The reduction fractions were combined with the as-is calibration values to generate values for the to-be simulation. These values were used to simulate shipbuilding operations using the three technologies. Table 1 shows the average completion rates of the 12 phases for the as-is (without technologies) and to-be (with technologies) scenarios.

TABLE 1. SIMULATION RESULTS: AVERAGE COMPLETION RATES OF SHIPBUILDING PHASES FOR AS-IS AND TO-BE SCENARIOS

		AVERAGE COMPLETION RATE (work packages / day)	
No.	**SHIPBUILDING PHASE**	**As-Is Scenario**	**To-Be Scenario**
1	Concept design	0.593	0.8958
2	Detailed design	3.115	4.454
3	Pre-construction planning	1.407	1.741
4	Block fabrication	3.084	9.302
5	Block assembly and outfitting	2.865	11.61
6	Keel laying and block erection	3.439	13.53
7	Pre-delivery outfitting	3.439	13.53
8	System testing	2.047	3.508
9	Sea trials	6.34	6.896
10	Post-delivery outfitting	3.273	13.27
11	Post-delivery tests	1.827	1.963
12	Post-shakedown maintenance	1.827	1.963

The results of the as-is and to-be system dynamics simulations of shipbuilding operations were used as input to the KVA model to estimate the ROI for each process for each scenario. Those values and the estimated changes in ROI due to the adoption of the new technologies are shown in Table 2.

TABLE 2. ESTIMATED CHANGES IN NAVAL SHIPBUILDING RETURN ON INVESTMENT DUE TO USE OF THREE INNOVATIVE TECHNOLOGIES

No.	SHIPBUILDING PHASE	As-is ROI	To-be ROI	Change in ROI	Automation Tools
1	**Concept design**	-2%	94%	**96%**	AM, PLM
2	**Detailed design**	561%	1826%	**1265%**	AM, PLM
3	**Pre-construction planning**	218%	244%	**25%**	PLM
4	**Block fabrication**	-67%	-31%	**36%**	3DLS, AM, PLM
5	**Block assembly and outfitting**	-17%	116%	**133%**	3DLS, AM, PLM
6	**Keel laying and block erection**	-63%	1%	**64%**	3DLS, AM, PLM
7	**Pre-delivery outfitting**	505%	1270%	**764%**	3DLS, AM, PLM
8	**System testing**	280%	582%	**301%**	3DLS, PLM
9	**Sea trials**	1018%	961%	**-57%**	PLM
10	**Post-delivery outfitting**	476%	1243%	**767%**	3DLS, AM, PLM
11	**Post-delivery tests**	239%	282%	**42%**	PLM
12	**Post-shakedown maintenance**	221%	201%	**-20%**	PLM
	TOTALS	**135%**	**464%**	**329%**	

Table 2 shows that the Detailed design (No. 2), Post-delivery outfitting (No. 10), and Pre-delivery outfitting (No. 7) phases of shipbuilding benefit the most from the use of the technologies; and that the Sea trials (No. 9) and Post-shakedown maintenance (No. 12) benefit least. Of more significance, the aggregate ROI for all processes combined increased by 329%.

The definition of ROI, the estimated benefits ($1.2 billion), and the as-is and to-be ROI values in Table 2 were used to estimate costs with and without technology adoption. The difference between these costs is $296.91 million and reflects the estimated potential savings for one hypothetical ship. This represents a potential savings of 24.74% ($296.91 million/$1,200 million) of the total cost to the Navy. This savings fraction is conservative when compared with the results reported by industry adopters of these technologies (e.g., up to 70% for AM [Martin, 2013]).

Conclusions, Limitations, and Call for Future Research

A simulation model of shipbuilding operations at the phase level was built and used to forecast the impacts of 3DLS, AM, and PLM technologies on shipbuilding processes. Descriptions and estimates of technology impacts on shipbuilding operations were used to generate two sets of simulations (without and with technology use). The output of the shipbuilding simulation model was used to build a KVA model of naval shipbuilding. The KVA model was used to estimate the ROI on shipbuilding with and without the three technologies. The outputs of the KVA model were used to estimate shipbuilding costs with and without the technologies. Finally, those cost estimates were used to estimate potential savings of using the technologies.

The scale and cost of the Navy's shipbuilding plan require the exploitation of advanced technologies. The results indicate that 3DLS, AM, and PLM can beneficially impact many phases of naval shipbuilding in multiple operations to reduce the costs and improve the value of shipbuilding core processes. Simulation results suggest that the U.S. Navy can save at least 24% and almost $300 million on the acquisition of a representative ship if the potential improvements available through 3DLS, AM, and PLM are fully exploited. These estimates support the assertion that these technologies can improve naval shipbuilding and indicate that the Navy should acquire and use these advanced technologies in shipbuilding as soon as possible.

Advanced technology adoption issues should be considered in implementing the previous recommendation. Those issues include whether the three technologies are to be implemented concurrently, which requires a larger budget and bears more uncertainties, or introduced more sequentially and selectively, which slows value creation. Adoption plans should also consider the capabilities of specific shipbuilders and how to best scale up the use of the new technologies.

The current work is limited by its scope and the assumptions used, which provide future research opportunities. That work can test and improve the models described in this article with additional data on the operational impacts of these technologies in both industrial and naval settings. Future work can also improve estimates of returns and cost savings, and may identify additional benefits and issues to be addressed. The work can be expanded by comparing the use of the technologies in the setting described herein to their use in other settings such as the industrial-scale spacecraft 3D printing at companies like Blue Origin & Velo3D and other naval settings.[3]

The models described in this article can be used to investigate other naval operations, such as ship maintenance and naval air repair processes, that may benefit from the adoption of these or other advanced technologies.

The current work has assumed steady state technology use after adoption of the tools. How to acquire and implement these tools is a particularly important issue that future research can investigate, as is the viability and cost of transporting the range and quantities of the “feedstocks” that 3DLS machines need to make different parts. Research into several aspects of technology adoption is warranted, including appropriate adoption rates, organizational and individual resistance to change, and the costs of adoption (implementation and learning curve costs). The research of Housel et al. (2019) addressed some of these issues. The implications of the suggested research may be widespread, with the results improving cost forecasting, evaluation methods, and the design and implementation of support services for new technologies.

The work has contributed to understanding the value of innovative technologies, to naval shipbuilding specifically, and potentially to other naval operations. It has also illustrated the combined use of system dynamics and KVA for investment evaluation and identified some important issues to be addressed in the adoption of advanced technologies. Continued modeling and analysis of technology investments can facilitate their adoption and use by the Navy and therefore increase value while reducing costs.

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Endnotes

[1] See Housel et al. (2016) for model details available on the Acquisition Research Program web page https://my.nps.edu/web/acqnresearch/ within the Publications section.

[2] Estimated prices of *Arleigh Burke* destroyers were $0.90 billion per ship (1997 dollars based on four ships) and $0.92 billion per ship (1998–99 dollars based on six ships), with estimates of future ships based on weight up to $1.4 billion per ship (Navsource Naval History, 2019).

[3] The authors thank the anonymous reviewer who identified these opportunities for this suggestion.

Appendix

Table: Potential Applications of Three Advanced Technologies to Naval Shipbuilding

No.	Shipbuilding Process Step	Advanced Technology: 3D Laser Scanning Technology	Advanced Technology: Additive Manufacturing	Advanced Technology: Product Life-cycle Management
1	Concept Design		Prototype generation	Integrated ship development Design & construction document management
2	Detailed Engineering Design		Prototype generation	Integrated ship development Design & construction document management
3	Pre-construction Planning			Integrated ship development Design & construction document management
4	Block Fabrication	Manufacturing inspection Construction inspection	Final parts manufacturing	Integrated ship development Design & construction document management Final parts manufacturing RFID Animated instructions Construction inspection
5	Assembly & Outfitting of Blocks	Manufacturing inspection Construction inspection	Final parts manufacturing	Integrated ship development Design & construction document management Final parts manufacturing RFID Animated instructions Construction inspection
6	Keel Laying & Block Erection	Manufacturing inspection Construction inspection	Final parts manufacturing	Integrated ship development Design & construction document management Final parts manufacturing RFID Animated instructions Construction inspection
7	Pre-delivery Final Outfitting	Manufacturing inspection Construction inspection	Final parts manufacturing	Integrated ship development Design & construction document management RFID Animated instructions Construction inspection
8	System Testing & Commissioning	Animated shipbuilding instructions		Integrated ship development Design & construction document management Animated instructions
9	Sea Trials			Integrated ship development Design & construction document management
10	Post-delivery Final Outfitting	Manufacturing inspection Construction inspection	Final parts manufacturing	Integrated ship development Design & construction document management RFID Animated instructions Construction inspection
11	Post-delivery Tests & Trials			Integrated ship development Design & construction document management Animated instructions
12	Post Shakedown Availability			Integrated ship development Design & construction document management

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Studying Acquisition Strategy FORMULATION of INCREMENTAL DEVELOPMENT APPROACHES

COL Robert F. Mortlock, USA (Ret.)

This is a study of the challenges that acquisition professionals confront in formulating the Department of Defense's preferred acquisition–incremental development. The research surveys acquisition professionals to recommend the components of an acquisition strategy associated with a typical acquisition program undergoing program/project milestone review and approval. This work provides insights into how program managers use typical programmatic decision inputs (requirements, technology maturity, risk, urgency, and funding) to formulate the components of an acquisition strategy. The results suggest that acquisition policy should perhaps require a justification for most programs of record if an incremental development approach is not planned. Adoption of the recommended acquisition policy changes would make the defense acquisition system more responsive to the warfighter by fielding improved capability as quickly as possible and reducing risk of the eventual delivery of the full required capability.

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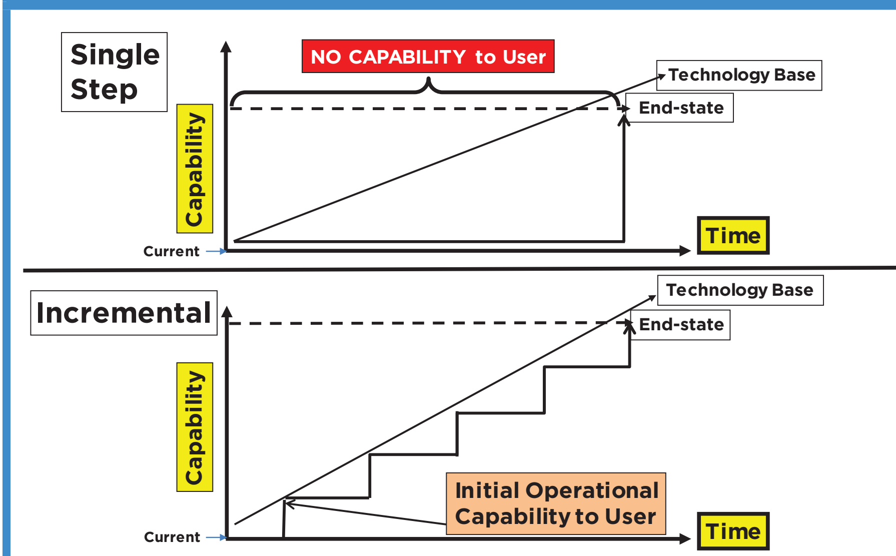
Keywords: *Critical Thinking, Decision Making, Evolutionary Acquisition, Incremental Development, Responsive Acquisition, Acquisition Reform*

Image designed by Michael Bubar-Krukowski

Within U.S. defense acquisition, an evolutionary strategy with an incremental development (ID) approach is the preferred strategy for most programs, specifically major defense acquisition programs (MDAPs) involving technology development efforts (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics [OUSD(AT&L)], 2007). The basic advantage over a single-step acquisition developmental approach is that the warfighter gets some capability sooner rather than waiting for full capability. Figure 1 outlines the basic advantage of the incremental approach versus a single-step approach, where the warfighter or user gets no capability until the end of a successful development. In contrast, using the incremental approach, the warfighter gets some improved capability (over their existing level) in a shorter time period.

FIGURE 1. SINGLE STEP VERSUS INCREMENTAL DEVELOPMENT APPROACH



Department of Defense Directive (DoDD) 5000.01, *The Defense Acquisition System* (OUSD[AT&L], 2007), provides guidance on the preference for ID approaches, but how difficult is it for program managers (PMs) to recommend, plan, and obtain approval of this approach? This research studies how challenging it is for a PM to formulate an evolutionary acquisition (EA) strategy with an ID approach for a specific program using a case study-based framework. The research also includes an analysis of the importance of typical program data—such as requirements, technology maturity, risk, and funding—as inputs to the PM decision-making process for determining a recommended acquisition strategy.

The goal is to provide insight into the unique challenges of formulating an incremental approach within defense acquisition and to suggest acquisition policy changes. The work aligns with general research in the areas of project management, defense acquisition reform, strategic leadership, and organizational behavior. This research supports the 2018 National Defense Strategy approach to reform the Department of Defense (DoD) for greater performance and affordability (DoD, 2018), and also addresses the challenges of "enabling effective acquisition and contract management" highlighted in a 2018 Office of the DoD Inspector General report (p. i).

"This research studies how challenging it is for a PM to formulate an evolutionary acquisition (EA) strategy with an ID approach for a specific program using a case study-based framework.

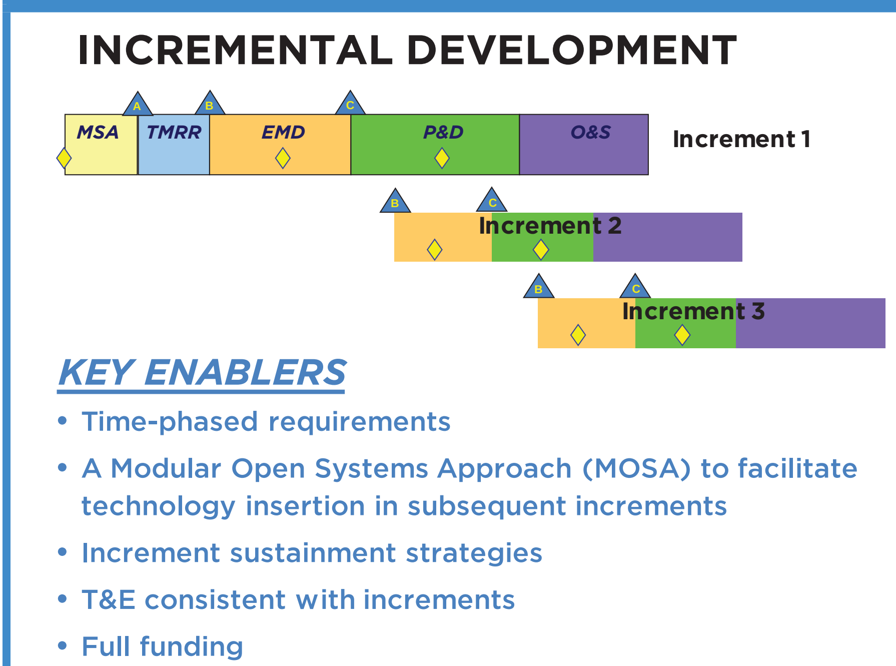
According to DoDD 5000.01, *The Defense Acquisition System,* responsiveness is one of five policies that governs the Defense Acquisition System. Specifically, DoDD 5000.01 defines responsiveness as follows:

> Advanced technology shall be integrated into producible systems and deployed in the shortest time practicable. Approved, time-phased capability needs matched with available technology and resources enable **evolutionary acquisition** strategies. Evolutionary acquisition strategies are the preferred approach to satisfying operational needs. **Incremental development** is the preferred process for executing such strategies. (OUSD[AT&L], 2007)

The accompanying DoD Instruction (DoDI) 5000.02 further expands on the use of ID strategies (OUSD[AT&L], 2017). In fact, the words *incremental* and/or *increment(s)* appear 52 times in the 110-page instruction. The DoDI 5000.02 recognizes the importance of a modular open systems approach (MOSA)—modular designs coupled with open business models—to successfully implement incremental development efforts. Figure 2 outlines a basic ID strategy across the five phases of the acquisition framework from materiel solution analysis (MSA) to technology maturation and risk reduction (TMRR) to engineering and manufacturing development (EMD) to production and deployment (P&D) to operations and support (O&S). Key enablers for a successful implementation of an ID approach include time-phased requirements, MOSA, integrated test & evaluation (T&E),

and sustainment strategies, as well as full funding for each increment. Recently, the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD[A&S]) released DoDI 5000.80 (2019) and DoDI 5000.02 (2020), which both continue to emphasize the acquisition policy objectives of responsiveness, flexibility, and innovation facilitated through ID approaches. The *Defense Acquisition Guidebook* (DAG) reinforces the DoDD 5000.01 and DoDI 5000.02 by mentioning "increment(s)" or "incremental" hundreds of times in its 1,230 pages (Defense Acquisition University [DAU], 2012). The DAG defines an increment as "a militarily useful and supportable operational capability that can be developed, produced, deployed, and sustained" (DAU, 2012). Furthermore, Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 5123.01H, dated August 31, 2018, which replaces the CJCSI 3170.01 series, continues the theme on the importance of time-phased requirements for the success of EA strategies and ID efforts (CJCS, 2015, 2018).

FIGURE 2. STANDARD INCREMENTAL DEVELOPMENT APPROACH



Despite the emphasis on ID approaches in both DoD acquisition and requirements policy documents and regulations, many PMs struggle to develop and recommend the preferred approach at program approval milestones; and many programs are approved as single-step development efforts even when an ID approach may have been more appropriate and effective in delivering capability. The Government Accountability Office (GAO) continues to highlight the importance of EA and ID approaches as widely accepted best practices in commercial industry. For example, a 2010 GAO report titled *Defense Acquisitions—Strong Leadership Is the Key to Planning and Executing Stable Weapons Programs*, was a study on the stability of DoD MDAPs, and found that only 21% appeared to be stable. The GAO reported that stable MDAPs "pursued evolutionary or incremental acquisition strategies, leveraged mature technologies, and established realistic cost and schedule estimates that accounted for risk" (GAO, 2010, p. 2). In *Defense Acquisition Reform 1960–2009: An Elusive Goal*, J. Ronald Fox (2011) writes:

> **Evolutionary acquisition** is the preferred DoD strategy for rapid acquisition of mature technology for the user. An evolutionary approach delivers capability in **increments**, recognizing up front the need for future capability improvements. The objective is to balance needs and available capability with resources and to put capability into the hands of the user quickly. (p. 23)

This research narrowly focuses on programs that do not have time-phased requirements because it makes the development of an incremental approach more challenging. In this situation, PMs use a variety of inputs, such as requirements, technology maturity, risk, urgency, and funding to formulate the components of a strategy to meet the warfighters' needs and timelines, and to augment affordability for the Services.

The goal of this research is to examine the challenges in formulating an EA strategy with an ID approach. The objectives include the following:

- Develop insights into how acquisition professionals use typical programmatic decision inputs to formulate the components of an acquisition strategy with an ID approach.

- Recommend defense acquisition policy changes that better support the planning of successful ID acquisition strategies.

This article will show that acquisition professionals weigh typical programmatic decision inputs in various ways, resulting in a wide variety of recommended components of the acquisition strategy. It further reinforces the DoD acquisition policy of a preference for ID approaches and suggests that ID be the default strategy. Directly related to the research objectives is the primary research question to be addressed: given programmatic decision inputs for a specific program, can we gain a better understanding of how PMs or acquisition professionals formulate the components of the acquisition strategy? The research will address the following secondary questions:

- What is the most important factor in determining the components of the recommended acquisition strategy?
- How can the decision input factors be changed to enable a PM or acquisition professional to recommend an ID strategy that more closely resembles the actual strategy later adopted by the Services?

The answers to these questions address the objectives outlined above within the research goal—studying the challenges in formulating an EA strategy with an ID approach. The research uses the Joint Common Missile (JCM) program and the subsequent Joint Air-to-Ground Missile (JAGM) program as a case study to survey acquisition professionals not previously associated with either program. A questionnaire asks acquisition professionals to recommend the components of an acquisition strategy for the JCM program based on approved requirements, technology maturity, a technology risk assessment, urgency, and funding levels. These recommended strategies are compared to the actual strategy approved for the JCM program at the time (a single-step development approach) and compared with the strategy (an incremental approach) later adopted by the subsequent JAGM program (a follow-on program from JCM).

The survey results address three hypotheses. The first hypothesis was that the JAGM strategy (an incremental approach) would not be recommended based on the pressures to maintain the constraints of performance, cost, and schedule within the proposed acquisition program baseline (APB). Based on the pressures for affordability and rapid acquisition, the second hypothesis was that acquisition professionals would maintain the cost and schedule constraints in the draft APB and reduce programmatic risk by recommending delaying performance capabilities (pushing some requirements to later increments). The third hypothesis was that acquisition professionals would choose to delay capabilities associated with technologies with low technology readiness level (TRL) ratings and/or high-risk ratings. For the purposes of this research approach, the JCM acquisition strategy is recognized as an unsuccessful/ineffective approach because the JCM program was cancelled 6 months after Milestone B (MS B) approval, and no capability was developed or delivered to the warfighter. Alternately, the

JAGM acquisition strategy is recognized as a successful/effective approach because the strategy was adopted by the Services with approved MS B and C decisions; and the JAGM is on-track to deliver the first incremental capability to the warfighter.

Evolution of EA and ID Within Defense Acquisition

This section reviews the background of both EA and ID, and presents a historical review of how policy, regulations, and statutes have changed over time with respect to guidance on EA and ID for PMs. The seeds for significant acquisition reform were set in the 1980s. A 1986 RAND study titled *Improving the Military Acquisition Process* outlines broad recommendations to improve the acquisition process (Rich et al., 1986). Later that year, the Packard Commission also focused on acquisition reform. *A Quest for Excellence: Final Report to the President's Blue Ribbon Commission on Defense Management* (also known as The Packard Report) outlined significant acquisition reform recommendations, including the use of commercial-off-the-shelf (COTS) technologies (Packard, 1986). Ground-breaking legislation related to acquisition reform included the 1986 Goldwater–Nichols Department of Defense Reorganization Act, the 1990 Defense Acquisition Workforce Improvement Act (DAWIA), the 1994 Federal Acquisition Streamlining Act (FASA), and the 1996 Federal Acquisition Reform Act (FARA). These transformational acts laid the groundwork for significant congressional involvement in acquisition reform.

The annual National Defense Authorization Acts (NDAAs) have also had a significant impact on defense acquisition reform and on shaping EA and ID policy within defense acquisition. The Fiscal Year (FY) 1996 NDAA specifically calls for the incremental acquisition through "successive acquisitions of interoperable increments" (p. 506). Table 1 summarizes the NDAAs from 1996 to 2017 with a count of the number of times the words *evolutionary, increment,* or *block* are referenced with respect to defense acquisition (the terms block and increment are often used interchangeably in congressional language). Exceptionally, the NDAAs from 1997 to 2002 do not mention the words evolutionary, incremental, or blocks.

TABLE 1. NDAA SUMMARY OF EA AND ID WORD USE. DATA FROM NDAAs DATED 1996–2017

National Defense Authorization Act (NDAA)			
Fiscal Year	Total Page Count	Page Count of Title VIII—Acquisition Policy, Acquisition Management, & Related Matters	Uses of word "evolutionary" or "increment" or "block"
1996	519	10	40
1997	450	14	0
1998	450	22	0
1999	360	10	0
2000	466	16	0
2001	515	20	0
2002	384	18	0
2003	306	19	23
2004	436	20	1
2005	389	20	14
2006	423	32	16
2007	439	38	38
2008	602	70	48
2009	417	47	22
2010	656	23	16
2011	383	64	3
2012	566	45	49
2013	682	40	29
2014	494	13	14
2015	689	37	12
2016	585	80	52
2017	970	93	79

The consistent use of these terms by Congress in NDAAs provides an indication of Congressional intent. For example, the FY2003 NDAA defines *evolutionary acquisition* as "a process by which an acquisition program is conducted through discrete phases or blocks, with each phase or block consisting of the planned definition, development, production or acquisition, and fielding of hardware or software that provides operationally useful capability" (NDAA, 2003, p. 147). The term "increment ... means one of the discrete phases or blocks of a program" (NDAA, 2003, p. 147).

Subsequently, the 2009 Weapon Systems Acquisition Reform Act (WSARA) reiterates the importance of time-phased requirements to the success of EA and ID approaches and states that "the process for developing requirements is structured to enable incremental, evolutionary, or spiral acquisition approaches, including the deferral of technologies that are not yet mature and capabilities that are likely to significantly increase costs or delay production until later *increments* or *spirals*" (WSARA, 2009, p. 17). Note also that the terms increment and spiral are sometimes referred to synonymously. Congress again highlighted ID in the FY2017 NDAA, which states, "A major defense acquisition program … to enable incremental development and enhance competition, innovation, and interoperability" (NDAA, 2017, p. 254).

Through NDAA language over the years, Congress has included consistent guidance on the application of EA and ID within DoD acquisition programs. In response to this congressional direction and in an attempt to capitalize on commercial industry best practices, the DoD acquisition community has transformed its acquisition regulations and policies to include guidance on the application of ID approaches. Starting in the mid-1980s, EA, using an ID approach, was recognized as the best way to develop and deliver capabilities specifically for information technology (IT), which involved software-intensive development efforts.

In 1987, the Defense Systems Management College (DSMC) published the *Joint Logistics Commander's Guidance for the Use of an Evolutionary Acquisition (EA) Strategy in Acquiring Command and Control (C2)* (A'Hearn et al., 1987). The guide encouraged "consideration and use of an Evolutionary Acquisition (EA) strategy by the Services in acquiring C2 systems," but emphasized applicability to other kinds of acquisition programs (A'Hearn et al., 1987, abstract). The guide defines an EA strategy as:

> of a character that the system is not required to have full capability when deployed, but will evolve to full capability through one or more incremental upgrades … EA consists of first sequentially defining, funding, developing, testing, fielding, supporting, and evaluating increments of the system. (A'Hearn et al., 1987, p. v)

The guide defines EA as both "adaptive and incremental," and requiring a "core or baseline" capability necessary with an architectural framework upon which to build future increments for the delivery of the final desired full capability. The core or baseline element should "enhance the user's mission capability" and "be fielded quickly and sustained in its operational environment," and subsequent increments improve on the baseline capability (A'Hearn et al., 1987, p. 7).

The DoD 5000 series of regulations provides the basis for guidance to acquisition professionals and have evolved with the guidance from the NDAAs. In DoD's 5000 *Documents: Evolution and Change in Defense Acquisition Policy,* Ferrara (1996) summarizes the changes in the DoD 5000 series from 1971 to 1993—early versions of the documents laid the groundwork for later versions. Table 2 provides word counts of the key words (*evolutionary, incremental,* and *block*) within DoDD 5000.1 from 1971 through the still—valid 2007 version, and DoDI 5000.02 from 2000 to 2017. Use of the words gives an indication of DoD's emphasis of these concepts within defense acquisition. Uses of the words "evolutionary," "incremental," and "block" or "block upgrades" first appear in the 1980s versions and gradually increase in use through the 1990s versions, peaking in the early 2000s versions, consistent with NDAA references highlighted in Table 1.

TABLE 2. DODD 5000.1 SUMMARY OF EA AND ID WORD USE DATA

Department of Defense Acquisition Regulations			
Revision Year	**Total Page Count**	**Total Word Count**	**Uses of word "evolutionary" or "increment" or "block"**
1971	7	1,897	0
1975	8	2,308	0
1977	15	3,623	0
1980			*
1982			*
1985	16	4,808	1
1986	15	5,133	1
1987	15	4,425	2
1991	35	14,000	2
1996	14	5,734	4
2000	15	4,117	14
2001	12	4,220	14
2003	8	3,075	2
2007	10	3,210	3

Note. Adapted from DoDD 5000.1 dated 1971, 1975, 1977, 1980, 1982, 1985, 1986, 1987, 1991, 1996, 2000, 2001, 2003, & 2007; and from DoDI 5000.2 dated 1980, 1983, 1985, 1986, 1987, 1991, 1993, 2002, 2003, 2008, 2013, 2015, & 2017. * = could not determine.

In the 1985 and 1986 versions, the DoDD 5000.1 encouraged PMs to "consider evolutionary alternatives" to reduce programmatic risk (Office of the Under Secretary of Defense for Research & Engineering [OUSDRE], 1985a, 1986a, p. 2). The 1987 DoDD emphasizes that the evolutionary strategy is not limited to IT, command and control (C2) systems, or software development efforts (Office of the Under Secretary of Defense for Acquisition [OUSD(A)], 1987b). The 1991 DoDI defines EA as:

> an approach in which a core capability is fielded, and the system design has provisions for future upgrades ... With this approach, selected capabilities are deferred so that the system can be fielded while the deferred element is developed in a parallel or subsequent effort. (OUSD[A], 1991b, p. 5-A-5)

Department of Defense Acquisition Regulations			
Revision Year	**Total Page Count**	**Total Word Count**	**Uses of word "evolutionary" or "increment" or "block"**
1980	58	14,056	2
1983	34	*	1
1985	32	7,035	1
1986	34	7,117	1
1987	26	7,958	0
1991	345	92,029	10
1993	542	126,858	32
2002	193	46,636	98
2003	50	14,958	52
2008	80	28,852	62
2013	152	*	40
2015	154	61,220	68
2017	110	*	52

The 1996 DoDD further elaborates on the use of "nontraditional acquisition" referenced as incremental acquisition that involves the use "of nontraditional acquisition techniques, such as … evolutionary and incremental acquisition, and flexible technology insertion" (Office of the Under Secretary of Defense for Acquisition and Technology [OUSD(A&T)], 1996, p. 5).

The 2000 and 2001 DoDD versions use the words *evolutionary, incremental,* and *blocks* extensively. The 2000 DoDD builds on the themes in the 1996 version, which linked evolutionary acquisition to technology maturity. For the first time, the DoDD clearly defined evolutionary acquisition in terms of "increments" or "blocks" of capability:

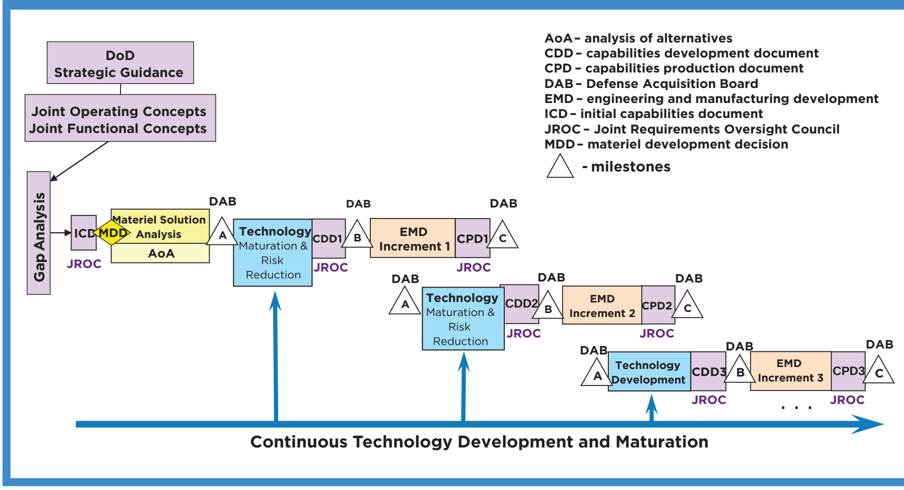
> Evolutionary Acquisition. To ensure that the Defense Acquisition System provides useful military capability to the operational user as rapidly as possible, evolutionary acquisition strategies shall be the preferred approach to satisfying operational needs. Evolutionary acquisition strategies define, develop, and produce/deploy an initial, militarily useful capability ("Block I") based on proven technology, time-phased requirements, projected threat assessments, and demonstrated manufacturing capabilities, and plan for subsequent development and production/deployment of increments beyond the initial capability over time (Blocks II, III, and beyond). In planning evolutionary acquisition strategies, program managers shall strike an appropriate balance among key factors, including the urgency of the operational requirement; the maturity of critical technologies; and the interoperability, supportability, and affordability. (OUSD[AT&L], 2000, p. 5)

The 2002 DoDI 5000.02 combined guidance for an MDAP with major automated information systems (MAIS), resulting in a spike in the use of the words evolutionary, increments, and blocks.

It is interesting that the 2003 version of the DoDD emphasizes evolutionary strategies as the preferred approach but introduces spiral development as the preferred process (OUSD[AT&L], 2003). The 2003 DoDI 5000.02 expands on this topic and explains the two options for EA development approaches: spiral or incremental. It defines *spiral development* as a process in which "a desired capability is identified, but the end-state requirements are not known at program initiation," and defines *incremental development* as a process in which "a desired capability is identified, an end-state requirement is known, and that requirement is met over time by developing several increments, each dependent on available mature technology" (OUSD[AT&L], 2003, p. 5).

The 2007 DoDD maintains nearly the same language as the 2003 version, with the important change of replacing the word "spiral" with "incremental," stating that "Evolutionary acquisition strategies are the preferred approach to satisfying operational needs. ***Incremental development*** is the preferred process for executing such strategies" (OUSD[AT&L], 2007, p. 3). Similar to the 2007 DoDD, the 2008 DoDI deletes references to spiral development and emphasizes ID, stating that each increment delivers a militarily useful capability to the warfighter, as depicted in Figure 3.

FIGURE 3. 2008 DODI 5000.02 EVOLUTIONARY STRATEGY WITH INCREMENTAL DEVELOPMENT



Note. Adapted from OUSD(AT&L), 2008.

The 2013, 2015, and 2017 versions of the DoDI 5000.02 continue to emphasize ID approaches but no longer use the word "evolutionary." The DoD acquisition directives and instructions, as well as the congressional guidance through NDAA language, have consistently recognized the benefits of ID over a period of several decades, and have called for their use and application in a variety of types of acquisition development programs. A continued emphasis on ID in DoD 5000 acquisition policy documents is expected and appropriate—directly tying to the relevance and long-term applicability of the research goal of studying the challenges in formulating an acquisition strategy with an ID approach. The next section provides a literature review related to EA and ID.

Literature Review of EA and ID Within Defense Acquisition

In 1998, a GAO report titled *Best Practices: Successful Application to Weapon Acquisitions Requires Changes in DOD's Environment* recommended that risk reduction within the DoD follow commercial practices of "using demonstrations of technology and incremental or evolutionary product developments" (p. 63). Furthermore, the 1998 GAO report referenced the Defense Science Board recommendation that "emphasizes incremental technology advancement, coupled with much shorter product development cycle times" (p. 8). The report also highlighted the National Center for Advanced Technologies' call for:

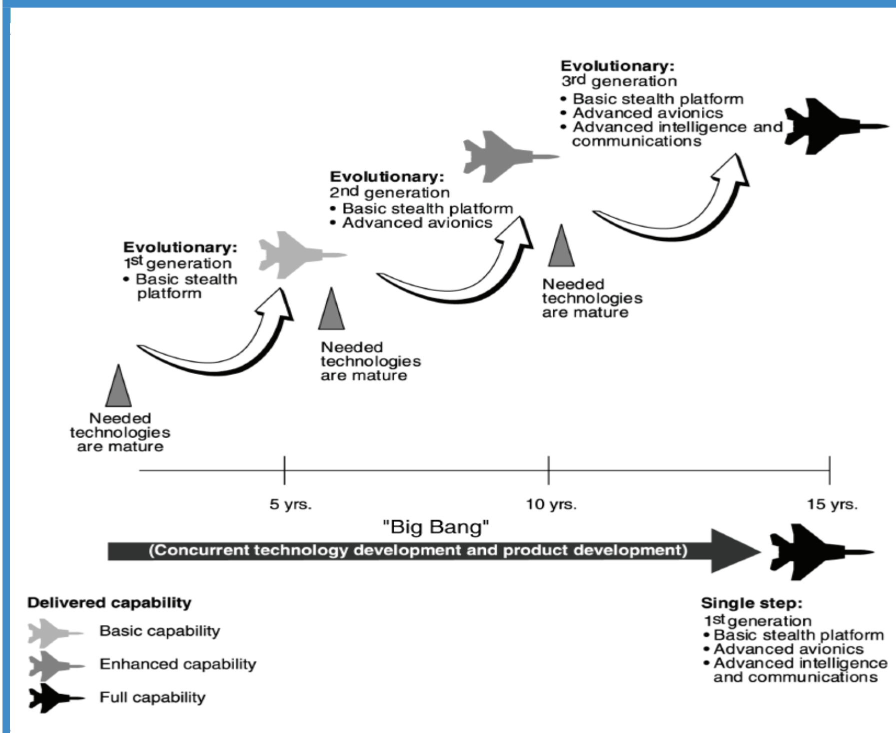
> a new culture that relies on an affordable, incremental approach that could reduce product development cycle times by 3 to 5 years. The new culture features an incremental approach to performance, with a threshold or minimum performance for the initial battle group with incremental upgrades and requirements that would be managed through cost tradeoffs to keep performance and cost in balance, avoid grand designs, and mitigate risk. (p. 71)

In a 2001 work, Williams studied the application of EA within the DoD. Williams found that despite several acquisition programs laying the groundwork for the application of EA, the use was not widespread, with further education and training required in the acquisition workforce. An *IEEE Computer Society* article by Larman and Basili (2003) titled *Iterative and Incremental Development: A Brief History* explained that even though some view agile methods or evolutionary development as relatively new concepts, the software development community had recognized the value of iterative and incremental development (IID) for decades. The authors noted that a great variety of EA and IID approaches exist, but they all avoid the "single-pass approach," often used in the DoD (Larman & Basili, 2003). Early practice of the IID approach in the 1970s, with IBM working on DoD space and avionics systems and the command and control (C2) system for the U.S. Trident submarine, successfully used an ID approach (Larman & Basili, 2003).

In 2003, the GAO reported to Congress on defense acquisitions in *DoD's Revised Policy Emphasizes Best Practices, but More Controls are Needed.* The GAO found that the DoD had tried to apply lessons learned from successful commercial companies by adopting a knowledge-based approach, specifically EA with time-phased ID in accordance with the requirements in the FY2003 NDAA (GAO, 2003b). Also in 2003, the GAO's *Best Practices: Better Acquisition Outcomes are Possible if DoD Can Apply Lessons from the F/A-22 Program* report used a case study approach with the F/A-22 program to illustrate "what can happen when a major acquisition program is not guided by the principles of evolutionary, knowledge-based acquisition" with ID—basically failing to deliver capability (GAO, 2003a, p. 2).

The GAO concluded that "an evolutionary environment for developing and delivering new products reduces risks ... While the customer may not receive an ultimate capability initially, the product is available sooner, with higher quality and reliability, and at lower, more predictable cost" (GAO, 2003a, p. 5). The GAO (2003a) recommended avoiding what they refer to as the "Big Bang" acquisition approach, or single-step acquisition, which is pictorially represented in Figure 4.

FIGURE 4. THE GAO COMPARISON OF EVOLUTIONARY AND BIG BANG APPROACHES



Note. (GAO, 2003a)

Following up on its earlier reports and at the height of military operations in Iraq and Afghanistan, in *DoD Acquisition Outcomes—A Case for Change,* the GAO reported to Congress that the DoD has been slow to fully adopt commercial industry's standard of knowledge-based acquisition that results "in evolutionary—that is, incremental, manageable, predictable—development" (GAO, 2005a).

The GAO studied the Joint Strike Fighter (JSF) program with a report in 2005 entitled *Opportunity to Reduce Risks in the Joint Strike Fighter Program With Different Acquisition Strategy,* concluding that the program's acquisition strategy failed to establish the commercially accepted best practice of ID (GAO, 2005b). In 2005, RAND published *Reexamining Military Acquisition Reform—Are We There Yet?* on behalf of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA[ALT]), which listed EA as a critical reform initiative within the acquisition enterprise (Hanks et al., 2005). The ASA(ALT) highlighted that the "move to greater use of 'evolutionary acquisition' (the initiative that encourages PMs to acquire systems in 'blocks' or 'increments' to reduce technical risk and meet delivery schedules) will be a good thing" (Hanks et al., 2005, pp. 35–36). In 2006, the GAO reported in *Defense Acquisitions—Major Weapon Systems Continue to Experience Cost and Schedule Problems under DoD Revised Policy* that DoD "continues to pursue revolutionary—rather than evolutionary or incremental—advances in capability" (p. 2).

In April 2009, Bussiere, Jester, and Sodhi presented a case study for the successful application of EA principles for management of the Navy's torpedo enterprise. The researchers highlighted the importance of MOSA design and stressed that "evolutionary updates via ID, modular design updates, technology refreshes, technology insertions" all come into play (Bussiere et al., 2009, p. 237). Dillard and Ford (2009) highlighted the risks of EA with an ID approach under certain instances. The authors studied two defense acquisition programs as case studies, and their conclusions were consistent with the fact that the principles of successful applications of EA and ID approaches had their roots in development efforts of software-intensive information systems.

In a 2014 RAND study titled *Prolonged Cycle Times and Schedule Growth in Defense Acquisition,* the authors comprehensively studied schedule growth within MDAPs and revealed that "the most commonly cited recommendations for reducing cycle time and controlling schedule growth are strategies that manage or reduce technical risk ... include using incremental fielding or evolutionary acquisition (EA) strategies, using mature or proven technology (i.e., commercial, off-the-shelf components)" (Riposo et al., 2014, p. xii). The authors opine that:

> incremental fielding and EA are acquisition strategies that have been employed as a way to speed fielding and control technical risks. They aim to provide some initial operationally useful capabilities more quickly than processes that use a single step to acquire a capability. EA achieves this goal through incremental improvements. (Riposo et al., 2014, p. 44)

The GAO continued to recommend more widespread acceptance of ID policies in a 2014 report titled *Agencies Need to Establish and Implement Incremental Development Policies,* and again in a 2016 report titled *Agencies Need to Increase Their Use of Incremental Practices.* In April 2015, the GAO issued a report entitled *Amphibious Combat Vehicle—Marine Corps Adopts an Incremental Approach* about the Marine Corps' effort following the cancellation of the Expeditionary Fighting Vehicle (EFV) program amid affordability concerns. The GAO (2015a) concluded that the Marine Corps' incremental approach for the ACV acquisition is consistent with best practices and can increase the likelihood of success.

As further evidence that the application of an ID approach is warranted across a wide spectrum of acquisition efforts, the GAO recommended in a 2015 report entitled *Evolved Expendable Launch Vehicle—The Air Force Needs to Adopt an Incremental Approach to Future Acquisition Planning to Enable Incorporation of Lessons Learned* that "when planning for the next phase of competition for launches, the Air Force use an incremental approach in the acquisition strategy" (GAO, 2015b, p. 2). A 2017 RAND study, *Program Characteristics That Contribute to Cost Growth,* compared Air

Force MDAPs. The study analyzed four programs with extreme cost growth and recommended that the Air Force "embrace incremental strategies with comprehensive and proven implementation strategies" (Lorell et al., 2017, p. xv).

Primarily through case studies of defense acquisition efforts, the literature review indicates that an ID approach continues to be highlighted as a key lesson learned for successful acquisition programs across a wide spectrum of efforts from software-intensive systems like IT and C2 systems and hardware-intensive development efforts like aircraft, tactical vehicles, launch systems, and missiles. The research in this article extends the body of knowledge in this field by also using a case study framework to study the challenges in formulating an ID approach for a typical MDAP involving technology development and facing a program approval milestone.

Acquisition Strategy Survey—Research Methodology and Data

Through case studies of past acquisition programs, EA with an ID approach is a well-documented commercial industry best practice for delivering customer products within performance, cost, and schedule constraints. With beginnings in software-intensive development efforts, the use of EA and ID spread to hardware-intensive development efforts. However, as discussed, the successful application to DoD acquisition efforts is spotty at best. Directives, regulations, and statutes have given guidance on the application of EA and ID over a period of three decades. This research examines how PMs decide on the components of an acquisition strategy for a development effort. It uses a case study framework of an actual acquisition program that went through an acquisition MS B approval to establish a program of record for a development effort.

Using the JCM program entering an MS B decision in 2004 as a case study, the research investigates how a PM can develop the key components of an acquisition strategy. The study surveys acquisition professionals and asks them to formulate the components of an acquisition strategy using the actual JCM program milestone decision input data. These proposed strategies are then compared to the approved original JCM acquisition strategy and the approved JAGM program strategy subsequently adopted by the Army and Navy over 10 years later. Insights into the importance of crucial decision inputs to PMs will provide policy recommendations for the DoD to consider to better support PMs in developing the Department's preferred strategy—an ID approach. This research is a study of the original

JCM decision inputs (requirements, technology maturity, risk assessments, urgency, and funding) to see if the JAGM strategy that was subsequently adopted could have been envisioned using the original JCM milestone data, thus avoiding a "lost decade" of delivering no improved capability to the warfighter and possibly delivering capability sooner.

> **"Through case studies of past acquisition programs, EA with an ID approach is a well-documented commercial industry best practice for delivering customer products within performance, cost, and schedule constraints.**

Problem Statement: Program managers and acquisition professionals struggle to formulate the preferred approach at program approval milestones, and many programs are approved as single-step development efforts whereas an incremental approach may be more appropriate and effective in delivering capability.

Primary Objective: To answer the following questions, by developing insights into how acquisition professionals use typical programmatic decision inputs to formulate the components of an acquisition:

Primary question: Given programmatic decision inputs for a specific program, can we gain a better understanding of how PMs or acquisition professionals formulate the components of the acquisition strategy?

- **Secondary questions:**
    - What is the most important factor in determining the recommended acquisition strategy?
    - How can the decision input factors be changed to enable a PM or acquisition professional to recommend an ID strategy that more closely resembles the actual strategy later adopted by the Services?

This research uses the JCM program as a case study in part because it did not have requirements that were time-phased. Therefore, the survey participants balanced the inputs of requirements, resources (approved funding), and technology maturity (TRLs and risk assessments) to try to develop the components of an acquisition strategy to meet the warfighter's required needs and timelines, and to augment affordability for the Services.

The JCM program was studied because the Services have maintained a consistent long-term need to replace existing capabilities, and because the program is well suited to the benefits of an ID approach. The JCM program was initiated in the late 1990s (Common Missile Project Office, 2003; JCM Program Office, 2004). It was a Joint (Army, Navy, Marine Corps) effort to replace Hellfire, Maverick, and aviation-launched, tube-launched, optically-tracked, wire-guided (TOW) missiles fired from both rotary wing (AH-64 Apaches, AH-1 Cobras, and MH-60 Seahawks) and fixed wing (F/A18 E/F Super Hornets) aircraft. The JCM program had a successful MS B in early 2004 with an approved capabilities development document (CDD) and subsequently awarded an Engineering and Manufacturing Development (EMD) contract for a planned 4-year EMD phase (Joint Requirements Oversight Council [JROC], 2004). The approved JCM acquisition strategy had a planned single-step development approach to meet all required capabilities. In late 2004 (approximately 6 months after program approval), the JCM program was cancelled primarily for affordability reasons (Wolfowitz, 2004). In 2015, the follow-on program, renamed the Joint Air to Ground Missile (JAGM), applied the key lesson learned from the failed JCM effort—adoption of an ID approach. The JAGM program emerged with a successful MS B and awarded the EMD contract 10 years after the original JCM program (JAGM Project Office, 2014, 2015, 2016).

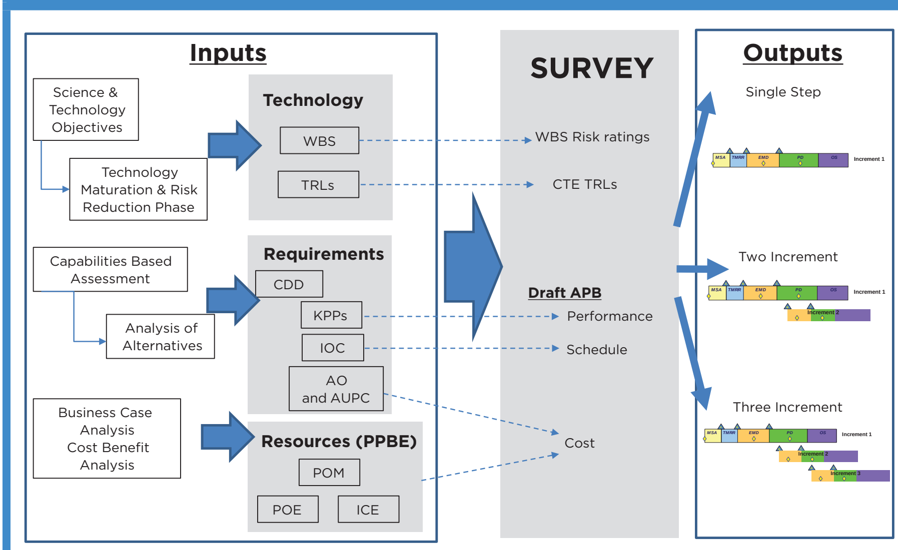
The Army and Navy planned the JCM program for a decade prior to the MS B or official designation of the program of record and start of the EMD phase (Mortlock, 2005). The science and technology (S&T) communities matured the underlying missile technologies through S&T objectives and a technology maturation and risk reduction phase. A high-level government work breakdown structure (WBS) enabled a risk assessment for the JCM development effort as well as TRL determinations for the critical technology elements (CTE) of the missile for the MS B decision (U.S. Army Test & Evaluation Command [ATEC], 2003).

At the same time as the missile technologies were being matured, the requirements generation system, formally named the Joint Capabilities, Development, and Integration System (JCIDS), completed both a capabilities-based assessment (CBA) and analysis of alternatives (AoA) (Sleevi, 2003). The CBA and AoA supported the JROC approval of the JCM capability development document (CDD), which contained key performance parameters (KPP), initial operational capability (IOC) dates, acquisition objective (AO), and an average unit procurement cost (AUPC) (JROC, 2004). Simultaneous with the technology maturation and requirements solidification, the resourcing plan for a JCM program was being worked in the planning, programming, budgeting, and execution (PPBE) system. The JCM business case analysis supported the JCM program office estimate (POE), the Army and Navy program objective memorandum (POM) submissions, and an independent cost estimate (ICE) (R. P. Burke, personal communication, April 16, 2004; E. J. Gregory, personal communication, May 7, 2004).

The acquisition strategy survey puts the participant in the shoes of PMs as they prepare for the approval of the JCM program of record to start EMD, and asks for a recommendation of the components of an appropriate strategy—single step or incremental—based on program requirements and constraints. The survey participants decide whether to maintain the planned single-step development strategy or develop an alternate, incremental strategy. The baseline survey provides acquisition professionals with the actual JCM MS B data used by the PM, program management office (PMO), program executive offices (PEO), Service Acquisition Executives, and Milestone Decision Authority (MDA) (the Defense Acquisition Executive [DAE] who, at the time, was the USD[AT&L]). The survey data are consolidated into the important program information, including background program data, the draft APB, the Service's affordability determinations, the independent cost estimate, the risk assessment, and TRLs of CTEs based on the JCM WBS.

Figure 5 outlines the general survey approach. The inputs to the survey include three main areas: technology, requirements, and resources. The technology portion of the survey was presented to the participant in the form of a high-level missile design WBS, which included missile component risk ratings and TRLs for each of the missile CTEs. The requirements section summarized the KPPs, IOC, AO, and AUPC from the approved CDD, and the resources section summarized the approved POE and ICE. Both the requirement and resources sections of the survey were presented to the participants in the form of a draft APB with performance, schedule, and cost sections. The survey was developed based on the work of Gress, Kohtz, and Noll (2018) in the Naval Postgraduate School (NPS) thesis entitled, "Evolutionary Acquisition with an Incremental Approach."

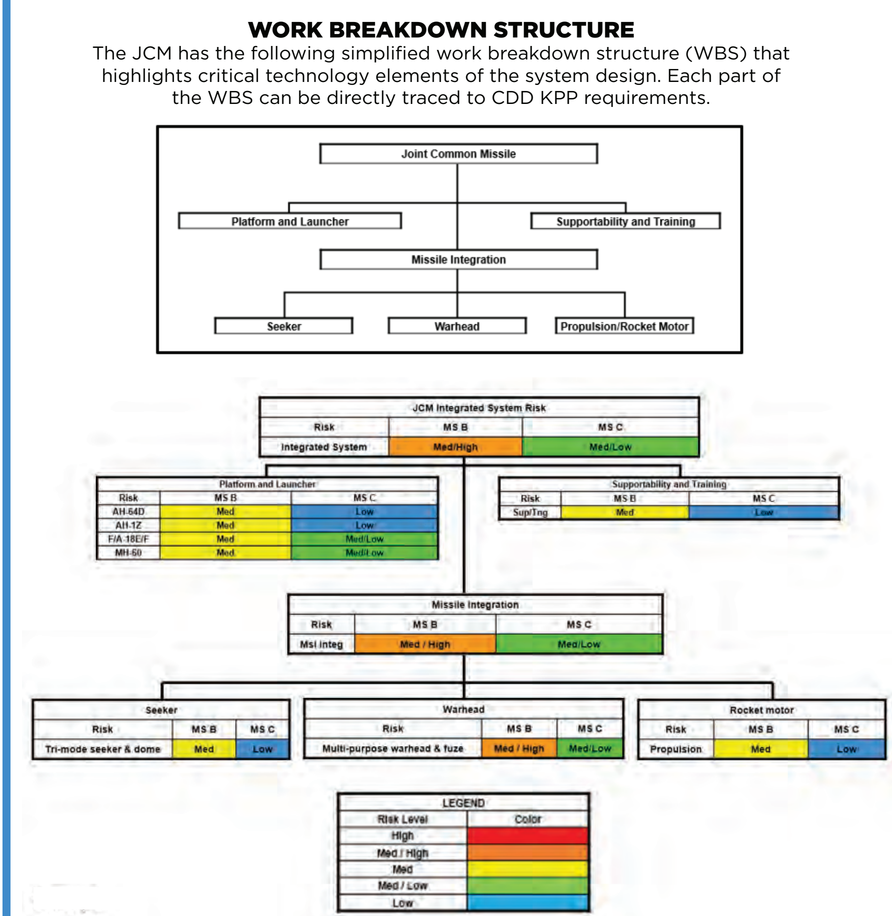
FIGURE 5. ACQUISITION STRATEGY SURVEY APPROACH



The survey provides each individual with sufficient data to make an informed recommendation on the components of the most appropriate acquisition strategy. Further, it provides a situation and the background information for the JCM program outlined in Appendix A and described previously.

The performance section of the APB contains the approved CDD KPPs. The schedule section of the APB came from the approved IOC date found in the CDD, and the cost section of the APB came from the approved AO and AUPC—also found in the CDD (JROC, 2004). Appendix B presents the draft APB, and Figure 6 presents the WBS and risk ratings presented in the survey as data for the survey participants. The risk assessment in Figure 6 presents the risk ratings for the critical development efforts associated with the missile (based on the WBS) at MS B and projected at MS C. The overall risk rating for the missile at the milestones is taken as the highest risk rating on any of the WBS subcomponent areas. For example, at MS B, the multipurpose warhead was rated as medium/high risk, which made the missile integration risk medium/high and the overall JCM integrated system risk medium/high at MS B.

FIGURE 6. ACQUISITION STRATEGY SURVEY JCM WBS AND RISK RATINGS



Survey participants were then asked to define the capabilities, cost, and schedule components for their recommended acquisition strategy. Specifically, they decided on whether to recommend a single-step development approach, a two-increment development approach, or a three-increment development approach based on the following programmatic data: the draft MS B APB, the WBS risk rating, and a CTE TRL for the three missile areas (seeker, warhead, and motor). The survey constrained the options with respect to performance, cost, and schedule. For example, with respect to performance, acquisition professionals only decided whether the desired KPP requirements were developed in an increment or delayed to a later increment. With respect to schedule and cost, the participants decided only whether to recommend the Services' POE or ICE AUPC estimates and EMD phase duration for each increment.

As stated previously, the baseline survey used the following actual JCM MS B data for eight risk ratings and three TRL ratings (ATEC, 2004; JCM Program Office, 2004):

- Critical Technology Element (CTE) TRLs:
    - Tri-mode seeker (s): 6
    - Multipurpose warhead (w): 6
    - Common motor (m): 6
- Risk ratings (RR) based on JCM WBS:
    - Tri-mode seeker (s): medium (m)
    - Multipurpose warhead (w): medium/high (m/h)
    - Common motor (m): medium (m)
    - Missile integration (i): medium/high (m/h)
    - AH-64 Apache platform integration (64): medium (m)
    - AH-1 Cobra platform integration (1): medium (m)
    - MH-60 Seahawk platform integration (60): medium (m)
    - F/A18E/F Super Hornet platform integration (18): medium (m)

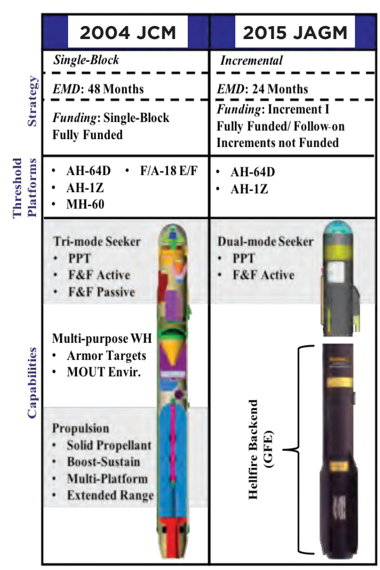
[Note that the risk ratings had a range from low (l), low/medium (l/m), medium (m), medium/high (m/h) to high (h).]

The original JCM acquisition strategy recommended by the Army and Navy, supported by the warfighters, and approved by the DAE in the spring of 2004 after a successful MS B was a single-step development effort that met all the KPPs. The JCM program was later cancelled as a program of record by the Office of the Secretary of Defense (OSD), and re-designated as a technology base effort (Wolfowitz, 2004). Eventually, the effort was renamed as the JAGM program.

The JAGM program was approved as a program of record and successfully awarded an EMD contract after an MS B approval in 2015 (11 years after the JCM attempt for an EMD program of record). However, the capabilities to be delivered under the JAGM program were greatly reduced from the capabilities desired in the JCM program. Figure 7 displays the differences between the JCM and JAGM programs. The documented lessons learned emphasized the avoidance of extensive unprioritized requirements, multiple threshold platforms, and the fixed-wing F18 platform in particular. The Army and Navy lessons applied to the JAGM effort emphasized an ID effort of the warfighter's highest priorities, reduced the threshold platforms, and leveraged the existing Hellfire missile warhead and motor to reduce risk, cost, and schedule.

FIGURE 7. JCM/JAGM ACQUISITION STRATEGY COMPARISON

- **JCM Program (MS B in Spring 2004)**
  - Joint (USA, USN, USMC) and International Cooperative UK
  - Intended to replace TOW, Hellfire, Maverick, Brimstones and SEA SKUA existing missiles
  - Tri-mode seeker, multipurpose warhead, common motor for three RW & one FW threshold platforms
- **JAGM Program (MS B in Spring 2015)**
  - Joint USA and USMC
  - Intended to replace Hellfire and air-launched TOW
  - Dual-mode seeker, Hellfire warhead and propulsion as GFE, for two threshold RW platforms



Note. Adapted from Gress, Kohtz, & Noll, 2018.

Survey Participants

The survey participants included 31 acquisition professionals representing a broad spectrum across the DoD, including active duty officers and government civilians from the Army, Navy, and Air Force. All the respondents were members of the acquisition workforce with various Defense Acquisition Workforce Improvement Act (DAWIA) acquisition certifications. The survey was intended to be taken by acquisition professionals in the DoD acquisition workforce. "The acquisition workforce is generally defined as uniformed and civilian government personnel, who are responsible for identifying, developing, buying, and managing goods and services to support the military" (Schwartz, et al., 2016). The size of the acquisition workforce has stabilized to approximately 150,000 total personnel (about 90% civilian and 10% uniformed personnel) across 14 distinct career fields that include engineering, contracting, life cycle logistics, program management, production & quality management, test & evaluation, facilities engineering, business–financial management, IT, auditing, S&T manager, business–cost estimating, purchasing, and property (Schwartz et al., 2016). The survey research protocol was reviewed by the Naval Postgraduate School Institutional Review Board and found to meet exemption category 2 in accordance with 32 CFR 219.101(b). Although not required, best practices of informed consent were followed. Additionally, the volunteer nature of the survey participation was emphasized, and no personably identifiable information (such as names, organizations, job titles, etc.) was recorded or could ever be traced to specific individual answers. The survey participants had no prior experience within either JCM or JAGM programs. They took the survey as part of leader development seminars sponsored by PEOs or as students in a master of science in program management or master of business administration in systems acquisition management. Prior to taking the survey, the respondents participated in discussions on critical thinking, risk and knowledge-based decision making, and the benefits of ID approaches.

Research Survey Data

The baseline survey uses the actual JCM MS B data, presents the draft JCM acquisition strategy, and asks survey participants to develop an appropriate acquisition strategy based on this data. The survey results are presented in Table 3. Table 3 tallies the responses of each participant for their recommended components of the strategy in terms of capabilities developed, schedule, and AUPC costs for each increment. Of the 31 participants, seven recommended a single-step strategy, 13 recommended a two-increment strategy, and 11 recommended a three-increment strategy. Within each strategy type, read across the row to follow the tally of how many respondents recommended a specific strategy with respect to seeker, warhead, propulsion, platforms, schedule, and costs. The survey asked the participants to decide the following for each increment based on the given data:

- Seeker: development of dual or tri-mode seeker (laser, millimeter wave, and infrared) or use of a nondevelopmental (NDI) single mode seeker.
- Warhead: development of multipurpose warhead or use of an NDI single warhead.
- Propulsion: development of a common motor or use of an NDI single motor.
- Platforms: rotary wing (AH-64, AH-1, or MH-60) or fixed wing (F/A-18E/F)
- Schedule: (length of EMD phase)
- AUPC costs: (POE or ICE)

To address the research questions and help analyze the data, three hypotheses were studied. The first hypothesis was that the JAGM strategy would not be recommended based on the pressures to deliver all KPPs by the required IOC within the cost and schedule constraints of the Service-approved POE. The JAGM strategy was an incremental approach with the first increment developing a dual mode seeker and using an NDI warhead and NDI motor, while only being incorporated on the AH64 and AH1 platforms. The second hypothesis was based on the nearly constant emphasis on affordability and rapid acquisition, articulated by senior leaders and Congress over many years. It proposed that acquisition professionals would reduce programmatic risk by maintaining the cost and schedule constraints in the draft APB and recommending delaying performance capabilities (pushing some KPPs to later increments). Given that an incremental strategy was recommended, the third hypothesis was that acquisition professionals would choose to delay capabilities associated with technologies with low TRL ratings and/or high-risk ratings (for example, only the multipurpose warhead had medium/high risk rating and would be delayed to later increments).

TABLE 3. SURVEY DATA RESULTS

		Seeker			Warhead	
	Respondents (n)	Single Mode (NDI) TRL 9	Dual Mode	Tri-mode APB KPP TRL 6 Med Risk	Single (NDI) TRL 9	Multipurpose APB KPP TRL 6 Med/High Risk
	31					
Single Step	7		1	6	1	6
Two-Increment Approach						
Increment I	13		8	5	7	6
Increment II				13		13
Three-Increment Approach						
Increment I	11	4	5	2	8	3
Increment II			4	7	5	6
Increment III				11		11

Hypothesis No. 1: Acquisition professionals would not recommend the JAGM acquisition strategy from the JCM MS B data. For a sample size of 31, 7 of 31 (23%) recommended a single-step approach, 13 of 31 (42%) recommended two increments, and 11 of 31 (35%) recommended three increments. None (0 of 31, or 0.0%) of the respondents recommended an acquisition strategy resembling the JAGM strategy (dual mode seeker, NDI warhead, NDI motor, and integration of only AH64 and AH1 in first increment)—providing evidence that supports hypothesis No. 1 that acquisition professionals did not recommend the JAGM ID strategy based on the actual JCM MS B programmatic data.

Propulsion		Platform				Schedule (EMD length)		Cost (AUPC)	
Single motor (NDI) TRL 9	Common APB KPP TRL 6 Med Risk	AH64 APB KPP	AH1 APB KPP	MH60 APB KPP	F18 APB KPP	48 months APB POE	72 or 144 months ICE	$108K or $120K APB POE	$153K ICE
1	6	6	6	6	7	1	6	2	5
Two-Increment Approach									
3	10	12	11	10	5	7	5	8	4
	13	13	13	13	13	3	8	5	8
Three-Increment Approach									
10	1	10	8	6	5	9	2	7	4
8	3	10	9	9	8	7	4	6	5
1	10	10	9	9	10	7	4	6	5

Hypothesis No. 2: Most acquisition professionals would maintain the approved Service cost and schedule constraints and choose to delay capability, given the JCM MS B data. For single-step acquisition, 5 of 7 respondents (71%) chose the ICE-recommended 6-year schedule and $153,000 AUPC with no capability increments; and 2 of 7 (29%) of the respondents chose a 4-year or 12-year schedule and $120,000 AUPC with no capability increments. For the first increment in two-increment strategies, 5 of 13 (38%) recommended delaying some capability with a first-increment schedule of 6 or 12 years, with ICE-recommended $153,000 AUPC; and 7 of 13 (54%) recommended delaying some capability with a first increment schedule of 4 years and $120,000 AUPC. For the first increment in three increment strategies, 7 of 11 (64%) recommended delaying some capability but maintaining the Service-approved 4-year schedule and $108,000 AUPC. In summary, only 14 in 31 respondents (45%) decided to maintain the approved Service cost and schedule constraints and incrementalize capability—indicating evidence counter to hypothesis No. 2.

Hypothesis No. 3: For those acquisition professionals that recommended an incremental approach, they would recommend delaying capabilities linked to technologies with low TRLs and/or high-risk ratings. For the baseline survey, 24 of 31 (77%) recommended an incremental approach, with 13 recommending two increments, and 11 recommending three increments. Of the 13 recommending a two-increment approach, 8 of 13 delayed seeker capability, 7 of 13 delayed warhead capability, 3 of 13 delayed motor capability, and 11 of 13 delayed a platform to increment two. Of the 11 recommending a three-increment approach, 9 of 11 delayed seeker capability, 8 of 11 delayed warhead capability, 10 of 11 delayed motor capability, and 8 of 11 delayed a platform to later increments. For the baseline survey, the three CTEs had a TRL of 6, six risk areas were ranked as medium risk, and the warhead and integration were ranked as medium/high. These results neither confirm nor deny hypothesis No. 3 because the warhead was highlighted as higher risk, and 15 of 24 (63%) respondents pushed the multipurpose warhead to a later increment. However, 17 of 24 (71%) respondents pushed the seeker to a later increment despite the tri-mode seeker having the same TRL rating as the multipurpose warhead and a lower risk rating. The recommended approaches do not appear to be entirely data-driven based on the CTE, TRL, and risk ratings.

Research Limitations

The following observations acknowledge the limitations of this research framework and data.

- A small sample size of 31 participants representing a diverse acquisition workforce.
- The research case study framework leverages only one effort—the evolution of the JCM program to the JAGM program—as a typical acquisition effort representing a great variety of defense acquisition efforts.
- The assumption that the components of an acquisition strategy can be developed from milestone decision data of requirements (KPPs), technology risks (TRLs and CTE risk ratings), costs (AUPC predictions from POE and ICE), and schedule (required IOC).

- The assumption that the acquisition strategy can be summarized by describing the components of capability desired (planned KPPs to be achieved), the schedule (length of development effort), and costs (AUPC) for each increment within the strategy.

- The research assumptions that the JCM acquisition strategy was ineffective because the program was cancelled, resulting in no warfighter capability, and that the JAGM acquisition strategy was effective because the program was not cancelled, resulting in improved warfighter capability.

Analysis of Results

This section presents the results detailed earlier to address the research questions.

Primary Research Question

Given programmatic decision inputs for a specific program, can we gain a better understanding of how PMs or acquisition professionals formulate the components of the acquisition strategy? The survey results indicated that acquisition professionals used knowledge of TRLs and risk ratings to recommend the components of an acquisition strategy in terms of performance, cost, and schedule. To reduce programmatic risk, most participants chose to recommend an incremental approach rather a single-step acquisition as originally planned.

Additionally, most participants chose to relax performance constraints by delaying requirements to later increments, relax schedule constraints by extending the EMD length, and relax cost constraints by recommending the higher ICE AUPC. This result directly addresses the primary research question by providing evidence that acquisition professionals have difficulty in prioritizing the triple constraint of cost, schedule, and performance; therefore, they tended to relax all three rather than choose just one element to reduce programmatic risk.

These results provide data to support a recent GAO (2015c) conclusion, in *Joint Action Needed by DOD and Congress to Improve Outcomes,* that defense acquisition provided incentives for PMs to promote successful acquisition strategies (defined as approved and leading to successful milestones) rather than sound acquisition strategies (defined as executed within cost, schedule, and performance constraints, and leading to fielding capability). This research suggests that acquisition policy needs to provide more guidance to assist PMs in developing acquisition strategies like ID approaches to optimally balance near-term program milestone approval and long-term program executability in terms of maintaining cost, schedule, and performance baselines and delivering capability.

Secondary Research Question

What is the most important factor in determining the recommended acquisition strategy? The survey results indicated that when acquisition professionals recommended an incremental approach, neither a low-component TRL nor high-risk rating was more important in recommending that a capability be delayed to a later increment. Acquisition professionals were equally likely to recommend a delay, to a later increment, of the seeker capability and the warhead capability, despite the latter technologies being rated at a higher risk level. The research results suggest that acquisition professionals used other than the provided data on TRLs and risk ratings. The results also indicate that acquisition professionals did not link the KPPs to the TRLs and risk ratings. For example, the development of the common motor was directly linked to the requirement for delivery from both rotary wing and fixed wing (F/A-18E/F). However, acquisition professionals recognized this connection in their recommended acquisition strategy less than 50% of the time, and recommended delaying the common motor development and the F/A-18E/F platform to later increments.

PMs basically have two choices to reduce programmatic risk when formulating acquisition strategy—either request more time and money for the effort as defined or request a reduction in scope for the time and money planned. Requesting more money or additional schedule is unrealistic for a development program that has been in the TMRR phase with a planned EMD phase, and it risks program approval with Service leaders who already approved the funding and the schedule to go along with that funding. The more likely choice to reduce programmatic risk would be to maintain cost and schedule constraints and recommend a reduction in scope or performance capability.

This is difficult for the PM to recommend because the warfighter wants all the required capability. This is where the benefits of an ID approach can help alleviate some concerns by delivering improved capability (albeit not full desired capability) in increments while the full capability is developed simultaneously. In this research, 71% recommended an ID approach, indicating good training and education of the acquisition workforce on the benefits of ID. Even though most acquisition professionals recommended an ID approach, only 41% maintained the cost and schedule constraints. The participants believed that they not only had to reduce performance by delaying requirements, but had to recommend a longer schedule and request more funding.

This puts the PMs in the difficult position of not being able to deliver on cost, schedule, or performance requirements, and it increases the risk that the program will not get approved as a program of record at the milestone. This pressure to get program approval must be balanced with the PM's risk of trying to execute a program with a high probability of encountering cost over-runs, schedule slips, and underperformance in delivering the proposed capabilities.

The results indicate what many experienced acquisition professionals intuitively know: at program initiation for a complex defense research and development effort, it is extremely hard to plan the components of an acquisition strategy that does not need to be later adjusted by fact-of-life changes in the acquisition environment. The problem is that these acquisition strategy adjustments usually require APB changes that put the program at risk for cancellation due to schedule slips, cost increases, and/or inability to deliver required performance capability. The inputs to the acquisition strategy survey here typify the data that would be provided to the MDAs to approve planned acquisition strategies. Some might argue that more data and time are needed to make a truly informed decision; however, in reality, less data and time are normally available. It is also noted that acquisition strategies are usually developed through integrated product teams (IPTs) leveraging the concepts of integrated product and process development. In the end, however, the PM makes recommendations through the chain of command to the MDA for decisions; IPTs don't make decisions—they enable a more informed recommendation from the PM and a more informed decision by the MDA.

In this case for the JCM program, the requirements were well established and supported by years of analysis with a set capability need date. The technologies needed to turn those requirements into capabilities for the warfighter had matured to the point that they were deemed mature (TRL 6) and ready for integration and development work. Additionally, the funding to support the JCM program of record for a development and engineering work and procurement of missiles was aligned to the required need date (IOC). The PM triple constant of cost, schedule, and performance was all synchronized and set within the planned APB. However, for the JCM program, a single-step acquisition strategy to deliver all required capabilities was eventually cancelled and the warfighter received no capability. Had an ID approach similar to the subsequent JAGM acquisition strategy been adopted initially, the warfighter would have received improved capability more than a decade sooner.

Future Research

This research could not address the secondary research question—how can the decision input factors be changed to enable a PM or acquisition professional to recommend an ID strategy that more closely resembles the actual strategy later adopted by the Services? To address this research question, the input variables in the survey would need to be changed from the original JCM data in different versions of the survey. The results of the modified surveys could be compared to one another to study which survey input variables resulted in a higher percentage of acquisition professionals recommending a JAGM incremental acquisition strategy. Future work investigating the relative importance of CTE TRL ratings versus CTE risk ratings in determining the recommended components of the strategy would shed light on the importance of these ratings in decision making. Table 4 represents a proposed design-of-experiments approach showing how the eight risk ratings and TRL ratings could vary in different survey versions.

A comparison of the results between surveys No. 1 through No. 4 could be undertaken to see whether acquisition professionals recommend an incremental approach to the development of the tri-mode seeker in situations with a low seeker TRL and/or high seeker risk rating. Surveys No. 5–7 would support the results of surveys No. 1–4 by varying the warhead data, rather than the seeker data.

TABLE 4. PROPOSED FUTURE SURVEY DESCRIPTIONS

	Technology Readiness Level (TRL)		
Survey Number	**Seeker (s)**	**Warhead (w)**	**Motor (m)**
Survey #1 - baseline	6	6	6
Survey #2 - seeker TRL	4	6	6
Survey #3 - seeker RR	6	6	6
Survey #4 - seeker TRL & RR	4	6	6
Survey #5 - warhead TRL	6	4	6
Survey #6 - warhead RR	6	6	6
Survey #7 - warhead TRL & RR	6	4	6
Survey #8 - motor TRL & RR	6	6	4
Survey #9 - F18 platform RR	6	6	6
Survey #10 - MH60 platform RR	6	6	6
Survey #11 - motor TRL & RR and F18 RR	6	6	4
Survey #12 - motor TRL/RR and F18/MH60 RRs	6	6	4
Survey #13 - integration RR	6	6	6
Survey #14 - JAGM	4	4	4

Similarly, surveys No. 8–12 would study the missile motor as well as the platforms that would accept the missile. For example, the results of survey No. 9 would study the question, "Did a higher percentage of acquisition professionals recommend delaying integration of the missile onto the F18 platform if the risk rating was high rather than medium?"

Survey No. 13 would study the importance of the integration risk rating in relation to the CTE TRLs or CTE risk ratings. The results of this survey may indicate that an integration readiness level (IRL) has the same level of acceptance as TRLs and manufacturing readiness levels (MRLs) within acquisition policy.

The results of survey No. 14 would reveal whether acquisition professionals do indeed recommend an incremental approach at higher percentages when the TRLs are low and risk ratings are high. Survey No. 14 data input is set up to determine whether respondents recommended a JAGM strategy more often than the baseline data in survey No. 1.

Risk Ratings (RR)							
Seeker (s)	Warhead (w)	Motor (m)	Integration (i)	AH-64 Apache (64)	AH-1 Cobra (1)	MH-60 Seahawk	F/A18E/F (18)
m	mh	m	mh	m	m	m	m
m	mh	m	mh	m	m	m	m
h	mh	m	h	m	m	m	m
h	mh	m	h	m	m	m	m
m	mh	m	mh	m	m	m	m
m	h	m	h	m	m	m	m
m	h	m	h	m	m	m	m
m	mh	h	h	m	m	m	m
m	mh	m	mh	m	m	m	h
m	mh	m	mh	m	m	h	m
m	mh	h	h	m	m	m	h
m	mh	h	h	m	m	h	h
m	mh	m	h	m	m	m	m
h	h	h	h	m	m	h	h

Conclusions and Recommendations

The results highlight the importance of the Service affordability constraints in establishing the acquisition program's cost and schedule parameters in the APB. After cost and schedule constraints are set, the senior leaders, acquisition professionals, and warfighters must come together and agree on an incremental approach to deliver some capability as soon as possible to the warfighter and delay the full capability to later increments. If this struggle does not happen initially for a complex development program, then the program may never deliver capability because of the high risk of cancellation due to schedule slips and cost overruns.

Once the program's cost and schedule parameters are planned, programmed, and budgeted in the Service POM, the importance of considering alternate acquisition strategies, such as to delay desired capability to later increments, is evident. PMs must coordinate and balance the inputs from the S&T, testing, and warfighter communities to recommend the integration of the least risky technologies for inclusion in the first increment of a new warfighting capability. The use of both TRLs and risk ratings for the development of CTEs and integration risk ratings may help increase the chance of program success (defined in terms of improved fielded capability to warfighters).

In the case of the JCM program, the cost and schedule constraints indicated the need to recommend an ID approach and delay some capability to later increments. The JCM program was cancelled after a successful MS B, and it took more than 10 years for the new JAGM program to pass an MS B—this time with an incremental approach that leveraged existing government furnished equipment (GFE) and NDI components. Meanwhile, during this "lost decade," the warfighter got none of the desired capabilities required.

This research suggests that the guidance in DoDD 5000.1 should encourage PMs to plan acquisition strategies for programs of record with an ID approach using set affordability parameters with respect to cost and schedule for development efforts. Further, allow the Services the ability to fit what is affordable from a performance (requirements) perspective into the first increment of the program of record by delaying the achievement of some requirements (even KPPs) to subsequent increments to allow more time for technology maturation. Warfighters would benefit from some capability increase, and acquisition programs would be less likely to fail due to cost overruns and/or schedule slips.

Results of this research suggest that the defense acquisition system should break the concept of the PM's triple constraint of cost, schedule, and performance. The triple constraint ties the hands of the PMs and may contribute to high program failure and no delivered capability. The bottom line is that if all three—cost, schedule, and performance—are set, then the program may have an unnecessarily high risk of failure. If affordability sets the constraints of cost and schedule, which must be done in a government/defense industry domain like defense acquisition, then flexibility in determining which requirements to pursue by allowing ID approaches would loosen the triple constraint stranglehold. In the end, the warfighter must determine whether the first capability increment offers enough capability improvement over the current systems to warrant the investment of time and money. The current defense acquisition system incentivizes PMs to get through an improved milestone—often with a program that cannot be executed in terms of cost, schedule, and performance and has a high risk of cancellation and failure. A better approach would incentivize fielded and delivered warfighter capability by allowing PMs to develop acquisition strategies that balance gaining program approval and maintaining acquisition baselines.

"Results of this research suggest that the defense acquisition system should break the concept of the PM's triple constraint of cost, schedule, and performance. The triple constraint ties the hands of the PMs and may contribute to high program failure and no delivered capability.

The following recommendations, specific to defense acquisition policy, result from this study:

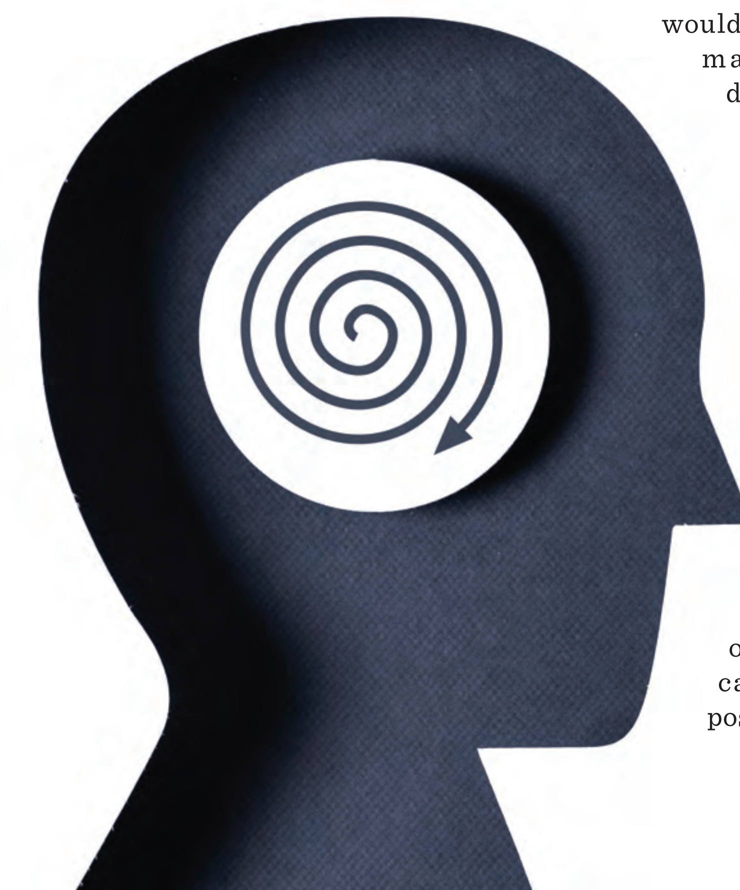
- For major defense acquisition programs, especially technology development efforts, the DoDD 5000.01 should continue to state the preferred approach as ID. Although the sample size is relatively small, this work suggests that DoD should consider modifying acquisition policy to make ID the default strategy, requiring MDAs to justify any single-step acquisition.

- The use of TRLs for specific component technologies is well entrenched in defense acquisition training for PMs, specifically the requirement for all component technologies to achieve TRL 6 for an MS B or entry to the EMD phase. However, TRLs alone do not provide sufficient information for PMs and MDAs to make well-informed choices on appropriate incremental strategies. Component technology TRLs should be augmented with risk ratings. Specifically, risk ratings should be medium or lower for all program-identified risks before proceeding into the EMD phase of the first increment.

- The integration risk should be specifically addressed at all milestone reviews, either through the program risk assessment or the introduction of an IRL, similar to the TRL and MRL levels.

This study focused on the challenges PMs have in formulating the DoD's preferred approach—an ID strategy. The conclusions and recommendations focus on acquisition policy changes to optimize the implementation of ID strategies. The goal is to make the defense acquisition system more responsive to the warfighter by fielding improved capability as quickly as possible and reducing risk to the eventual delivery of the full required capability.

A proposed extension of this research is a "new" area of research called "behavioral acquisition." Similar to behavioral finance that studies both economics and psychology within finance decision making, behavioral acquisition would combine the study of program management, organizational dynamics, defense acquisition, and psychology within acquisition decision making. A paradigm shift may be required within defense acquisition to realize the importance of research in behavioral acquisition. A solid understanding of how acquisition professionals think critically and make decisions or recommendations in the complex defense acquisition environment would lead to improved acquisition strategy planning and better acquisition program outcomes—specifically, warfighter capability delivered as soon as possible.



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APPENDIX A

ACQUISITION STRATEGY SURVEY SITUATION AND BACKGROUND

SITUATION

You are preparing for a Milestone (MS) B decision to enter engineering and manufacturing development (EMD) and award competitive EMD contracts. The joint common missile (JCM) program is an Acquisition Category-1D (ACAT-1D) program with planned MS B in 6 months.

BACKGROUND

The JCM program just finished a very successful 3-year technology maturation and risk reduction (TMRR) phase, which met all exit criteria in which all critical technology elements (CTE) were assessed at technology readiness level (TRL) 6. Successful science and technology objectives (STO) efforts by Research Development and Engineering Command (RDECOM) preceded the TMRR phase. Comprehensive analysis during the TMRR phase underpinned the requirements for the JCM program. The capabilities based assessment (CBA) documented the need for JCM, along with an approved initial capabilities document (ICD). An approved analysis of alternatives (AoA) solidified the Joint Requirements Oversight Council (JROC)-approved capability development document (CDD) requirements, including the key performance parameter (KPP) thresholds/objectives.

The user has an operational and logistical need for development of the JCM to replace the Hellfire, Maverick, and aviation-launched TOW missiles for the Army and Navy. The Services desire increased range, capability, force protection, and a decreased logistics footprint. The current platforms and accompanied missiles are as follows:

- Army AH-64 Apache fires multiple versions of the Hellfire missile with either precision point (PP) targeting using laser designation or fire and forget (active) targeting using millimeter wavelength (MMW) radar and separate warheads for different target sets. The Hellfire Average Unit Procurement Cost (AUPC) averages $58.2K - $115.6K.

- USMC AH-1Z Cobra fires all versions of the Hellfire missiles and TOW missiles with wire guided targeting. The TOW AUPC averages $63.7K–$92.5K.

- Navy MH-60 Seahawk fires all versions of the Hellfire missiles and TOW missiles.

- Navy F/A-18 E/F Super Hornet fires Maverick missiles with either PP or fire and forget (passive) targeting using Infrared (IR) with separate warheads for different target sets. The Maverick AUPC averages $179K.

All current missiles have single-mode seeking capability only, with separate warheads. A single JCM is capable of replacing more than a dozen variants of Hellfire, Maverick, and TOW missiles.

The current draft JCM acquisition strategy (AS) outlines a 4 year EMD phase that meets the warfighter required initial operational capability (IOC) dates. The single step, 4 year EMD has support from the warfighting community, the Services' requirements communities, the Service Chiefs, and Service Acquisition Executives.

APPENDIX B

ACQUISITION STRATEGY SURVEY DRAFT JCM APB

DRAFT ACQUISITION PROGRAM BASLINE (APB)

The following performance, schedule, and cost data outline the constraints applied to the joint common missile (JCM) program

PERFORMANCE

CDD Performance Requirements			
#	KPP	Threshold/ Objective	Performance
1	Targeting	T=O	Precision Point (Laser Designated / Guided)
			Fire & Forget – Active (Radar Designated / Guided)
			Fire & Forget – Passive (IR Designated / Guided)
2	Combat Effectiveness	T=O	Anti-Tank (T90)
			MOUT (Personnel behind Triple Brick & Concrete Walls)
3	Range	T=O	Rotary Wing (RW): 16 KM
			Fixed Wing (FW): 28 KM
4	Interoperability (Platform)	Threshold	AH-64D (Apache), AH-1Z (Cobra), F/A-18 (E/F), MH-60R (Seahawk)
		Objective	UAVs, JSF, UK airframes
#	Additional Attributes	Threshold/ Objective	Performance
1	Physical Dimensions	Threshold	Weight:108 lbs.
		Objective	Weight: 90 lbs.
		T=O	Length: 70 Inches

(Acronyms: JSF = Joint Strike Fighter, MOUT = military operations in urban terrain, UAVs = unmanned aerial vehicles, UK = United Kingdom)

SCHEDULE

The current program is constructed to support a single-step acquisition strategy and will deliver full capability desired. The CDD documented an initial operational capability (IOC) for the JCM at MS B +5 years (60 months) based on the urgency of the need, the capabilities based assessment (CBA), and the analysis of alternatives (AoA) results. The engineering, manufacturing, and development (EMD) phase has been planned for 48 months. The schedule part of the APB has the following significant events: critical design review (CDR) at MS B + 2 years (24 months), MS C at MS B + 4 years (48 months), and IOC at MS B + 5 years (60 months).

COST

The acquisition objective (AO) for the JCM is 63,978 missiles to be procured for the Army and Navy. Cost estimates from Service affordability leads have determined an AUPC of $108K (with multiyear contract vehicle) and $120K (without multiyear contract vehicle). The program has been incorporated into the approved Services' POM positions and Services have certified that JCM is fully funded. The JCM joint cost proposal (JCP) has been approved and the Army and Navy fully funded a 48-month EMD with research, development, test and evaluation (RDT&E) funding and a 10-year production and deployment (P&D) with procurement funding.

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A Model for **EXOGENOUS LEARNING** on DEPARTMENT OF DEFENSE Procurement Programs

Patricia F. Bronson

Evidence of exogenous learning on Department of Defense (DoD) procurement programs for major weapon systems acquisition can be demonstrated and explained with an investment strategy model that maximizes the manufacturer's return on investment (ROI) over the life of the program. This article describes one such model. The model takes a list of investment and unit-cost-reduction pairs and a planned procurement profile and computes which investments should be made and in what order to maximize profit. Simulations conducted with this model explore the learning curve effects caused by regulatory lag (the period of time the contractor gets to keep the ROI before he has to pass savings onto the customer), the manufacturers' expected profit, and changes to the procurement rate.

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Keywords: *Exogenous Learning, Economic Incentives, Regulatory Lag, Numerical Models, Investment Planning*

Image designed by Michael Bubar-Krukowski

Exogenous Learning Based on Economic Incentives

A learning curve is a graphical representation of the cost of producing an item against the number of items produced over time. In 1936, Theodore Paul Wright described the effect of learning on production costs in the aircraft industry (Wright, 1936). Comprehensive reviews exist on learning curves (Womer, 1979), the theory behind them (Adler & Clark, 1991; Hall & Howell, 1985; Zollo & Winter, 2002), and empirical analysis of manufacturing data (Ittner et al., 2001). From these sources and others (Lapr'e & Nembhard, 2010), it is known that learning occurs with repetition because workers make fewer mistakes and spend less time thinking and hesitating. It is also known that learning occurs when workers and resident production engineers modify the manufacturing process with preexisting resources. For example, engineers can streamline existing processes, standardize processes across manufacturing lines, and make better use of existing equipment. Furthermore, changes made by management, such as changes in the labor mix, can also improve learning for a manufacturing process. All these reasons for increased efficiency are internally driven improvements and do not require a specific monetary investment; this type of learning is known as *endogenous learning.*

Exogenous learning, conversely, requires the company to invest money up front, to change something specific, with the expectation that the investment will produce a future return in the form of lower costs to manufacture that exceeds the cost of the investment. These are usually investments in major design improvements that can include changes in material content of the product, or major streamlining of production processes that can include automation. Investments in information technology can also increase efficiency on the manufacturing floor and reduce overhead support costs. Dutton and Thomas (1984) discuss "induced learning" and suggest the learning rate should be treated as a dependent variable. Zollo and Winter (2002) call it deliberate learning and suggest that tasks with high

economic importance should benefit from relatively higher investments. Hax and Majluf (1982) observed that investments can result in shifts to steeper learning curves.

Lee (1977) relates economic incentives inherent in DoD production programs and contracts to the shape of the learning curve and considers economic incentives to be returns on investment (ROIs) that drive the unit cost down. When price is closely coupled to cost, which is true in most DoD procurement contracts for major weapons systems, Lee concludes that manufacturers have few economic incentives to invest in producibility and production technology that lower the cost to manufacture. If the cost of the items go down over the life of the program, so does the profit.

"Exogenous learning, conversely, requires the company to invest money up front, to change something specific, with the expectation that the investment will produce a future return in the form of lower costs to manufacture that exceeds the cost of the investment.

Rogerson (1994) proposes that "regulatory lag" provides economic incentives for manufacturers to invest in cost-reduction initiatives when price is closely coupled to cost. As used by Rogerson, regulatory lag is a period of time that a manufacturer gets to keep ROIs before having to pass the savings onto DoD. At the end of that time period, the manufacturer must share its cost savings, and this is negotiated and written into the next contract. A long regulatory lag period translates into greater incentive for the manufacturer to reduce cost. Consequently, when potential investments to reduce production cost exist, regulatory lag becomes a major driver in determining the degree of learning on DoD procurement programs.

To complicate the manufacturer's decision process, DoD makes changes to the planned procurement profile with consequences to the manufacturer's expected ROI. If quantities are increased during the regulatory lag period, the returns increase, and if quantities are reduced during the regulatory lag period, the returns decrease from what was expected. This complication provides a negative incentive for the contractor to invest, especially when programs are routinely stretched to buy to the budget. On the other hand, multiyear procurement contracts create a positive incentive to invest because their use increases regulatory lag from a more normal 1 to 2 years out to 5 to 7 years.

The Decision-Making Model for Learning Based on Economic Incentives

The theoretical decision-making model described in this article is based on ideas in lecture notes of Rogerson (1994) for exogenous learning on a production program. The model takes the following inputs:

- A baseline endogenous learning curve
- A list of available investments that each yield a specific reduction in unit costs
- A planned procurement profile that specifies the yearly quantity per lot for the entire length of the procurement program
- The length of the regulatory lag period
- The manufacturer's expected profit
- The cost of capital (time value of money)

The model calculates the net return on each investment made in each year of the regulatory lag period and weighs it against the investment made to produce the reduction and the profit loss that will be experienced in future years because of the cost reduction. It can also compute the results of making an investment or not each year, just as the manufacturer could. However, it is constrained to use an investment-return pair only once, if at all. Lastly, the model computes outcomes on which investments should be made and in what order to maximize profit.

The outcome of a simulation conducted with the model represents the manufacturer's planned investment strategy for that specific procurement profile. With the planned investment strategy, the model generates the average cost per unit per lot, which is the learning curve that reflects both endogenous and exogenous learning on the program.

Starting with a list of investment-return and a planned procurement profile, the model builds a matrix that represents all realistic outcomes of the decision process.

The investment-return pair is represented in the model by I_{ij} and r_{ij} where the subscript i specifies the investment and the subscript j identifies the first period where the return will be realized, so that r_{ij} is the reduction in unit cost resulting from investment i made in lot j.

The cost of lot *j* can be written as in Equation 1 and is the exogenous learning curve:

$$C_j = q_j \times c_j - q_j \sum_{i=1}^{j} r_{ij} \ , \qquad \text{(Equation 1)}$$

where q_j is the quantity in lot *j*, and c_j is the average unit cost of lot *j* before any investments are made.

The model then populates the matrix with the information upon which the decision is based—that is, the net present value of the changes in profit. Equation 2 represents the net present value of the changes in profit due to investment *i* made in year *j*:

$$P'_{ij} = \sum_{i=j+1}^{j+1+\lambda} q_l r'_{i\lambda} - \gamma \sum_{l=j+2+\lambda}^{N} q_l r'_{i\lambda} - I_{ij} \ , \qquad \text{(Equation 2)}$$

where $r'_{i\lambda}$ is the net present value of the reduction in cost, λ is the number of years before prices adjust to reflect lowered costs (the regulatory lag period), γ is the manufacturer's expected profit rate, and *N* is the total number of years in the procurement program.

The first term in Equation 2 is the net present value of the cost reduction for λ years, after which the government reduces the offered price to account for the cost savings. The second term in Equation 2 represents the manufacturer's profit loss because of the reduction in cost, and the third term is the cost of the investment *i* in year *j*. It is interesting to note that, because the profits from reduction in cost are limited to a fixed number of years, and the losses from reduced profit extend to the end of the program, it can be optimal for the contractor to delay or not even make an investment to lower cost.

With the investment-return pairs and subsequent changes in profit defined, the model computes the stream of investments that maximizes the net present value of profit as given by Equation 2. In this application, a binary integer-programming routine returns the optimum order of the investment and represents the manufacturer's preferred investment profile given the planned production quantities per year. The model utilizes the binary integer programming routine available in MathWorks Optimization Toolbox™, Version 7.5 (R2007b). It is appropriate to use binary integer programming when each variable in the optimal solution can be represented as either a 0 or a 1. For this application, the condition was satisfied by presenting the decision-making model (or the manufacturer) with a list of investment-and-return pairs and a planned procurement quantity profile, and let the model either make an investment (1) or not make an investment (0) in a given period.

Numerical Experiments

Numerical experiments are designed to explore the optimal learning curve's sensitivity to the length of the regulatory lag period, the manufacturer's expected profit, the cost of capital, and reductions in the planned procurement quantity per lot.

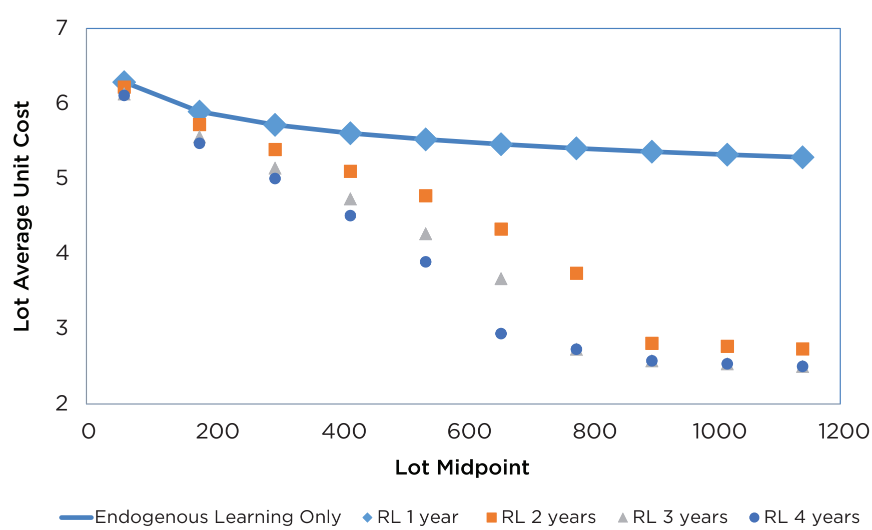
Each experiment starts with a list of 20 investment and unit-cost-reduction pairs. The unit-cost-reduction values vary from about 1% to about 11% of the first unit cost. If all 20 reductions were realized, the unit cost would be about 50% of the first unit cost. The investment and unit-cost-reduction pairs are specified so that each investment returns at least its cost over 2 years relative to a 10-year baseline program. Each cost-reduction investment is sized to matter, and the magnitude of the maximum possible reduction is plausible. These conditions are, at least nominally, realistic for the experiments performed, that is, to examine how exogenous learning changes as the variables for regulatory lag period, length of the procurement program, manufacturer's expected profit, and the time value of money are changed.

Experiment 1: Varying the Regulatory Lag Period

This experiment starts with a procurement program that buys 1,200 units over a 10-year period at a rate of 120 units per year. The endogenous learning curve slope for this contract is assumed to be 96% (the remainder of the learning to be earned by investments), the manufacturer's expected profit is 10%, and the cost of capital is 7%. Four scenarios explore the results when the regulatory lag period increases from 1 to 4 years.

Figure 1 presents the results of Experiment 1 in graphical form with average unit cost per lot versus lot midpoint for each scenario, and the endogenous learning curve shown for reference.

FIGURE 1. LEARNING CURVES ON A 10-YEAR PROGRAM WITH REGULATORY LAG 1, 2, 3, & 4 YEARS



With the regulatory lag period 1 year long, there is no exogenous learning because the model did not make any investments. With regulatory lag periods of 2 years, the model makes investments in years 1 through 8, producing a steeper learning curve (average slope of about 82% over the life of the program). With increasing length of the regulatory lag period, the model generates more and sometimes different investments with the number of investments increasing (and the slope of the learning curve) with each year added. According to this simulation, 2 years of regulatory lag reduces total procurement cost on the 10-year program by 22% from the purely endogenous case.

Experiment 2: Stretching a Procurement Program

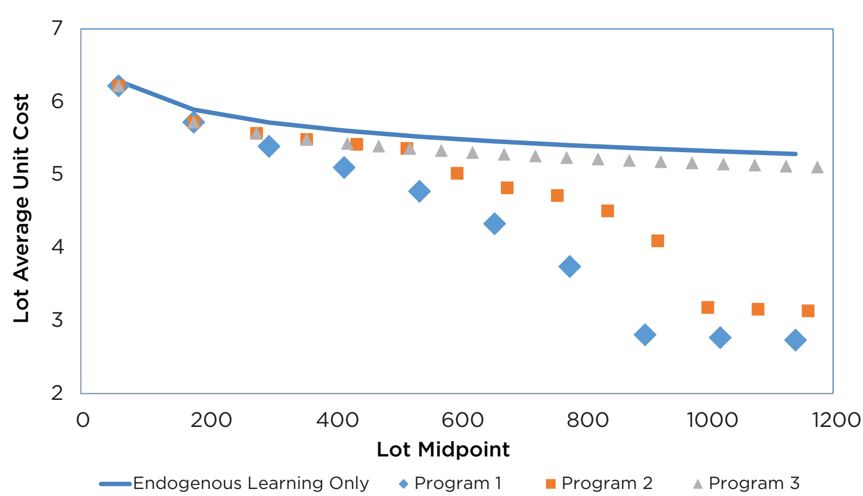
This experiment starts with a procurement program that buys 1,200 units over a 10-year period at a rate of 120 units per year (Program 1). The endogenous learning curve slope for this contract is 96%, the manufacturer's expected profit is 10%, the cost of capital is 7%, and the regulatory lag is 2 years. The initial investment plan is calculated before production begins.

Program 2 reflects the result of a decision made during the first year of production to stretch the procurement program starting in year 3. The program is stretched to 14 years by decreasing the planned procurement quantity from 120 to 80 per year, from year 3 through year 14.

Program 3 reflects the result of a decision made in year 2 to stretch the program again, starting in year 5, by decreasing the planned procurement per year from 80 to 50, resulting in a 20-year procurement program.

Figure 2 presents the results of Experiment 2 in graphical form with average unit cost per lot versus lot midpoint for each scenario, and the endogenous learning curve shown for reference.

FIGURE 2. LEARNING CURVES DEMONSTRATING LOSS OF LEARNING AS THE PROGRAM IS STRETCHED



Investments are made in Program 1 that increase exogenous learning each year from years 1 through 8. When the program is stretched starting in year 3, no investments return a positive net present value until year 7. Investments are made in years 6 through 11 for reductions in years 7 through 12. When the program is stretched the second time starting in year 5 (Program 3), exogenous learning stops. The loss of learning from the first stretch increases the total procurement cost by 11% and the second stretch to 24%.

Recall, the model was designed with no fixed cost per lot, so the changes in cost could be attributed to changes in the shape of the learning curve.

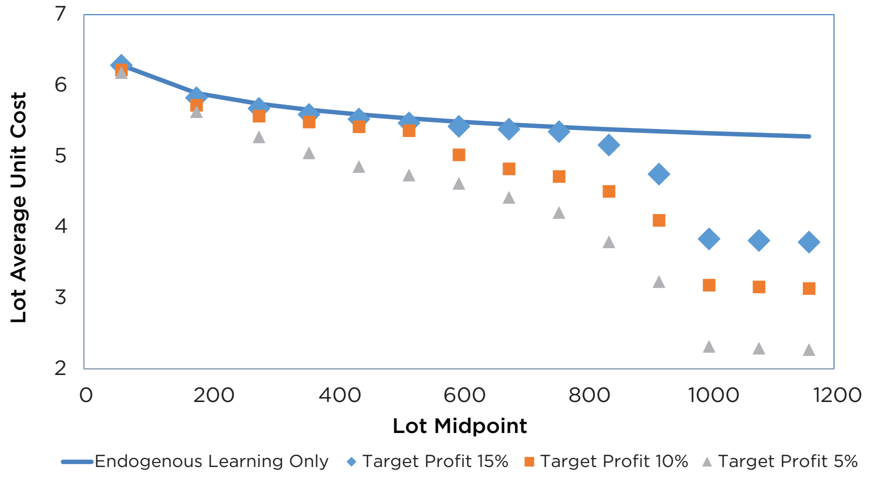
Experiment 3: Varying Manufacturer's Expected Profit

If the cost to manufacture an item is reduced after award of a firm-fixed-price (FFP) contract, the manufacturer gets to keep the difference as *additional* profit. (Note: An FFP contract provides for a price that is not subject to any adjustment on the basis of the contractor's cost experience in performing the contract. This contract type places upon the contractor maximum risk and full responsibility for all costs and resulting profit or loss. It provides maximum incentive for the contractor to control costs and perform effectively and imposes a minimum administrative burden upon the contracting parties [Federal Acquisition Regulation, 2019, § 16.2].)

Experiment 3 explores the consequences of changing the manufacturer's expected profit.

Figure 3 presents the results of Experiment 3 for Program 2 (stretched starting in year 3) in graphical form with average unit cost per lot versus lot midpoint for each scenario, and the endogenous learning curve shown for reference.

FIGURE 3. LEARNING WITH VARIOUS TARGET PROFIT VALUES



Reducing the manufacturer's expected profit reduces the cost of the procurement program. Recall that the decision to invest or not depends not only on the investment and cost reductions during the regulatory lag period but also on the profit loss due to those reductions after the end of the regulatory lag period. In this case, only three investments are made when the profit is 15%, 6 investments are made when the profit is 10% (lowering the total production cost by 7%), and 10 investments are made when the profit is 5% (lowering the total production cost by 17%).

Manufacturer's Profit and DoD Costs

This learning model features a decision process that represents the manufacturer's formulation of a specific investment plan. While the investment costs are used in the decision process, the amount by which the manufacturer actually carries the burden of this investment varies. The manufacturer may pay for the investment out of pocket but has a few options for passing those costs on to DoD. For example, the manufacturer can pass the investment costs directly to the DoD through value engineering change proposals (DoD, 2011; Mandelbaum & Reed, 2006) or indirectly through cost-of-money charges. Because there is no uniform treatment, the summary results on changes to the manufacturer's profit and government costs are presented both with and without the cost of making the investment.

Table 1 shows the manufacturer's additional profit due to investment in reducing unit costs for the baseline scenario that included 10% profit, a 2-year regulatory lag period, and 7% cost of money.

TABLE 1. MANUFACTURER'S ADDITIONAL PROFIT

		Without and with subtracting investment costs	
Program	**# Years**	**Without**	**With**
1	10	79%	27%
2	14	44%	0%
3	20	3%	0%

If the DoD pays for the investment, the manufacturer can increase profits by nearly 80% compared to the 10-year, endogenous-learning-only program. When the program is stretched the first time, the manufacturer's additional profit drops to about 45%. With the second stretch, additional profit increases by a few percentage points.

If the manufacturer pays for the investment, profits increase by about 25% for the 10-year program. When the program is stretched the first time, both the additional profit and incentive to invest are lost.

Table 2 shows the government's increase in procurement costs for the baseline scenario from stretching a program.

TABLE 2. CHANGES IN GOVERNMENT PROCUREMENT COSTS FROM STRETCHING A PROGRAM

Without and with investment costs							
		TOTAL PROCUREMENT		CHANGE		CHANGE (%)	
Program	# years	Price	Plus Investment	Price	Plus Investment	Price	Plus Investment
1	10	6,426	6,772				
2	14	6,816	7,114	390	342	6%	5%
3	20	7,201	7,224	774	452	12%	7%

If the DoD pays for the investments to reduce unit costs, a stretch of 40% costs the government 5% of the total procurement costs, and a stretch of 100% costs the government 7%.

Both the DoD and the contractor lose money when programs are stretched because the contractor loses incentives to invest in cost-reduction initiatives and DoD loses their share of the savings.

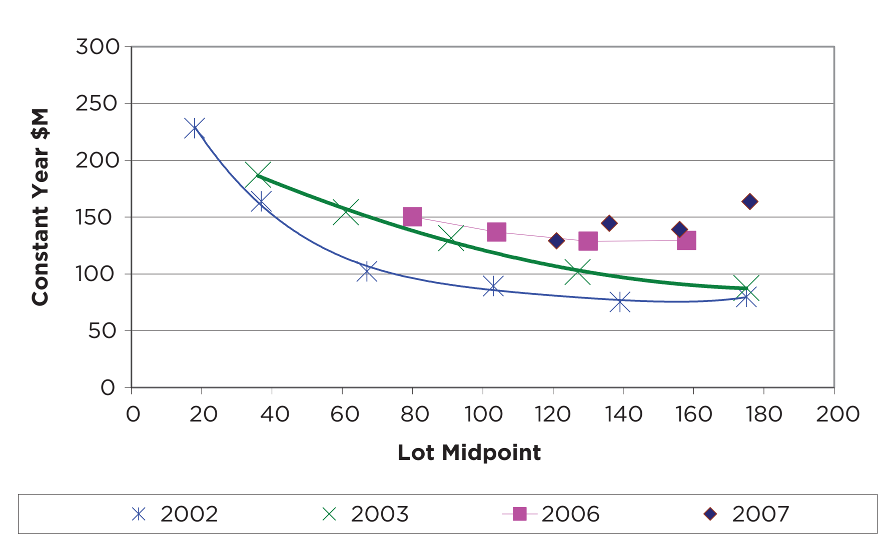
Remember that there are also increases in cost (not treated here) that are attributed to the additional fixed costs added to the program in the years into which the program was stretched.

Procurement Cost Data in Unstable Funding Environments

Actual procurement cost data that are available for the cost community to share are rare because of company proprietary rules. However, actual and projected average procurement unit costs are reported with the President's Budget and Future Years Defense Program and the Selected Acquisition Reports that are sent to the Congress annually.

Figure 4 shows the projected average unit costs as reported in 2002, 2003, 2006, and 2007 for the F-22 fighter procurement program, in constant-year dollars. The total projected quantity fluctuates between 160 and 180 units. The most obvious feature is the increasing projected average unit costs over time. Each successive learning curve is higher than the previous projections. The second most obvious feature is the flattening of the learning curves with each successive position.

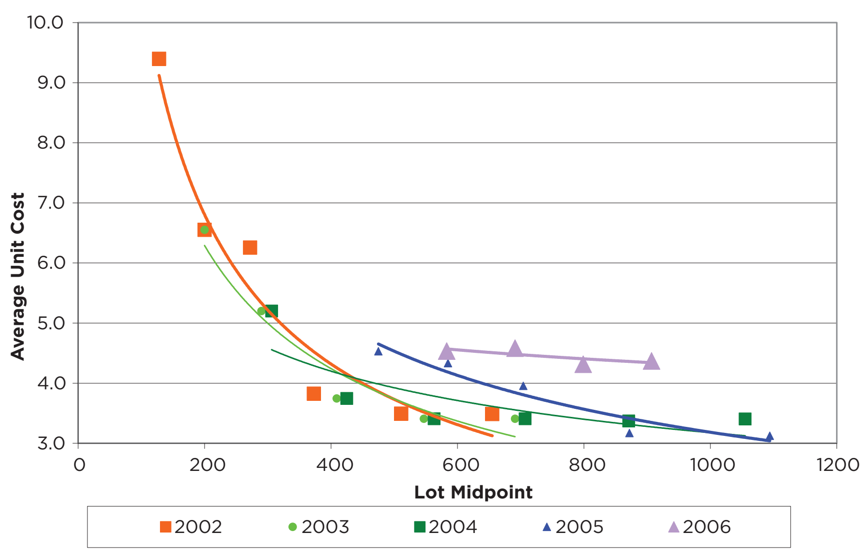
FIGURE 4. PROJECTED AVERAGE UNIT COSTS ON THE F-22 PROGRAM



A closer examination of the procurement data reveals that this program experienced several stretches in the procurement program, accompanied by decreases in the planned procurement quantity per year. Both the 2002 and 2003 President's Budget positions are 6-year programs, while the program is stretched to 7 years in 2006 and to 9 years in 2007.

The Phased Array Tracking Radar Intercept of Target (PATRIOT) Advanced Capability-3 (PAC-3) missile procurement program also experienced significant instability in planned procurement profiles. Figure 5 shows projected average unit costs by lot midpoint by the indicated President's Budget positions. While considerable scatter is shown around the trend lines associated with each position, several curves display clearly different slopes.

FIGURE 5. PROJECTED AVERAGE UNIT COSTS ON THE PAC-3 PROGRAM



If the only dynamics at work behind the projections in these two real-world examples were decreases in the quantity per year, the lot midpoint from series to series would be displaced up the curve to the left but remain on the same curve. If an additional cost per unit was being realized, the learning curve would be higher but maintain the same slope. The fact that the slope changes from one position to the next indicates another mechanism is in force, and that is the loss of economic incentives for the manufacturers to invest in cost-reduction initiatives.

Observations and Conclusions

This mathematical model was developed to provide a vehicle for quantifying the relationship between economic incentives and rate of exogenous learning on DoD procurement programs. It is not intended as a predictive tool.

Multiyear procurement contracts are one vehicle by which the DoD could control the length of the regulatory lag periods to increase the manufacturer's incentive to invest in cost-reduction initiatives. A long multiyear procurement is a contractual long regulatory lag, and the penalties for reneging on a multiyear procurement contract can be viewed as compensation for profit loss, both from the direct cost of the investments made and from the reduced future profits.

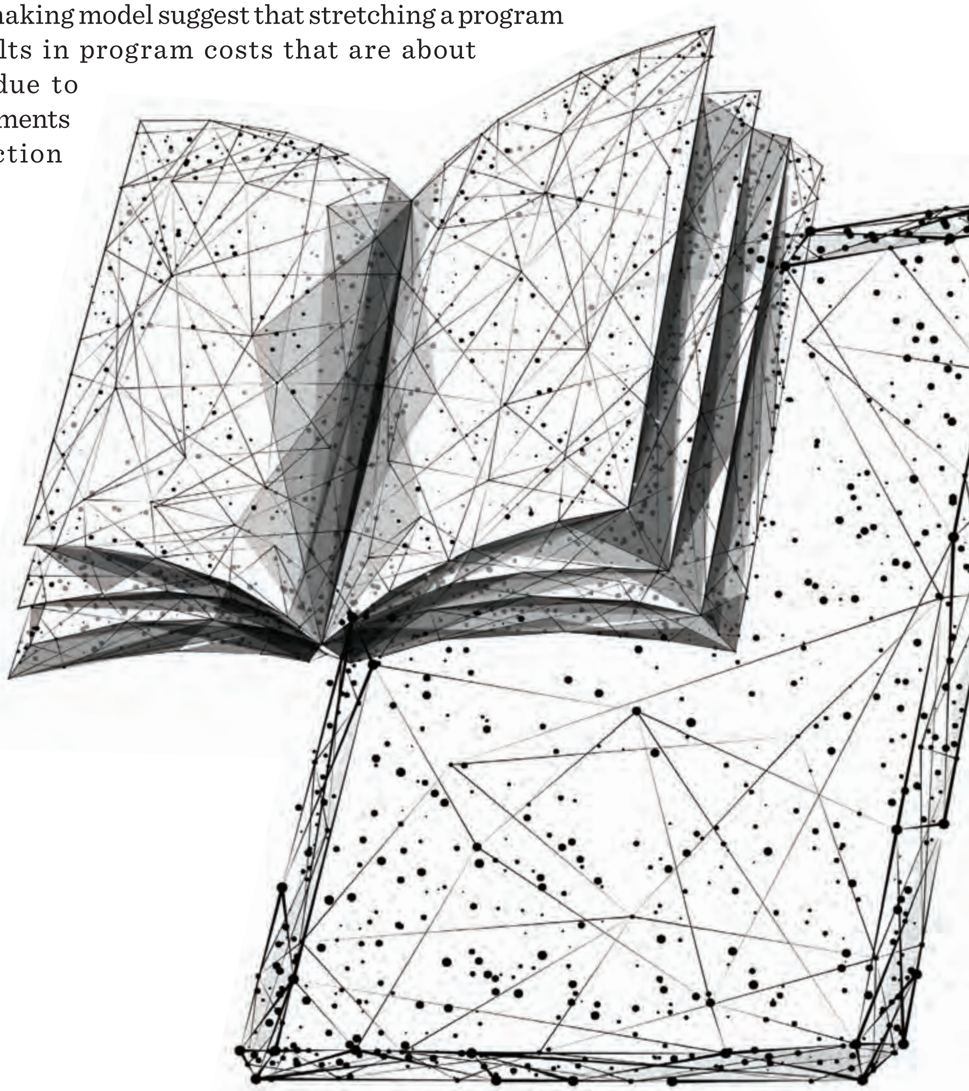
The results of the numerical experiments suggest that eliminating the regulatory lag period eliminates economic incentives for the manufacturers to invest in cost-reduction initiatives, thus increasing the cost to manufacture. The results also suggest that increasing the regulatory lag period increases the manufacturer's economic incentives by permitting the manufacturer to keep additional profit as a reward for lowering the cost. Increasing the regulatory lag period, however, has a diminishing return for the DoD because the government does not realize the cost savings until the end of the regulatory lag period. This result deserves more study to see whether there is an optimal solution that weighs government cost.

> **"It is readily accepted that stretching the planned buy profile (decreasing the quantity made per year while extending the length of the procurement program) increases the average unit cost of a procurement program because it adds a level-of-effort cost per year to the procurement program.**

According to the results of simulations with this model, profit plays an important role in the manufacturer's incentive to reduce cost. When deciding to invest, the manufacturer is weighing the additional profit gained in the regulatory lag period against the projected profit loss in the years after the regulatory lag period.

The results of these numerical experiments look very much like the actual planned and projected learning curves for the F-22 and PAC-3 procurement programs, both of which experienced major changes to the procurement buy profiles.

In summary, it is readily accepted that stretching the planned buy profile (decreasing the quantity made per year while extending the length of the procurement program) increases the average unit cost of a procurement program because it adds a level-of-effort cost per year to the procurement program. This level-of-effort cost is incurred by the program in the years into which the program is stretched. It appears the DoD is paying an additional amount to stretch a program; these costs are incurred throughout the execution of the program and can best be described as changes in the slope of the projected learning curves. The experimental results of this decision-making model suggest that stretching a program by 100% results in program costs that are about 10% greater due to reduced investments in cost-reduction initiatives.



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Author Biography

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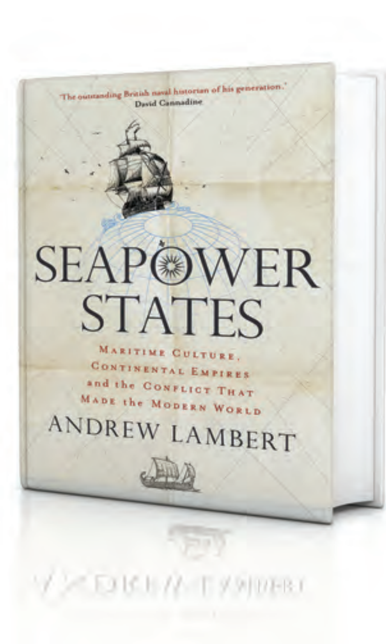
Featured Book

Seapower States: Maritime Culture, Continental Empires and the Conflict that Made the Modern World



Author: Andrew Lambert

Publisher: Yale University Press

Copyright Date: 2018

Hardcover: 424 pages

ISBN-13: 9780300230048

Reviewed by: : Dr. Mary C. Redshaw, Chair of the Defense Strategy, Acquisition and Resourcing Department at the Dwight D. Eisenhower School for National Security and Resource Strategy

I was a newly commissioned ensign in the United States Navy attending the Surface Warfare Officers School at Newport, Rhode Island, when first introduced to Mahan's *The Influence of Sea Power upon History, 1660-1783.* Young and eager to prove myself a capable naval officer, I accepted at face value one instructor's assertion that the United States is inherently a maritime nation. Years later, I believe the United States has prospered from seaborne global trade and has built the most powerful Navy in the world—both to protect its interests and project power if those interests are threatened. Lambert's book helped me understand why I no longer characterize the United States as *inherently maritime.*

Lambert differentiates between becoming a seapower and leveraging *sea power.* According to Lambert, "becoming a *seapower* was altogether more complex than acquiring a navy (p. 4)" and required a carefully constructed, maritime-focused national identity. Further:

> Seapowers were maritime imperial great powers, dependent on the control of ocean communications for cohesion, commerce, and control. Mahan's new phrase was restricted to the strategic use of the sea by any state with enough men, money, and harbours to build a navy—a list that included more continental hegemons than cultural seapowers. (p. 4)

Lambert's book examines five states that waxed and waned as *seapower great powers:* Athens, Carthage, Venice, the Dutch Republic, and Great Britain. In his view, these states "shaped the global economy and the liberal values that define the contemporary Western world" (p. 6). Leaders in these states consciously developed the political and fiscal tools necessary to build and leverage their seapower identities to achieve great power status. These leaders faced political opposition from within and security threats from outside their borders.

Lambert employs multiple lenses to examine the common features and approaches that allowed each seapower to achieve great power status and the conditions that ultimately led to its destruction, defeat, or decline. Knowledge and understanding of its predecessors' histories allowed Britain to manage its decline with skill, retaining its great power status until 1945. "In the end, economic ruin, the loss of empire, and the atomic bomb brought the British seapower state to an end, enabling the economic and industrial power of the United States to separate seapower strategy from seapower identity" (p. 327). That statement was a stark assessment coming from an author who is a Professor of Naval History at King's College and a Fellow of the Royal Historical Society—and a sobering thought for his American reader.

Although Lambert's target audience may be fellow historians, defense acquisition professionals and members of the larger national security community can benefit from reading his book. Building and sustaining a powerful navy—and other systems required to project power—requires national commitment and resources. An understanding of strategic context and political forces is as important to leaders who want to employ seapower as part of a national strategy emphasizing great power competition as it was to those who built the five great seapower states.

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Current Research Resources in DEFENSE ACQUISITION

INTELLECTUAL PROPERTY AND DATA RIGHTS IN GOVERNMENT PROCUREMENT

Each issue of the *Defense Acquisition Research Journal* will bring to the attention of the defense acquisition community a topic of current research, which has been undertaken by the DAU Knowledge Repository (KR) librarian team in collaboration with DAU's Director of Research. Both government civilian and military Defense Acquisition Workforce (DAW) readers will be able to access papers publicly and from licensed resources on the DAU KR website: https://identity.dau.edu/EmpowerIDWebIdPForms/Login/KRsite.

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Pricing Intellectual Property in Defense Competitions

James Hasik

Summary

The ownership of the intellectual property (IP) underlying the design of complex weapon systems has been at issue—between governments and their contractors—for over a century. To find the negotiating space over IP rights to complex weapon systems, the author devises a model of a defense procurement competition with one buyer and two potential sellers, in which the weapon and its IP are priced separately. The author's findings are that the room for a deal depends strongly on the difference between the government and the respective contractors' avowed discount rates. Deals may generally be possible because a government's rate is arguably much lower than that of any business.

APA Citation

Hasik, J. (2019 November). *Pricing Intellectual Property in Defense Competitions* [White paper Series No. 2.]. George Mason University Center for Government Contracting. https://pdfs.semanticscholar.org/36c2/e88decd876e0dd278efe32cdcd38b726dd31.pdf

Technical Data as a Service (TDaaS) and the Valuation of Data Options

George E. Thompson and Michael McGrath

Summary

Current DoD policy requires program managers (PMs) to consider procuring technical data and associated data rights during acquisition, and current practice is to negotiate for and acquire a complete Technical Data Package (TDP) in anticipation of future unspecified needs. However, because those needs are uncertain, it is difficult to determine a fair and reasonable price. Some data that are eventually needed may not be acquired, and some data that are acquired may never be used. To help meet these challenges, this research develops and demonstrates a new approach to the valuation of technical data, based on the application of real options theory.

APA Citation

Thompson, G.E., & McGrath, M. (2019 June). *Technical Data as a Service (TDaaS) and the Valuation of Data Options.* Naval Postgraduate School. https://calhoun.nps.edu/bitstream/handle/10945/63010/ANS-LM-19-175.pdf?sequence=1&isAllowed=y

Intellectual Property and Architecture: New Research on How to Avoid Lock-In

Maj Chris Berardi, USAF, and Bruce Cameron

Summary

Intellectual property lock-in is a wicked problem that is particularly pervasive in the Department of Defense. This work postulates that the conjuncture of architecture and intellectual property can induce lock-in. To investigate links between intellectual property, architecture, and lock-in, the authors formulated and executed an intermediate-N fuzzy-set Qualitative Comparative Analysis research approach. Within the sample, they found that an accessible intellectual property architecture is sufficient to avoid lock-in. The authors suggest that software architectures with small core groups are more conducive to lock-in.

APA Citation

Berardi, C., & Cameron, B. (2019). Intellectual property and architecture: New research on how to avoid lock-in. *Defense Acquisition Research Journal, 26*(1), 44–79. https://doi.org/10.22594/dau.18-803.26.01

2018 Report Government-Industry Advisory Panel on Technical Data Rights

The Advisory Panel on Technical Data Rights

Summary

The Panel recognizes that the DoD and industry have different business models, which at times may be in conflict. In exploring common ground, the Panel members received the testimony of many defense and industry officials, reviewed the history of relevant legislation, and identified "tension points" of disagreement between the government and industry. Following extensive deliberations, Panel members prepared white papers to address the tension points and to make recommendations for legislative, regulatory, and policy changes that recognize and seek to balance the equities of both parties.

APA Citation

Advisory Panel on Technical Data Rights. (2018, November). *2018 report–Government-industry advisory panel on technical data rights.* http://www.ndia.org/-/media/Sites/NDIA/Policy/Documents/Final%20Section%20813%20Report

Department of Defense Access to Intellectual Property for Weapon Systems Sustainment

Richard Van Atta, Royce Kneece, Michael Lippitz, and Christina Patterson

Summary

This paper reports the findings of a project requested by the Office of the Secretary of Defense (OSD), Defense Procurement and Acquisition Policy, to comply with Section 875 of the Fiscal Year 2016 National Defense Authorization Act, which called for a review of: (a) "Department of Defense (DOD) regulations, practices, and sustainment requirements related to Government access to and use of intellectual property rights of private sector firms; and (b) DOD practices related to the procurement, management, and use of intellectual property rights to facilitate competition in sustainment of weapon systems throughout their lifecycle."

APA Citation

Atta, R, Kneece, R., Lippitz, M., & Patterson, C. (2017, May). *Department of Defense access to intellectual property for weapon systems sustainment*. Institute for Defense Analyses. https://www.ida.org/-/media/feature/publications/d/de/department-of-defense-access-to-intellectual-property-for-weapon-systems-sustainment/p-8266.ashx

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- determine if the study can be replicated, and
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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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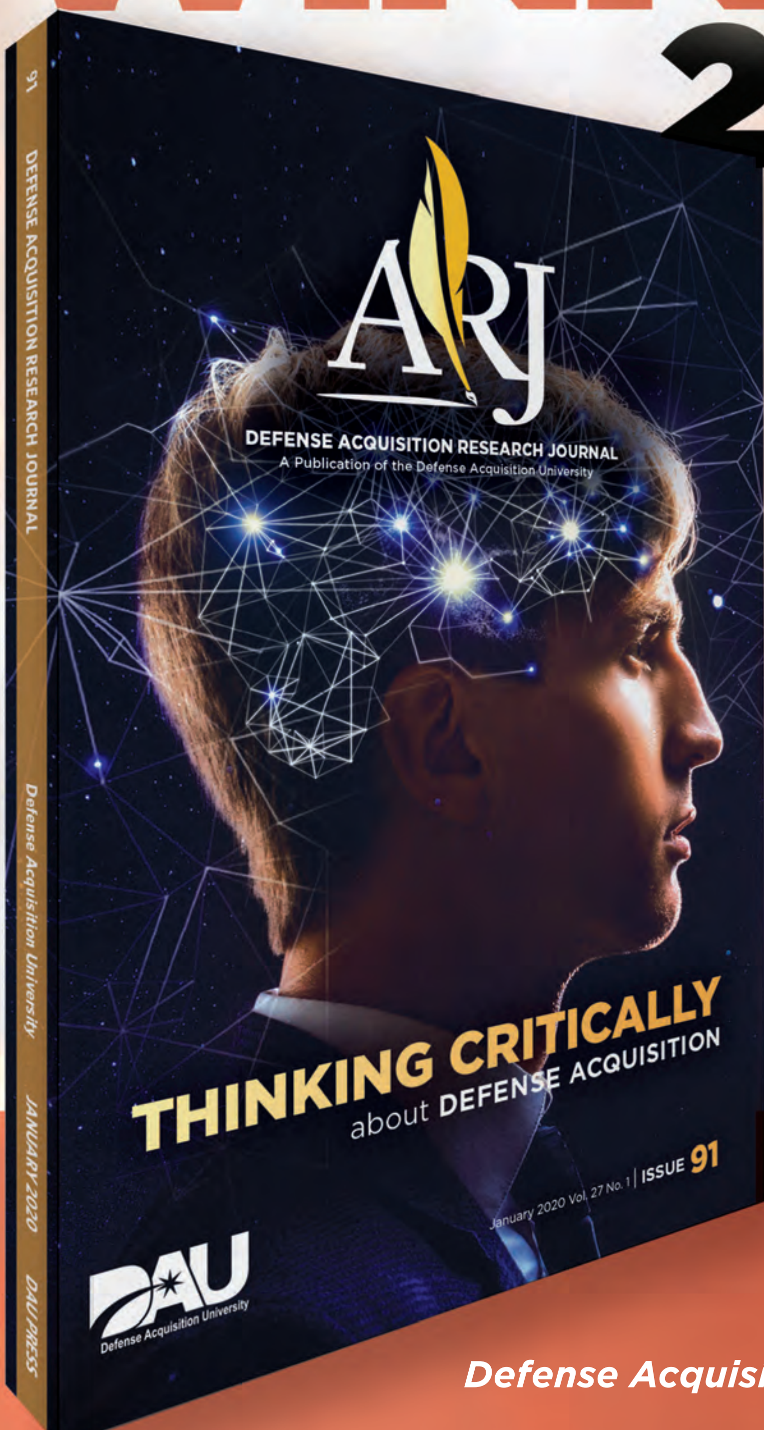

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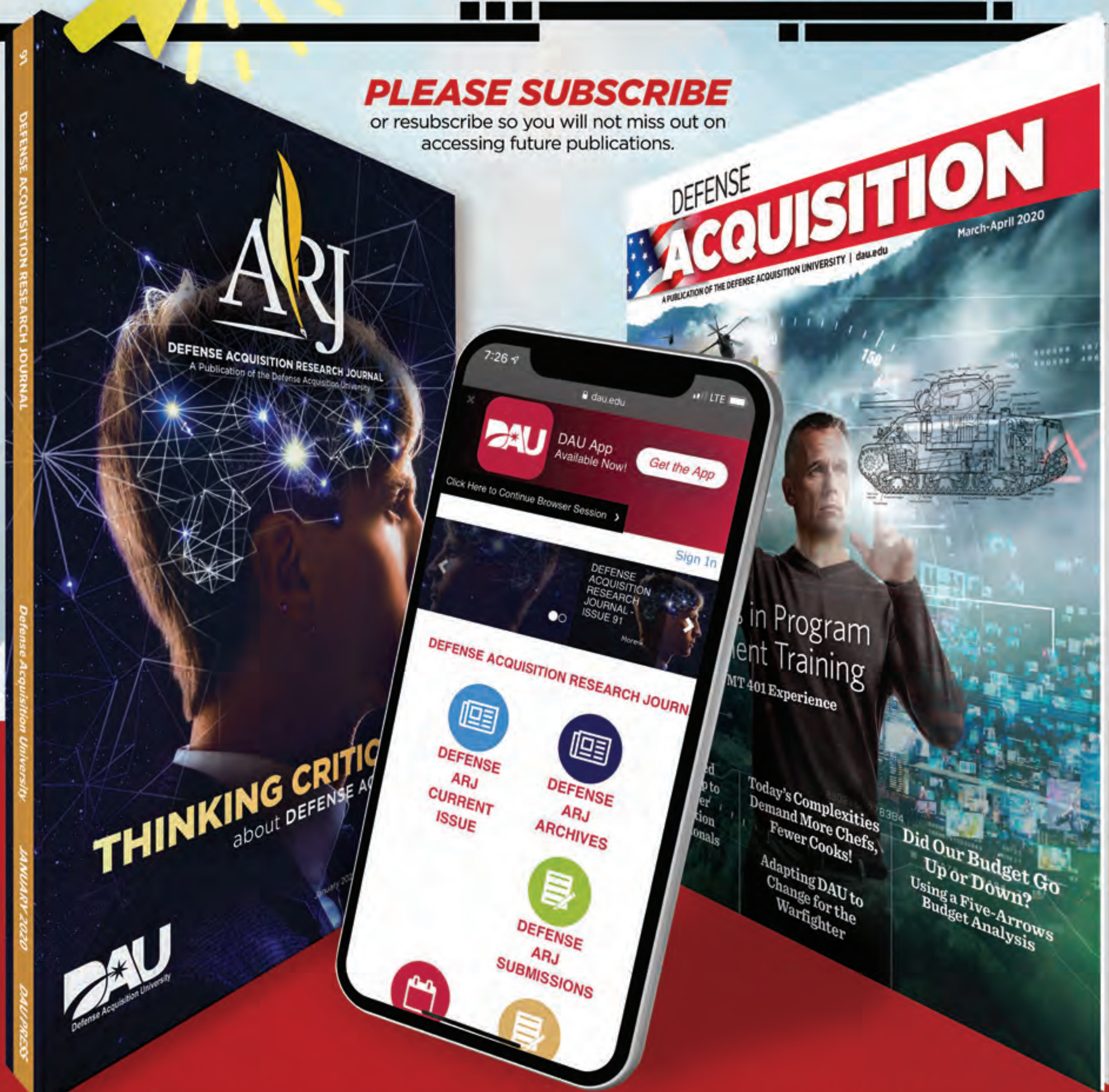

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