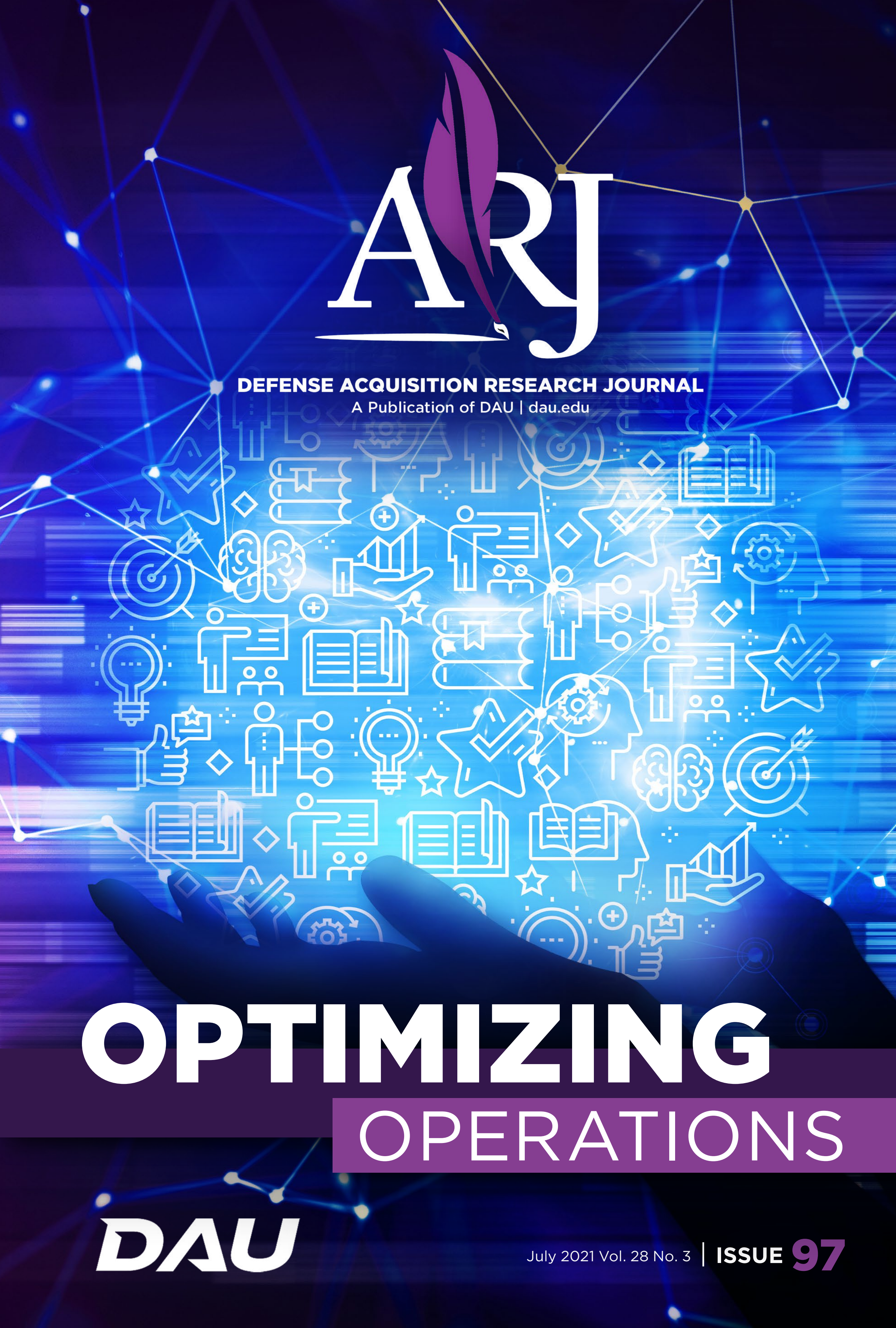

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OPTIMIZING OPERATIONS

DAU

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Distributed Operations in Response to COVID-19: Assessing Workforce Perceptions of Productivity and Success
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ARTICLE LIST

ARJ EXTRA

The Defense Acquisition Professional Reading List
Leadership Is Language: The Hidden Power Of What You Say—and What You Don't
Written by CAPT L. David Marquet, USN (Ret.)
Reviewed by Brian J. Duddy

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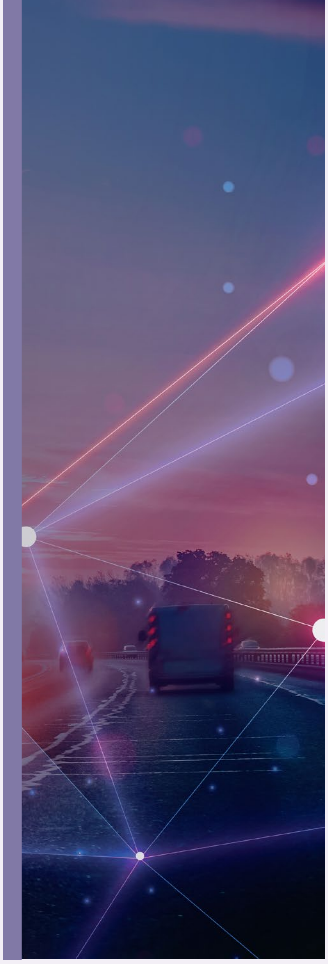
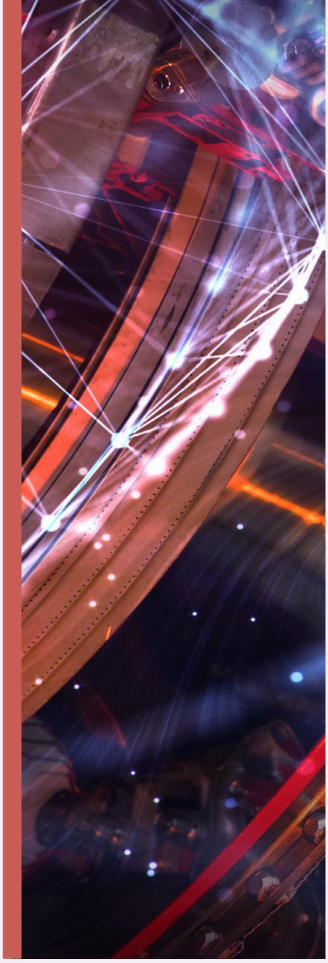
CONTENTS | Featured Research





320

Quantifying the Effects of Aircraft Engine Upgrades on Operating and Support Costs

Bradford A. Myers, Edward D. White, Jonathan D. Ritschel, and R. David Fass

In this exploratory study, the authors investigate how new engines for fixed wing Air Force aircraft empirically affect operating and support costs. Results suggest that improved fuel efficiency offsets a potential increase in maintenance costs, resulting in a net savings.

CONTENTS | Featured Research

FROM THE CHAIRMAN AND EXECUTIVE EDITOR

Dr. Larrie D. Ferreiro

The theme for this issue is "Optimizing Operations."

The first article addresses a timely subject. "Distributed Operations in Response to COVID-19: Assessing Workforce Perceptions of Productivity and Success," by Glenn Tolentino, John Wood, and Shane Riley, shows how the Department of Defense workforce transitioned to distributed, maximum telework operations because of the COVID-19 pandemic crisis. This study shows the effects of maximum telework on an organization in the areas of personnel productivity and project success.

The second article is "A Simulation-based Optimization Approach to Logistic and Supply Chain Network Design" by Michael C. Jones, Thomas A. Mazzuchi, and Shahram Sarkani. The authors evaluate how simulations can overcome problems with over-simplifications made in logistics and supply chain analysis, such as constant per-unit transportation costs regardless of the size of the shipment or the route taken. They propose a practical approach to optimizing supply chains in the face of uncertainty.

The third article, by Bradford A. Myers, Edward D. White, Jonathan D. Ritschel, and R. David Fass, is "Quantifying the Effects of Aircraft Engine Upgrades on Operating and Support Costs." The authors explore how new engines for fixed wing Air Force aircraft empirically affect operating and support costs, and conclude that better fuel efficiency more than offsets maintenance costs, resulting in a net savings.

This issue's Current Research Resources in Defense Acquisition focuses on another timely subject—Remote Work.

The featured work in the Defense Acquisition Reading List book review is *Leadership Is Language: The Hidden Power of What You Say—and What You Don't*, by CAPT L. David Marquet, USN (Ret.), reviewed by Brian J. Duddy.

Dr. Richard Altieri has left the Editorial Board. We thank him for his service.

We welcome Mr. Eric Lofgren to the Editorial Board.

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

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DAU CENTER FOR DEFENSE ACQUISITION

RESEARCH AGENDA 2021

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

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

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

Affordability and Cost Growth

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

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

Industrial Productivity and Innovation

Industry insight and oversight

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

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

Independent Research and Development

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

Competition

Measuring the effects of competition

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

Strategic competition

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

Effects of industrial base

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

Competitive contracting

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

Improve DoD outreach for technology and products from global markets

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

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

Comparative studies

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

Cybersecurity

General questions

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

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

Costs associated with cybersecurity

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

Acquisition of Services

Metrics

- What metrics are currently collected and available on services acquisition:
  - a. Within the Department of Defense?
  - b. Within the U.S. Government?
  - c. 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?
  - d. How many metrics should be used?
  - e. What is the efficacy of each metric?
  - f. What is the predictive power of each metric?
  - g. What is the interdependence (overlap) between metrics?
- How do we collect data for services acquisition metrics?
  - h. What is being done with the data currently being collected?
  - i. Are the data being collected on services acquisition reliable?
  - j. 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?
    a. What are the parameters that affect Make/Buy decisions in government services?
    b. 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 service contracts, what is the best organization? Is the System Program Office a good model? What parameters should be used in evaluating the advantages and disadvantages of an organization to manage large service contracts?
- What effect does strategic sourcing and category management have on small business if the small business is a strategic source or whether the small business is not a strategic source?
- Do the on-ramping and off-ramping requirements of some service contracts have an effect on the industrial base? If so, what are the impacts?

Industry practices

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

Make/Buy

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

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

Category management/strategic sourcing

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

Contract management/efficacy

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

Policy

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

Administrative Processes

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

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

Human Capital of Acquisition Workforce

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

Defense Business Systems

Organizational structure and culture in support of Agile software development methodologies

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

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

Defense Acquisition and Society

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

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DISTRIBUTED **OPERATIONS** in Response to COVID-19:

ASSESSING WORKFORCE PERCEPTIONS OF **PRODUCTIVITY** AND **SUCCESS**

Glenn Tolentino, John Wood, and Shane Riley

During the midst of the Coronavirus 2019 (COVID-19) pandemic, a large Navy Working Capital Funded government laboratory transitioned from a traditional on-site/physical daily operational presence to a distributed, virtual maximum telework posture. The direction given in March 2020 was that unless performance of a specific approved tasking was required at the physical workplace, the laboratory workforce was to telework from a safe location while practicing social distancing. To this extent, a majority of the organization's workforce continued performing the duties associated with their programs and projects in a virtual and secure distributed environment. This new norm certainly raised questions and considerations related to the effectiveness of the workforce while under maximum telework. As a result, two surveys were conducted to assess the perceived work-effectiveness of the organization. The perceived work-effectiveness was assessed at the operational (work unit) level, focusing on project impacts of telework, and from the macro-organizational perspective. The first survey was conducted on a project that was 2 weeks into this virtual maximum telework environment. The second survey was performed one layer above the project at the division level, thereby extending the aperture of the data. Both surveys provided a great deal of information and insight on how project teams perceived work performance and effectiveness during telework. The purpose of the study was to understand the impact of distributed telework in workforce productivity and project success as well as assess workforce perceptions on the effects of telework.

DOI: https://doi.org/10.22594/dau.21-866.28.03
Keywords: *Telework, Pandemic, COVID-19, Productivity, Distributed*

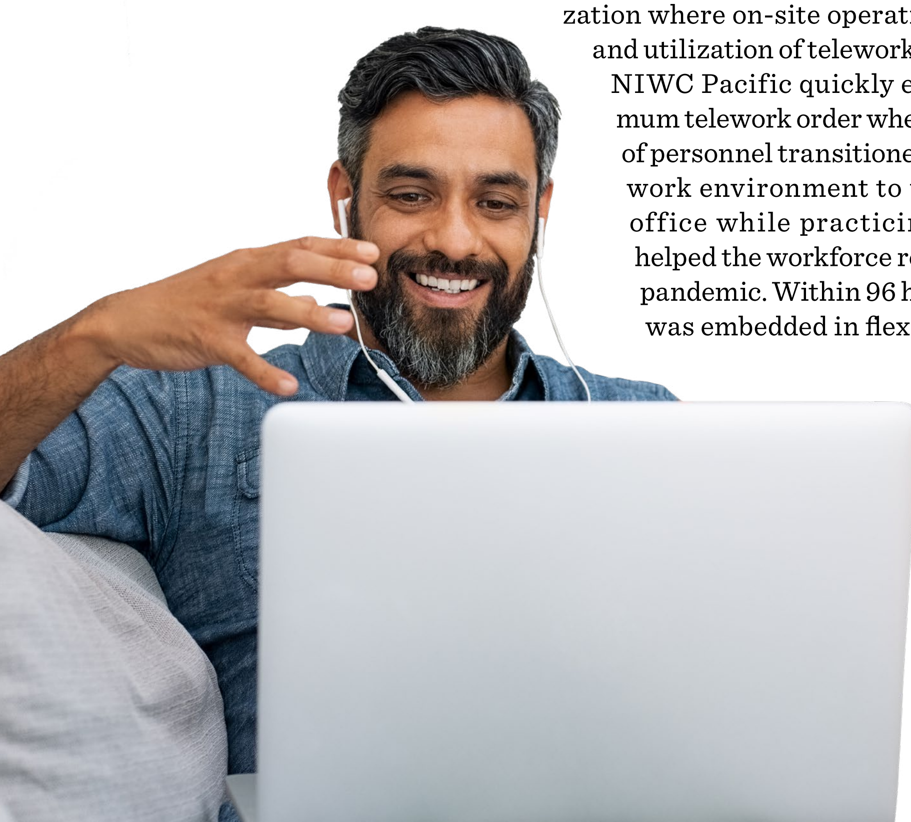
Image designed by Nicole Brate

Background

Naval Information Warfare Center (NIWC) Pacific is a critical component in the U.S. Department of the Navy (DoN) family for performing research, development, test, and evaluation. Additionally, NIWC Pacific provides deployment and sustainment of command, control, communications, computers, intelligence, surveillance, and reconnaissance systems; cyber systems; and space systems that support Warfighters around the world (NIWC Pacific, n.d.).

NIWC Pacific has a presence in California, Hawaii, Guam, and Japan. The workforce consists of about 5,000 highly educated (200+ PhD/JD, and over 1,500 MS degrees) diverse professionals in core domains focused in the areas of science and technology, engineering, acquisition, and program/project management. The NIWC workforce in San Diego, California, is complemented by one of the largest concentrations of active-duty military personnel stationed at a laboratory, which helps NIWC Pacific address operational challenges during war, peace, humanitarian, and world crisis events.

DoD agencies are often criticized (Pomerleau, 2016) as slow and inefficient in adapting to change and transforming in nontactical campaigns (e.g., policy and culture). While this may be true in some cases, this was not the case during the COVID-19 pandemic crisis. In previous years, NIWC Pacific utilized the Department of Navy telework instruction in complementing the predominant on-site work schedule (Space & Naval Warfare Systems Command, personal communication, July 22, 2015). Although an organization where on-site operations were the norm and utilization of telework was at a minimum, NIWC Pacific quickly established a maximum telework order where the vast majority of personnel transitioned from their on-site work environment to their virtual home office while practicing guidelines that helped the workforce remain safe from the pandemic. Within 96 hours, the workforce was embedded in flexible, geographically distributed, maximum telework operations from the comfort and safety of their homes.

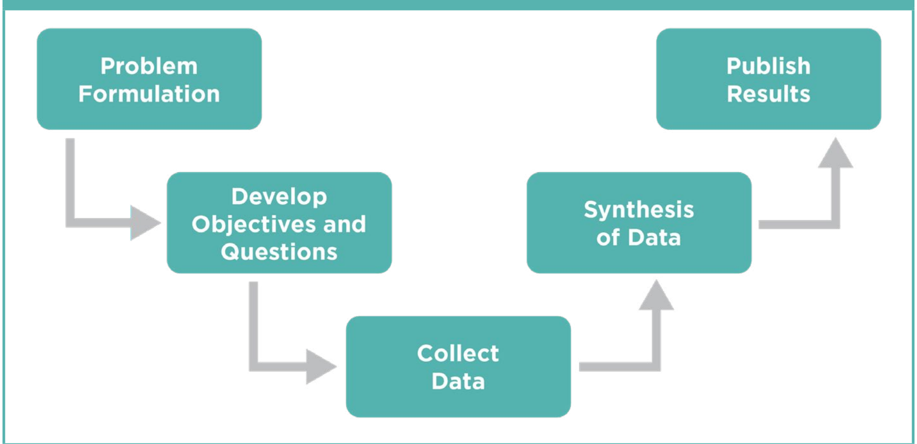


Within 1 week after the maximum telework order was issued, NIWC Pacific leadership estimated continuity of operations status was more than 90% offsite, while remaining mission-essential personnel continued working onsite. However, under maximum telework operations, many wondered whether or not NIWC Pacific would still be able to maintain its ability to support Warfighters while the workforce was adapting to, and operating in, a distributed environment. In studying how effective the current workforce was operating, NIWC Pacific leadership wanted two questions answered. First, how has maximum telework affected workforce productivity? Second, how has maximum telework affected project success?

Research Framework

In support of this study, a research framework was put in place (Figure 1) to illustrate and conceptualize the structure of the research plan. The framework provided a structure to address the basis of the problem and the approach for accomplishing the research (Maxwell, 2012). In this framework, survey questions were developed by identifying key themes and concepts central to the core research questions. A set of objectives was then defined along with the survey questions that address these themes and objectives. Data were then collected and synthesized to verify whether the framework addressed the problem statement.

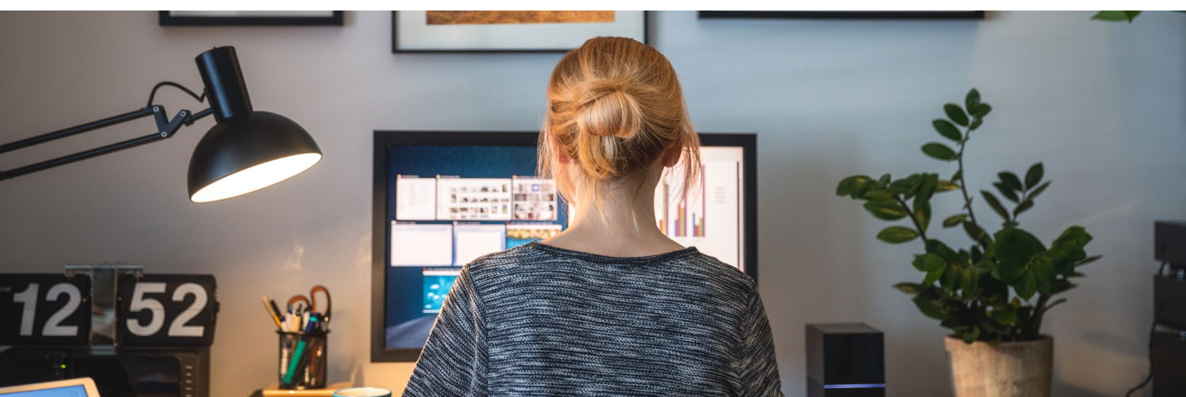
FIGURE 1. MAXIMUM TELEWORK RESEARCH FRAMEWORK



This framework was utilized during the two phases of the research study along with the underlying methodologies for collecting and analyzing the data. The first phase of the research focused on a single project, while the second phase focused on multiple projects.

Research Framework—Phase 1 (Single Project)

Two weeks into maximum telework, the sample project considered how the team was operating in their distributed (off-site) teleworking environment. The project consisted of 140+ personnel where a small percentage of the project workforce was previously (i.e., pre-pandemic) operating in a distributed manner across the continental United States. However, there remained questions regarding productivity and success of the project, as a whole, since entering the state of maximum telework. As a result, this project was selected to be the first sample for this research in identifying the effectiveness of the project workforce while under maximum telework. Specifically, how has maximum telework affected workforce productivity and how has maximum telework affected project success?



In assessing the workforce in this study, objectives were first identified to determine what constituted workforce productivity and project success. Subsequently, a set of questions was developed to address the objectives and sent to the project workforce via email, which explained the survey and gave a web link to the questions. The survey was selected for data collection because it was a fast and effective method to collect information at low cost, with good sample representatives, standardized stimulus, and precise results (Nayak & Narayan, 2019). Survey questions included multiple-choice and open-ended. The respondents had 48 hours to respond to the survey questions.

The survey results came back in two forms—scaled multiple-choice answers and free-form text data. The scaled multiple-choice answers were categorized and analyzed based on groupings by their scaled answers (McLeod, 2019). However, the free-form text data required an additional method for analysis. That method used a form of coding. In the traditional approach of coding, someone or a group of people will read through the collected free-form text data and use their judgment to identify some main categories that are common among the results of a specific question (Elliott, 2018). The researchers in this study utilized a similar approach with respect to text coding. After the data were coded, the number of occurrences of the category subject were grouped, and popular groupings were elevated for review.

These were the survey questions:

1. What is your position/role?
2. On a scale of 1 (much less) to 5 (much more), how productive are you today under maximum telework compared to a month ago when most personnel were onsite daily?
3. On a scale of 1 (much less) to 5 (much more), how successful do you feel your project is today under maximum telework compared to a month ago when most personnel were onsite daily?
4. What has been the most positive thing about maximum telework?
5. What could be done to make maximum telework more positive and/or productive?
6. What has surprised you the most about maximum telework?
7. What should the new normal look like for the project team once maximum telework ends?

The major limitation of this portion of the research is that it focused on a single project, and those results may or may not apply to other acquisition projects. However, the second portion of the research (described later in this article) mitigated this limitation by surveying multiple projects. Researchers identified a number of additional limitations as beyond their control, but such limitations did not pose any issues during this study. However, it warrants defining the limitations as they may affect future studies in the same area.

The first limitation was the number of participants, which consisted of 140 project personnel, composed of both government workers and contractors. The average survey response rate needed to garner statistically significant findings is about 33% (Lindemann, 2019). Since this study garnered responses from 54% of the workforce, the sample data were more than sufficient to analyze for validity. The second limitation of this study related to the scope of the workforce, which was deployed to only one specific project. Finally, the third limitation was the personnel makeup of the project, which consists of mostly engineers with minimum administrative or general/clerical specialists.

The survey guaranteed anonymous responses in order to instill some level of trust and psychological safety (Zayed, n.d.), thereby encouraging the workforce to provide information that was as accurate as possible in response to the questions. In addition, the survey requested no specific, personally identifiable information that could be referenced back to a specific individual.

FIGURE 2. PRODUCTIVITY UNDER MAXIMUM TELEWORK

Answer Choices	Responses	
1 - Much Less Productive	0.00%	0
2 - Somewhat Productive	2.99%	2
3 - As Productive	41.79%	28
4 - More Productive	32.84%	22
5 - Much More Productive	22.39%	15
Total		67

FIGURE 3. PROJECT SUCCESS UNDER MAXIMUM TELEWORK

Answer Choices	Responses	
1 - Much Less Successful	0.00%	0
2 - Somewhat Successful	16.42%	11
3 - As Successful	52.24%	35
4 - More Successful	22.39%	15
5 - Much More Successful	8.96%	6
Total		67

Findings—Phase 1 (Single Project)

Once the survey closed, the researchers collected the data and analyzed the results. These were the summarized results for each question:

1. The project workforce roles consisted of software developers, cloud engineers, cyber engineers, test engineers, systems engineers, product leads, information technology specialists, systems administrators, project managers, and systems architects. As expected, the project operated as a highly technical team with diverse roles supported by technical leads and project management.
2. The response to this question about productivity was encouraging (Figure 2), with 97% of the team reporting they were as productive, more productive, or much more productive under maximum telework than during the previous operating conditions where most people were in the physical office each workday. A small number of people (3%) reported they were somewhat productive, while no one reported that they felt less productive than under previous operating conditions. Overall, the workforce said that they were productive under maximum telework.
3. Regarding success, 84% of the team responded that the project was as successful, more successful, or much more successful under maximum telework as compared to previous operating conditions where most people were in the physical office each workday (Figure 3). A small number of the project workforce (16%) responded that the project was somewhat successful, while no one responded that the project was much less successful than under previous operating conditions. Overall, the project workforce said that the project was operating successfully under maximum telework.

> **The majority of responses indicated that some level of distributed telework should be included as part of the redefinition of normal operations.**

4. This question asked what the project workforce perceived as the most positive thing about telework. The consensus was that maximum telework created tangible benefits for them. The following summarized the specific results based on both professional and personal benefits.
    - Increased communication, collaboration, and teaming engagement
    - Increased focus with the ability to manage schedule and priorities
    - Eliminated wasted physical travel between home, work, and face-to-face meetings.
    - Increased sleep/rest, health, and work-life balance
    - Eliminated work distractions (water cooler chatter, drive-by office visits, parking issues)
    - Validated the ability to work with modern technology
5. When asked what they thought could be done to make maximum telework more positive and/or productive, the respondents expressed a need for better tools to collaborate in order to get their jobs done as well as opportunities to improve administrative processes.
    - Better information technology infrastructure to support project operations
        - Better communication and collaboration tools for sharing information that is reliable (e.g., Chime, WebEx, etc.)
        - Access to internal administrative websites from telework locations
        - Better access to lab resources (i.e., virtual machines and shared network)
        - Better and additional hardware and peripherals for teleworkers at teleworking site

- Better concept of operations for teleworking
- Establishing core meeting times, teleconference etiquette, and well-defined meeting agendas

6. This question asked the project workforce what surprised them the most about maximum telework. The majority of the team felt that maximum telework increased and streamlined communication among the whole organization. The respondents also felt increased productivity due to minimum in-office "distractions."
    - Perceived increase in communication between team members as well as productivity, effectiveness, efficiency, and promptitude
    - Ability to perform work using available tools
    - Impact on productivity and efficiency from diminished or nonexistent commuting time between work and meetings
    - In-office distractions, often the cause of less productivity and wasted time, reduced to a minimum
7. This question asked the project workforce what they desired to be the "new normal" once maximum telework ends. The majority of responses indicated that some level of distributed telework should be included as part of the redefinition of normal operations.
    - Open to full telework with planned face-to-face meetings on a regular basis
    - Flex spaces available to reserve for communal work, meetings, or for just getting out of the house

The project respondents reported that they were productive in performing their jobs in support of the project while operating in a distributed, maximum telework environment. While the survey reported a number of improvements, the respondents suggested the provision of better communication and collaboration tools. Overall, they responded that project success was continuing without any major problems in satisfying the workforce tasking while meeting their schedule. Also, a number of surprises emerged that affected their personal lives in the form of less stress and more productivity due to reduced commuting time, fewer in-office distractions, and a perceived, more positive balance of work and life.

The defense acquisition community is an area that is certainly concerned with satisfying the cost, schedule, and performance of projects and programs (DAU, 2010). This study showed that, given a difficult situation and the need to transition to a different environment to continue the existing support of the Warfighters, the workforce associated with this single project was able to quickly overcome the challenges and adapt to their new, modified normal.

> **"While phase one of this study targeted a single project, the researchers agreed that expanding the study to multiple projects and the diverse support and leadership roles would help confirm whether or not distributed operations in the form of maximum telework is an effective means to support the Warfighters.**

The outcome of this study helped answer some initial questions on workforce productivity and project success. More importantly, it helped focus management on insights provided by the individuals on a specific technical project in three core areas. First, it helped verify that individuals believed they were being at least as productive as they were prior to maximum telework. Second, the individuals also believed that nothing impeded the project's successful continuation during maximum telework. Also, the workforce shared their thoughts on the positive aspects, enhancements required, and surprises related to maximum telework. Lastly, the workforce provided feedback on what the "new normal" should be once the pandemic has subsided.

Since the outcome of the project survey provided useful information for action by NIWC leadership, the researchers decided to expand the maximum telework study to a specific division where multiple projects are involved in order to include diverse technical, managerial, and administrative roles.

Research Framework—Phase 2 (Multiple Projects)

Four weeks into maximum telework and after the phase one study for the project workforce survey was completed and analyzed, the researchers wanted to expand the scope of the survey to multiple projects within a division. At NIWC, a division is composed of diverse leadership and support positions, enabling the execution of multiple projects (NIWC, 2020). While phase one of this study targeted a single project, the researchers agreed that expanding the study to multiple projects and the diverse support and leadership roles would help confirm whether or not distributed operations in the form of maximum telework is an effective means to support the Warfighters. Therefore, the same research questions were posed to the division organization with multiple projects, concerning how productive the workforce is and how successful the projects are while under maximum telework.

In assessing the division workforce in this study, phase two used the same methodology employed in phase one. The data were acquired through the use of survey questions given to the division workforce via an email that explained the survey provided a web link to the questions. This survey easily and efficiently collected data across a broader scope of the division workforce. As in phase one, the questions required both multiple choice and open-ended text answers.

Once the data were collected, the multiple-choice answers were categorized and analyzed based on groupings of their scaled answers. Similarly, coding was applied to the free-form text data. This methodology matched that of phase one of the study.

These were the survey questions:

1. Select the area you support the most.
2. What is your position/role?
3. On a scale of 1 (never) to 5 (daily), how often do you interface with classified materials and/or systems?
4. On a scale of 1 (much less) to 5 (much more), how productive are you today under maximum telework compared to a month ago when most personnel were onsite daily?
5. On a scale of 1 (much less) to 5 (much more), how successful do you feel your project is today under maximum telework compared to a month ago when most personnel were onsite daily?
6. What has been the most positive thing about maximum telework?
7. What could be done to make maximum telework more positive and/or productive?
8. What has surprised you the most about maximum telework?
9. What should the new normal look like for your project team once maximum telework ends?

A number of identified limitations were beyond the control of the researchers, but they did not pose an issue during this phase. However, defining these limitations is warranted because they may affect future studies in the same area. The first limitation was the number of participants during the division survey, which was sent to 136 government employees. As mentioned in the previous phase, the average survey response rate is at about 33%. In this study, 32% of the division workforce participated in the survey. The second limitation was the scope of the participants. In this specific project study, the survey was deployed only to one specific division with many projects. The third was the personnel makeup of the division, which consisted of technical leaders, management leaders, and administrative support staff.

The questions were sent out as an anonymous survey in order to instill some level of trust with no retribution, thereby encouraging the workforce to provide accurate information in response to the survey. In addition, no specific, personally identifiable information was requested that could be referenced back to a particular individual.

FIGURE 4. HANDLING OF CLASSIFIED MATERIALS

Answer Choices	Responses	
1 - Never	48.84%	21
2 - Rarely	39.53%	17
3 - Monthly	4.65%	2
4 - Weekly	2.33%	1
5 - Daily	4.65%	2
Total		43

FIGURE 5. DIVISION PRODUCTIVITY UNDER MAXIMUM TELEWORK

Answer Choices	Responses	
1 - Much Less Productive	0.00%	0
2 - Somewhat Productive	6.98%	3
3 - As Productive	48.84%	21
4 - More Productive	27.91%	12
5 - Much More Productive	16.28%	7
Total		43

FIGURE 6. DIVISION SUCCESS UNDER MAXIMUM TELEWORK

Answer Choices	Responses	
1 - Much Less Successful	0.00%	0
2 - Somewhat Successful	6.98%	3
3 - As Successful	67.44%	29
4 - More Successful	20.93%	9
5 - Much More Successful	4.65%	2
Total		43

Findings—Phase 2 (Multiple Projects)

Once the project workforce survey closed, the researchers collected and analyzed the results. The survey was summarized in each of the sections.

1. The researchers were requested by division management to collect the various project titles associated with the results. To help further the privacy and anonymity of the survey respondents, the specific results of this portion of the survey will not be published. However, from this data we learned that team members assigned to 13 of 16 projects participated in the survey.
2. The roles were similar compared to the project survey, including software developers, cloud engineers, cyber engineers, test engineers, systems engineers, product leads, information technology specialists, systems administrators, project managers, and systems architects. In addition, administrative assistants, supervisors, scientists, software engineers, web developers, and administrative staff participated in the survey, including division, contracts, and financial management. As expected, the division survey provided a broader scope on the roles in the collected data.
3. In understanding the makeup of the division's handling of classified materials, the researchers were interested in determining whether handling of classified material has a direct correlation to telework effectiveness. The survey showed that 88% never or rarely accessed classified materials. On some regular basis, only about 12% accessed classified materials on a daily (4.7%), weekly (2.6%), and monthly (4.7%) schedule. In summary, most of the surveyed workforce did not handle classified materials on a day-to-day basis, and therefore they were able to operate in a distributed environment during maximum telework, with minimal need for individuals to visit their office for the purpose of accessing classified materials (Figure 4).

4. This question focused on team productivity while distributed away from the office in maximum telework. The survey showed that about 93% of the project workforce responded that they are productive, more productive, or much more productive under maximum telework than under the previous operating conditions, where most people were in the physical office every workday. This is slightly lower than the percentage recorded for the first phase of the study, which focused on a single project. Also, a small number of survey participants (7%) responded that they were somewhat productive, and no one indicated they were much less productive than under the previous operating conditions (Figure 5).

"In understanding the makeup of the division's handling of classified materials, the researchers were interested in determining whether handling of classified material has a direct correlation to telework effectiveness.

5. Responding to this question, 93% of the team said that the project was as successful, more successful, or much more successful when distributed under maximum telework than under the previous operating environment, where most people were in the physical office every workday. This is slightly higher than recorded for the first survey, which focused on a single project. A small number of people (7%) responded that they were somewhat successful, and no one responded that they were much less successful than under the previous operating environment. Overall, the data showed that people believed their project continued to be successful while operating as distributed under maximum telework (Figure 6).
6. This question asked the division workforce what they perceived as the most positive thing about telework. Similar to the first survey, people believed that maximum telework has created favorable benefits for them. The following summarized the results based on both professional and personal benefits.
   - Increased collaboration and productivity
   - Increased sleep, rest, health, and work-life balance

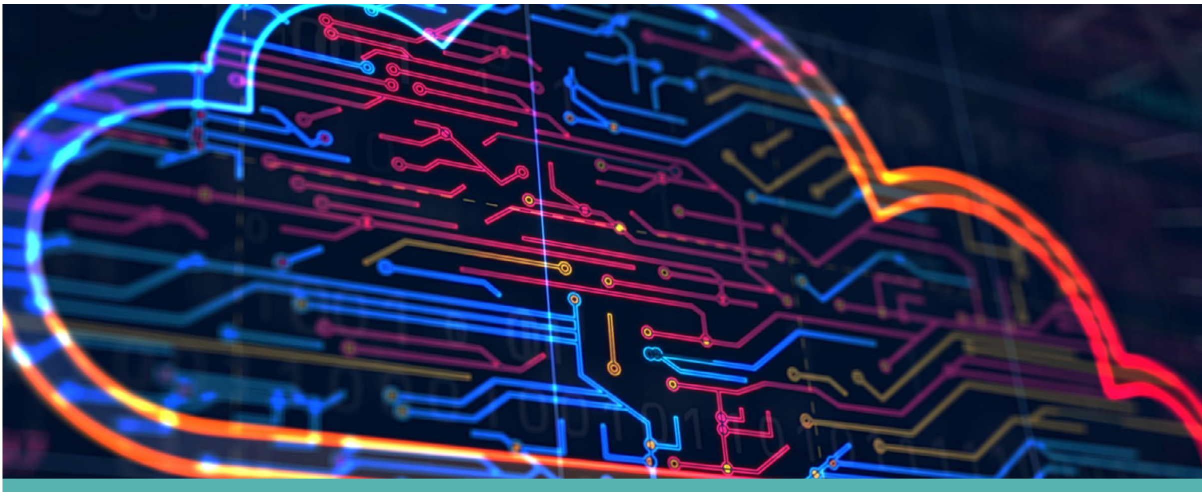
- Decreased distractions and interruptions (e.g., water cooler chatter, drive-by office visits, parking issues, etc.)
- Eliminated wasted physical travel between home, work, and face-to-face meetings

7. This question asked the division workforce what they thought could make maximum telework more positive and/or productive. The respondents requested better collaborative tools to get their jobs done as well as opportunities to improve administrative policies and processes.
   - Better information technology infrastructure to support project operations
     - Need better collaboration tools
     - Need space and equipment at home or maximum telework location
     - Better access to private networks and internal resources
   - Better concept of operations for teleworking
     - Defined teleworking policies
     - Less status updates to supervisor
8. This question asked the division workforce what surprised them the most about maximum telework. The majority of the team responded that maximum telework increased and streamlined communication among the whole organization. The respondents also felt that work-life balance increased with less stress due to less commute and no office distractions.
   - Increased communication
   - Increased life-work balance
   - Less additional stress due to no commute, no parking issues, and no distractions
   - Limited information technology and collaborative tools to support telework
   - Adaptability by personnel
9. This question asked the division workforce what they perceived to be the "new normal" once maximum telework ends. The majority of the response was in favor of instituting distributed telework as part of the new normal.

- Back to normal in an office setting
- Increased telework with office visits
- Maximum telework with minimum to no office visits
- Better communication regardless of telework

As previously stated, the defense acquisition community has been concerned with ensuring the DoD workforce is able to satisfy the cost, schedule, and performance of national security and defense projects and programs. During phase one of this study, we showed that given a difficult situation and the necessity to quickly transition to a different environment, a project workforce was able to overcome challenges quickly to support the Warfighters. In phase two of this study, a division was sampled, which revealed positive perceptions associated with the workforce and their ability to complete multiple projects on behalf of the Warfighters during maximum telework (Loubier, 2017). Both samples suggest that Warfighter support does not decline during periods of distributed operations in the form of maximum telework.

The phase two survey provided additional data and insight that reflects on the division's ability to support the Warfighters during maximum telework. The extension of the study to the division workforce complemented phase one in that, given a challenging situation and the necessity to transition to a maximum telework environment, the division workforce, which was associated with multiple projects and division leadership, was able to support the Warfighters effectively. Thus, both phases of this study will be utilized by the organization in developing and determining the plan for the "new normal" once the immediate, short-term pandemic crisis has subsided.



Suggestions for Future Research

This study can be replicated with the same survey methodology and a variety of subjects and participants. The survey allows for the flexibility and ease to deploy quickly to other organizations needing immediate answers on the impacts a new operating environment has on their workforce productivity and project success. It can also be applied to other situations in an attempt to determine whether roles, age groups, or cultures influence factors associated with perceived workforce productivity and/or project success during distributed operations.

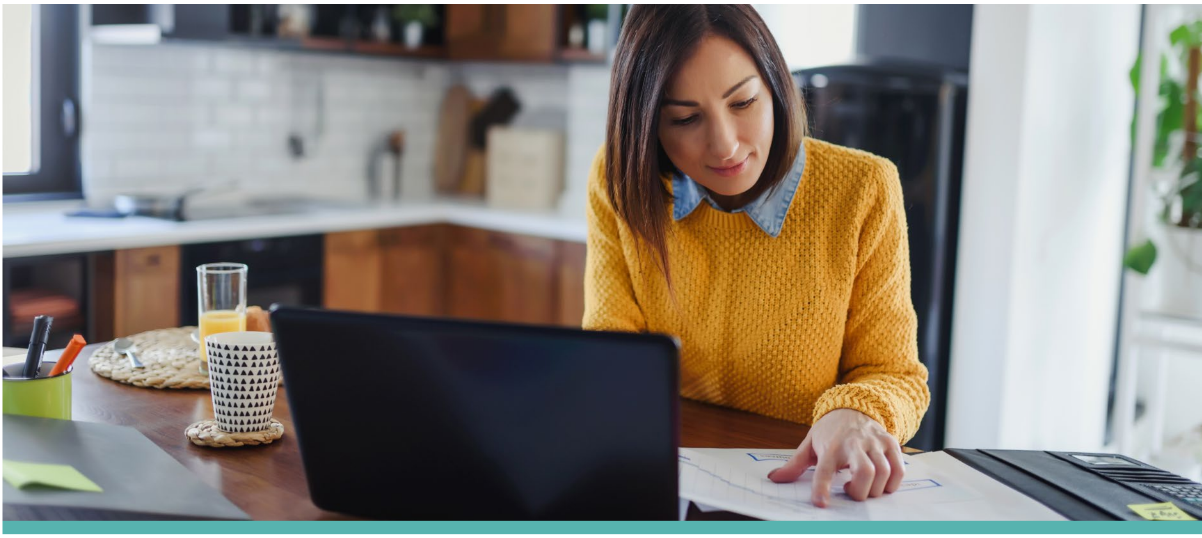
Based on this research, study of the following future research topics may help build on this body of knowledge:

- Impact of supporting a classified project or program, with the workforce performing some level of telework
- Age and gender factors in the workforce and performance in a teleworking environment
- Assessing impacts and perceptions by trade/function (i.e., management vs. technician, administrative personnel, etc.)
- Measuring productivity of teleworkers by organization management in relating to performance assessments
- Research beyond NIWC Pacific, including other systems center commands and acquisition organizations, both technical and administrative, to expand a broader study
- Decision-making process by leadership under uncertainty, risk, and stress during a pandemic

“Overwhelmingly, the project workforce responded that they were at least as productive and their projects were at least as successful during maximum telework as compared to the previous operating environment, where most personnel were in the physical office every workday.

Conclusions

In conclusion, the surveys sent to the various project teams and management staff provided insightful data for understanding the effects that operating in a distributed, maximum telework environment had on the personnel supporting the NIWC Pacific organization. It provided key information on the effects that teleworking had on workforce productivity and overall project success. Overwhelmingly, the project workforce responded that they were at least as productive and their projects were at least as successful during maximum telework as compared to the previous operating environment, where most personnel were in the physical office every workday. In fact, most responded that they were more productive and their projects were more successful under maximum telework. Also, a great deal of insight was related to distributed operations such as increased communication by the team and improved work-life balance. Revealingly, the team responded that they were less productive under the previous, nonteleworking environment due to dealing with the logistics of commuting, parking, and office distractions. Ultimately, the sampled workforce is interested in seeing some level of telework factored into the new definition of normal operating environment. They also responded that further investment in collaborative information technology infrastructure will aid in their effectiveness and overall project success (Lopez, 2020). Without a study such as this, NIWC leadership could have viewed the distributed telework environment as a degraded state that should be avoided. Now, they view telework as an enabler that should be embraced on a regular basis.



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A SIMULATION-BASED Optimization Approach to LOGISTIC AND SUPPLY CHAIN Network Design

Michael C. Jones, Thomas A. Mazzuchi, and Shahram Sarkani

The Department of Defense (DoD) operates a world-wide supply chain, which in 2017 contained nearly 5 million items collectively valued at over $90 billion. Since at least 1990, designing and operating this supply chain, and adapting it to ever-changing military requirements are highly complex and tightly coupled problems, which the highest levels of DoD recognize as weaknesses. Military supply chains face a wide range of challenges. Decisions made at the operational and tactical levels of logistics can alter the effectiveness of decisions made at the strategic level. Decisions must be made with incomplete information. As a result, practical solutions must simultaneously incorporate decisions made at all levels as well as take into account the uncertainty faced by the logistician. The design of modern military supply chains, particularly for large networks where many values are not known precisely, is recognized as too complex for many techniques found in the academic literature. Much of

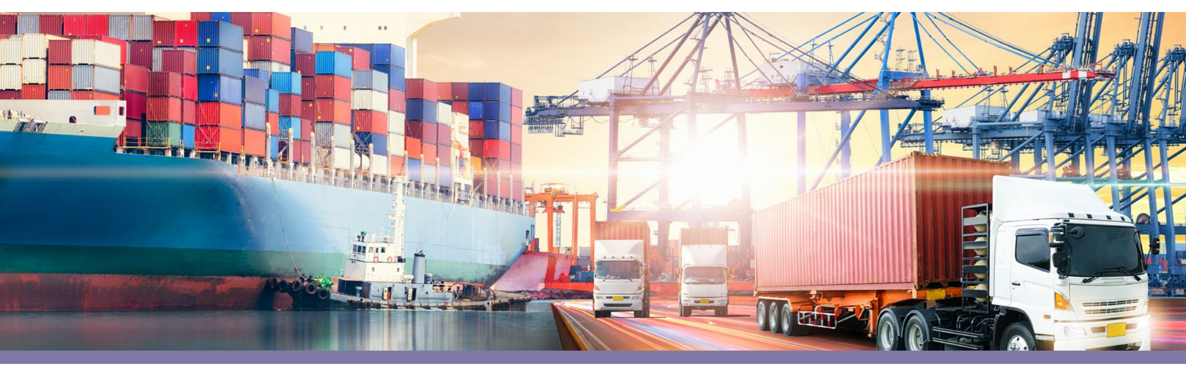
the literature in supply chain network design makes simplifying assumptions, such as constant per-unit transportation costs regardless of the size of the shipment, the shipping mode selected, the time available for the delivery, or the route taken. This article avoids these assumptions to provide an approach the practitioner can use when designing and adapting supply chain networks. This research proposes a simulation-based optimization approach to find a near-optimal solution to a large supply chain network design problem of the scale faced by a theater commander, while recognizing the complexity and uncertainty that the practicing military logistician must confront.

DOI: https://doi.org/10.22594/dau.20-860.28.03
Keywords: *DoD Supply Chains, Simulation-Based Optimization, Discrete Event Simulation, Uncertainty, Multimode Transportation*

Image designed by Nicole Brate

In 1990, as the nation struggled to determine the root cause of a major scandal resulting from a lack of oversight within the Department of Housing and Urban Development, the Comptroller General of the United States sent a letter to Congress identifying the top 14 areas across the federal government where tax dollars might be wasted through mismanagement (Bowsher, 1990). This letter grew into a standard practice, wherein the Government Accountability Office (GAO) sends a letter to each new Congress updating the status of these high-risk government operations. The Department of Defense (DoD) supply chain was on the original list, and remained on the list through 2017 (Dodaro, 2017). In the 2017 letter, the Comptroller General wrote that the DoD should, "integrate distribution metrics data, including cost data, from the combatant commands and other DoD components, as appropriate, on the performance of all legs of the distribution system, including the tactical leg."

While the GAO removed DoD supply chains from the high-risk list in 2019, the Comptroller cautioned that the DoD supply chain still required significant monitoring and improvement, and committed to continued GAO oversight of DoD supply chains (Dodaro, 2019).



Supply Chain Configuration

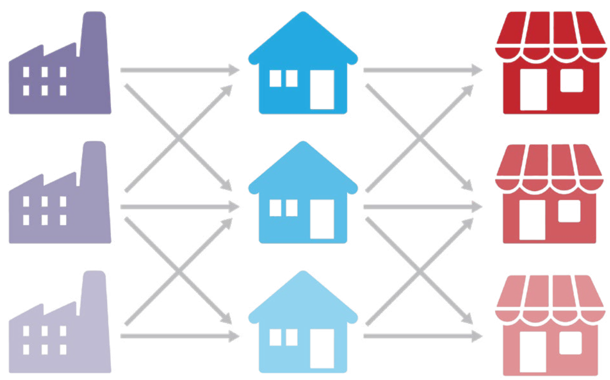
Supply Chain

The Council of Supply Chain Management Professionals (CSCMP, 2013) defines a supply chain as:

1. starting with unprocessed raw materials and ending with the final customer using the finished goods, the supply chain links many companies together.
2. the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user. All vendors, service providers, and customers are links in the supply chain.

A typical supply chain may consist of one or more production facilities producing one or more products, one or more warehouses or distribution facilities, one or more retail outlets, the logistics and transportation links that connect them, and the communications and information systems that coordinate the flow of products and materials between them.

FIGURE 1. VERY SIMPLE SUPPLY CHAIN NETWORK



Supply Chain Network

Figure 1 illustrates a representative supply chain network (SCN). This SCN consists of three echelons or layers. The first echelon consists of one or more factories on the left. Each factory produces products and ships them to one or more warehouses in the middle echelon. The warehouses store products and distribute them, when required, to one or more retail locations in the third echelon, where the products are available to consumers. Other common variations include the addition of raw material suppliers as a fourth echelon of the SCN; the return of defective or used products to the manufacturer in a closed loop supply chain; and the use of environmentally friendly materials, manufacturing technologies, and modes of transportation in green supply chains.

Transportation modes have inherent limitations, such as the maximum size or weight a vehicle may carry. A shipment slightly over this maximum would require an additional vehicle at an additional cost. The number of vehicles available for a route may be limited. Locations such as warehouses have limited storage space. In academic studies that acknowledge these limits, the transportation modes and storage locations are referred to as "capacitated." While many studies avoid this issue and study only incapacitated systems, studies involving capacitated systems are more relevant to the practitioner.

Several parameters characterize the SCN. Some of these parameters, such as the frequency of deliveries and the size of orders, are controlled by the logistician and are referred to in this article as "controlled parameters."

Others, such as the time it takes to move supplies from one location to the next or the cost of security for a convoy, are not completely within the control of the logisticians and are referred to as "uncontrolled parameters." The objective of the designer is to manipulate the controlled parameters in such a way as to maximize or minimize an objective function, such as fully burdened supply chain cost, while adhering to constraints, such as the requirement to deliver ammunition, food, and fuel to every unit regardless of their location or the speed with which orders are fulfilled. Figure 2 lists some of the parameters affecting the supply chain.

FIGURE 2. SUPPLY CHAIN NETWORK PARAMETERS

Supply Chain Management

The Council of Logistics Management (1998) defines supply chain management (SCM) as, "the systemic, strategic coordination of the traditional business functions and tactics across these business functions within a particular organization and across businesses within the supply chain for the purposes of improving the long-term performance of the individual organizations and the supply chain as a whole." Similarly, within the DoD, "Supply Chain Management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores so that merchandise is produced and distributed at the right quantities, to the right location, and at the right time, to minimize system-wide cost while satisfying service level requirements" (Assistant Secretary of Defense for Logistics and Materiel Readiness, 2003).

Supply Chain Network Design

For purposes of this article, supply chain network design (SCND) is the process of selecting the location and capacity of each facility within the supply chain as well as the transportation modes and routes connecting the facilities, including modifying existing supply chains.

SCM and SCND are recognized as critical to the survival of commercial firms, but are also critical to the success of a military operation where the costs of shipping, storing, protecting, and delivering a gallon of fuel can rise to $600 (Corley, 2009). The U.S. military includes the cost of purchasing consumable items along with the cost of shipping them to the end user who may be deployed anywhere in the world and engaged in combat operations. Such operations may require armed escorts for delivery, which is called the "fully burdened cost." One study found that 90.5% of the budget of one Navy major defense acquisition program was directly associated with logistics costs, predominantly the fully burdened cost of fuel (Corley, 2009). Forces employed in protecting these storage locations and convoys are diverted from conducting offensive military operations, adversely affecting the "tooth-to-tail ratio."

Decisions made in the context of SCM and SCND may be divided into three categories based on the duration of their implementation. The academic literature on supply chains defines the three levels as operational, tactical, and strategic (Vidal & Goetschalckx, 1997). While these terms are familiar to most military readers, it is important to recognize that the SCM and SCND literature uses them in a different order. Operational decisions are typically in effect for periods of 3 months or less and are often made at low levels in the organization. Operational decisions include route planning, selecting orders to be expedited, delivery sequence and scheduling, and allocation of cargo to specific vehicles. Tactical decisions occur at a higher level than operational decisions. Tactical decisions are often in effect for anywhere from 3 months to 3 years. Tactical decisions include establishing a selling price, selection of transportation mode (TM) for each route, and selection of inventory management policies such as safety stock and order size for each facility (Islam et al., 2019). According to authorities (Govindan et al., 2017), strategic decisions

- are long-lasting, intended to be in effect for multiple years
- include when to build or acquire new factory or warehouse capacity, how much capacity to acquire, and where it should be located
- often involve the commitment of significant financial resources and require long lead times.

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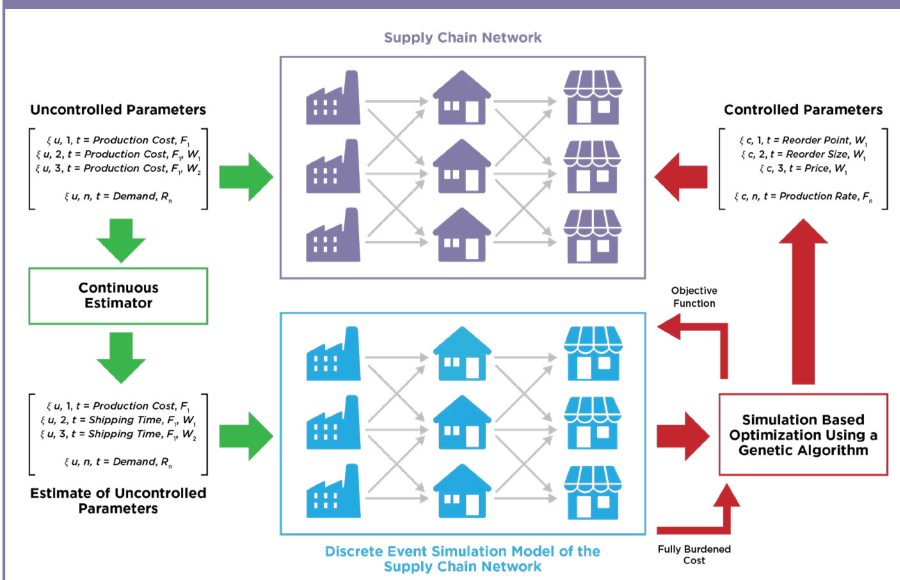
While operational, tactical, and strategic decisions are often considered separately in the literature, these decisions are tightly linked in practice (Daniel & Rajendran, 2005; Perera et al., 2017). The classic approach to making facility selection and location decisions relies on the assumption of a constant price per unit distance to transport products and focuses on minimizing the total demand-weighted distance along all flow paths in the supply chain. Because TMs include varying price structures, including minimum costs, maximum capacities, different per-mile rates, and rates based on differing metrics, the use of a single per unit of distance for transportation is not appropriate in many practical situations (Wang & Meng, 2017). The varying security requirements, and their impact on the fully burdened cost, make this assumption more impractical for the military supply chain. Introducing multiple TMs or volume discounts requires the focus to shift from minimizing total demand-weighted distance to minimizing total SCN cost or maximizing total SCN profits.

A 2002 literature survey focused on the value of integrating strategic and tactical decisions in the design of global supply chains (Goetschckx et al., 2002). The survey found that integrating the decisions when optimizing supply chains produced savings of 5–10% over first optimizing the strategic design and then optimizing the tactical decisions based on the strategic decisions. Despite this finding, most of the literature to date has followed the sequential, or 2-step, approach. The survey concluded that no adequate methodology existed for designs where strategic and tactical decisions are combined.

More recently, a seminal review examined 98 papers published between 1998 and 2008 to survey the literature on facility location problems (Melo et al., 2009). In a particularly powerful assessment, the authors state, "this research field has somehow evolved without really taking the SCM context into account… Extensions seem to have been mostly guided by solution methods." Eighty percent of the surveyed literature assumed the supply chain, including customer demand, was deterministic. Sixteen percent of the literature assumed stochastic variables, but only examined a single echelon of the supply chain. The authors concluded that integrating operational, tactical, and strategic decisions in a realistic way remained a gap in the literature.

The stochastic nature of SCNs has received considerable attention over the last 20 years. An even more recent literature survey reviewed 170 papers, published between 2000 and 2017, which addressed the topic of SCN design in the presence of uncertainty (Govindan et al., 2017). The papers found that the use of simplifying assumptions to allow the use of specific solution methods remains a concern. Quantity discounts and variable shipping rates were rarely considered. Only 10.5% of papers included TM selection. Of particular importance to the military logistician, the authors found no papers combining strategic and tactical considerations in the presence of uncertainty.

FIGURE 3. SIMULATION-BASED OPTIMIZATION APPROACH TO SUPPLY CHAIN NETWORK DESIGN



This article addresses this gap in the literature by creating a discrete event simulation (DES) of the SCN and using Simulation-Based Optimization (SBO). The DES allows multiple levels of decisions to be represented within the same model and optimized concurrently. The DES also allows the logistician to easily incorporate critical aspects of the SCN, such as the maximum capacity of vehicles. Figure 3 illustrates this approach. The SCN in blue represents the physical SCN under consideration. The red SCN is a DES representation of the blue SCN. To the extent possible, the DES should reflect the actual system as accurately as feasible, including the statistical distribution of any stochastic variables such as demand. The continuous estimator monitors the existing SCN and estimates the value of each uncontrolled parameter to update the DES as conditions change. The designer may adjust these values to reflect planned operations. For example, the designer could increase demand in certain areas where offensive operations are planned. Finally, the SBO engine modifies the controlled parameters in the DES to optimize, or nearly optimize, the objective function while satisfying each of the constraints. Once a near-optimal solution is identified, the controlled parameters from the SBO engine can be applied to the physical SCN and the process repeated.

The optimization function may be a simple calculation of the total cost of operating the supply chain or a more complex function, which includes incentives for speed of delivery, penalties for out-of-stock situations, or metrics related to combat readiness of the supported forces.

Research Questions

This research attempts to answers two primary research questions:

1. Can an SBO engine composed of a genetic algorithm (GA) converge to a solution for a large SCN of the scale used to support a theater commander, incorporating operational, tactical, and strategic decisions simultaneously while only making assumptions that are representative of the military logistician? Specific assumptions to be avoided include:
    a. The effectiveness of decisions made at one level are independent of decisions made at other levels within the chain of command.

   b. Transportation costs and transportation time are independent of shipment size, mode of transportation, required delivery time, or route selected.
   c. Warehouses, depots, and vehicles used for transporting materiel have unlimited capacity and availability.
   d. Demand, transportation price, and transportation time are fixed and deterministic.
2. Does the use of the SBO approach to optimize operational, tactical, and strategic decisions simultaneously result in a superior result to optimizing the decisions sequentially?

This SBO approach is shown to converge for large SCNs. This article quantifies the impact of making decisions at all three levels simultaneously by demonstrating a 3.5% cost saving over making the decisions sequentially.

Literature Review

Although other factors could be included by modifying the DES, this research already incorporates integrating decisions at multiple levels in the supply chain, deciding among capacitated transportation modes with different pricing structures and capacitated facilities, and the uncertainty that dominates modern military operations. The literature review will examine the state of research for each of these factors individually before reviewing the literature on the use of SBO and GAs in SCND.

SCND Integrating Multiple Decision Levels

The integration of decisions at multiple levels is known to provide a significant saving over considering these decisions sequentially (Goetschalckx et al., 2002; Govindan et al., 2017; Vidal & Goetschalckx, 1997). The problem studied in this article is a generalization of the location-inventory problem (Daskin et al., 2002; Shen et al., 2003). These problems are in a class of problems called NP-hard (Saha et al., 2020). Although unproven, it is widely believed that NP-hard problems cannot be solved in polynomial time, meaning the time required to solve them becomes prohibitive for any large scale. As a result, many approaches reduce the size of the network or limit the scope to a single decision level or a single echelon of the supply chain. A recent review of research on integrated production and distribution planning examined 72 papers published between 2010 and 2019 and found no papers integrating decisions made at all three levels (Kumar et al., 2020).

Ahmadi-Javid and Hoseinpour (2015) studied profit maximizing location-inventory problems, simultaneously making the strategic decisions of facility selection and allocation, and the tactical decisions of price and inventory policy. They formulate the SCND problem as a mixed-integer nonlinear programming model and propose a novel Lagrangian relaxation algorithm to solve the model. The algorithm converges to near-optimal solutions for uncapacitated networks but not for the capacitated networks used by practitioners.

Similarly, several approaches integrate decisions at multiple levels, but only on small scales or with uncapacitated networks. Saha et al. (2020) examined a joint location and inventory model quantifying the impact of the customers' preferences and backorders. Akbari and Karimi (2015) apply

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robust optimization to solve a mixed-integer programming (MIP) model of a multi-echelon, multi-product, multi-period SCN with uncertainty in the time required to manufacture products. Sun et al. (2019) propose a fuzzy, mixed-integer, nonlinear programming model to decide between two modes of transportation in an SCN under demand uncertainty.

SCND with Transportation Mode Decisions

Transportation mode selection has been shown to be an essential part of SCND. Because different modes have different cost structures, the use of a constant value for the cost per unit of product for transportation between two facilities is only valid for a limited range of potential solutions (Bureau of Infrastructure, Transportation and Regional Economics [BITRE], 2017). This assumption also ignores the military reality requiring additional security for some routes but not others.

Mendoza and Ventura (2014) studied the integration of TM selection and inventory policy in a single stage in the SCN. They considered two modes over a fixed distance for each route. One mode was a dedicated truck with a constant cost per trip, independent of the size of the shipment. The second mode was a shared truck such as an express delivery service, with a constant cost per unit of product shipped. Both modes included the cost of holding inventory as well as ordering costs and all-unit discounts, and minimized the total cost of the supply chain. The study found that this problem is NP-hard. A proposed algorithm, which took advantage of a special structure of the mixed-integer linear programming (MILP) model, solved the problem by using decomposition, and an exact solution was found for each subproblem. While the technique works for this special structure, it does not converge in the general case.

Sadjady and Davoudpour (2012) studied a two-echelon SCN including the selection from multiple TMs with different unit cost to transport product between facilities based on the mode of transportation and the distance. They showed the approach worked well for large networks with uncapacitated TMs, resulting in near-optimal solutions in reasonable execution times. The authors state that this approach would require major modification to incorporate the capacitated transportation modes found in practice.

Kheirabadi et al. (2019) studied a two-echelon supply chain incorporating quantity discounts and TM selection. However, the assumptions of deterministic demand required by this technique limit applicability by the military logistician.

SCND with Uncertainty

While much of the research assumes deterministic quantities, practitioners face decisions in a military environment where demand for their products, the lead time to fill orders, transportation costs, required time to acquire new facilities, the cost of holding inventory, and many other param-

eters are uncertain. For an SCND technique to be applied with confidence in this environment, the technique must capture the uncertainty and quantify the impact of the uncertainty on the performance of the objective function (Govindan et al., 2017).

Govindan and Fattahi (2017) studied a three-level supply chain under demand uncertainty. Stochastic demand was studied using weighted scenarios. The authors formulated the supply chain as a deterministic MILP model and used a two-stage stochastic programming approach to strategic and then tactical decisions. Strategic decisions include facility location and capacity in the first stage. Tactical decisions involving inventory were considered independently in the second stage. The approach was unable to obtain solutions for large networks in feasible times. The authors showed this can be mitigated in part through the use of scenarios to further decompose the problem. The scenario-based, stochastic programming approach was expanded by including an efficient tree structure to improve the generation and weighting of scenarios (Fattahi et al., 2018). However, the special structure required by this approach required simplifying assumptions such as a single TM.

SCND with SBO and GA

SBO has rarely been applied to SCND. A search on Scopus®, a database of peer-reviewed journals at www.scopus.com, was conducted using the

keywords (["supply chain management" OR "supply chain network design"] AND ["simulation-based optimization"]) in the title, abstract, or keyword list. The search found only 36 published articles, 18 of which included uncertainty or related terms in the title, abstract, or keyword list.

Jung et al. (2004) use a discrete event simulation within a gradient following optimization engine to determine optimal safety stock in a production facility with demand uncertainty. Schwartz et al. (2006) propose an SBO approach using a discrete event simulation involving simultaneous

perturbation stochastic approximation to determine the optimal inventory policy in an SCN in the electronics manufacturing industry. Nikolopoulou and Ierapetritou (2012) combine MILP with an agent-based simulation to overcome some of the complexity inherent in practical SCNs; however, their approach did not include stochastic variables.

GAs have frequently been applied to SCND, with a significant number of papers addressing uncertainty. A search on Scopus® was conducted using the keywords ([“supply chain management” OR “supply chain network design”] AND [“genetic algorithm”]) in the title, abstract, or keyword list. The search found 499 published articles, 174 of which included uncertainty or related terms in the title, abstract, or keyword list. Govindan (2016) published the results of a literature search on the application of evolutionary algorithms applied to SCM and predicted growing interest in their application to advanced problems in SCM such as the one addressed in this article.

Nezamoddini et al. (2020) used a GA and an artificial neural network to manage risk by making strategic and tactical decisions for an SCN in the presence of uncertainty in disruption and demand. Sajedinejad and Chaharsooghi (2018) apply a GA to the problem of supplier selection in an SCN through multi-objective optimization. Afrouzy et al. (2016) applied a priority-based GA to maximize profit during the introduction of a new product into an existing SCN, balancing production capacity and inventory between new and existing products. Table 1 summarizes the literature and places this research in context.

TABLE 1. REVIEW OF SUPPLY CHAIN NETWORK LITERATURE

Author	Echelons		Decision Levels			Transportation Modes				Stochastic Variables
	Modeled	Decisions	Operational	Tactical	Strategic	Mode Selection?	# Modes	Min Cost	Capacitated	
Ahmadi-Javid & Hoseinpour (2015)	2	1	-	Pr, I	Fs, A	N	-	-	-	-
Saha et al. (2020)	2	1	-	Pr, I	Fs, A	N	-	-	-	-
Mendoza & Ventura (2014)	1	1	-	Tm, I	-	Y	2	Y	Y	-
Sadjady & Davoudpour (2012)	2	2	-	Tm	Fs, C, A	Y	5	N	N	-
Kheirabadi et al. (2019)	2	1	-	Tm, I	Fs, A	Y	2	Y	Y	-
Govindan & Fattahi (2017)	4	2	-	I	Fs, C, A	N	-	-	-	D
Fattahi et al. (2018)	3	2	-	Pr, Ts, I, Pq	Cef, C	N	-	-	-	D
Sun et al. (2019)	2	1	-	Tm	-	Y	2	N	Y	D
Akbari & Karimi (2015)	3	3	-	Ts, I, Pq	Fs, C, A	N	-	-	-	Pt
Nezamoddini et al. (2020)	3	2	-	I	Fs, C, A	N	-	-	-	D, Ti, Pt
Yu & Solvang (2018)	4	4	-	-	Fs, C	N	-	-	-	D, Pc
Sajedinejad & Chaharsooghi (2018)	2	1	-	-	Fs	N	-	-	-	D, Ti
Hajiabolhasani et al. (2018)	3	2	-	I	-	N	-	-	-	D, C
Afrouzy et al. (2016)	4	3	O	I, Pq	-	N	-	-	-	D
Salemi (2016)	2	1	-	-	Fs, A	N	-	-	-	D
Che et al. (2014)	3	2	-	-	Fs, A	N	-	-	-	D
Lieckens & Vandaele (2011)	3	2	-	-	Fs, A	N	-	-	-	D, Ti, Pt
Han & Damrongwongsiri (2005)	2	2	-	I	A	N	-	-	-	D
Syarif & Gen (2003)	3	2	-	Pq, Ts	Fs	N	-	-	-	D
Jung et al. (2004)	3	1	-	I	-	N	-	-	-	D
Schwartz et al. (2006)	3	3	-	I	-	N	-	-	-	Su, D
Nikolopoulou & Ierapetritou (2012)	3	2	O	I, Pq	-	N	-	-	-	-
Our Research	3	3	O	Tm, I	Fs, A	Y	4	Y	Y	D, Ti

Note.
Operational Decisions
O: Place an order. **R:** Routing. **V:** Vehicle selection and loading
Tactical Decisions
Tm: Transportation mode. **Ts:** Transportation. **I:** Inventory (EOQ, ROP, SS). **Pc:** Production cost. **Pq:** Production quantity. **Pr:** Price
Strategic Decisions
Fs: Facility selection. **Cef:** Close existing facility. **C:** Capacity. **A:** Allocation
Stochastic Variables
Su: Supply. **D:** Demand. **C:** Capacity. **Ti:** Travel time. **Pt:** Production time.

Problem Definition and Modeling

This research on the SBO approach to SCND in the presence of uncertainty was conducted using an illustrative supply chain in Australia responding to a significant change in the cost of transporting goods over maritime routes. Australia was selected as a surrogate area of responsibility (AOR) due to its size being appropriate for a theater-size AOR with a diverse set of transportation modes and readily available information on the distance between locations by each mode as well as current cost information. In this example, supplies arrive in Australia via military or contracted commercial ships at one of a limited number of secure ports and are then transported to warehouses or depots before being delivered to the final units dispersed across the continent.

Problem Introduction

To develop a broad set of scenarios for this research, a major change in the fully burdened cost of maritime shipping was hypothesized, representing various levels of threats to shipping that required escort by warships. A high threat level was defined as a value of 100% and a high cost per mile of ship travel was established. Lower cost threat levels were established at 5% increments down to 70% of the maximum maritime transport cost to create seven unique scenarios. We limited the number of potential ports to three and the number of warehouses to five based on the high cost of defending such facilities. The design and optimization of this SCN for each of these scenarios was the focus of this research.

FIGURE 4. BASE LINE SUPPLY CHAIN NETWORK DESIGN

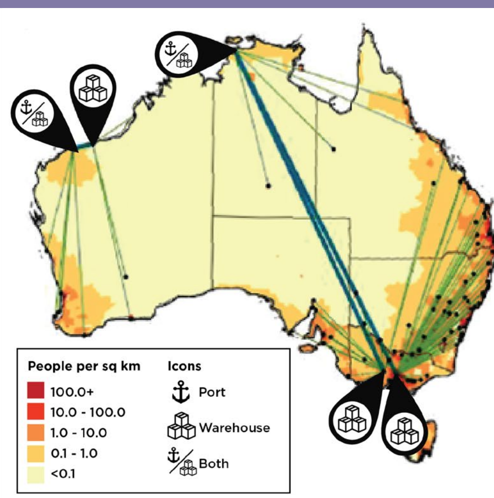


Figure 4 illustrates a base line SCN. The heat map of Australia, provided by the Australian Bureau of Statistics (ABS, 2016), shows the population density of Australia in 2016. The base line design used in this research consisted of only two ports and five warehouses. One port was at Darwin and the other at East Intercourse Island. Icons indicate the ports and warehouses. Thick blue lines represent shipments from ports to warehouses, and thin green lines represent shipments from warehouses to retail locations.

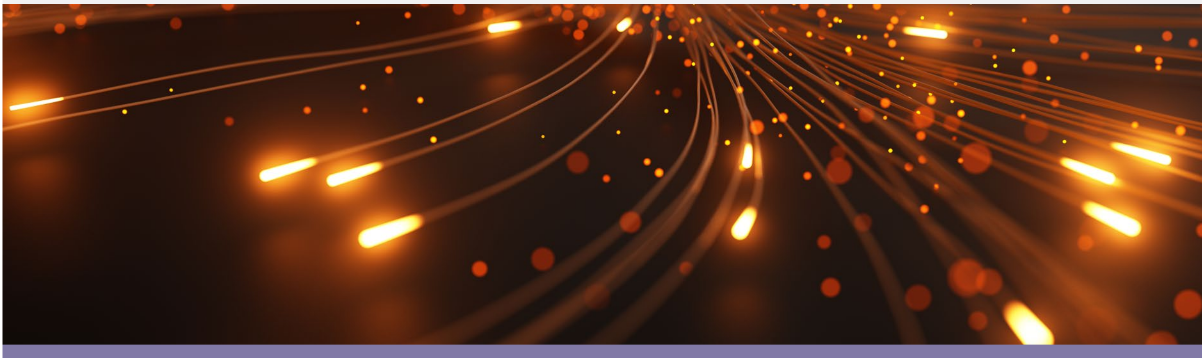
A recent study by Lee et al. (2017) found that the most efficient way of transporting products from Asia to Australia was via two routes. The first is between Singapore and the Australian port at East Intercourse Island, on the Northwest corner of Australia. The second is between Ningbo, a Chinese port on the East China Sea, and the Australian port of Townsville in the Northeast. While both of these routes deliver cargo to the Northern coast of Australia, the majority of the population is concentrated along the Southeast coast. Both of these routes require overland transport of the majority of the product to the Southeast coast. This study assumed the shipments originated at either Singapore or Ningbo. Lee et al. predicted that a reduction in maritime transportation costs relative to the cost of land transport, in particular rail transport, would shift the optimal maritime hubs south to ports such as Sydney, Canberra, or Melbourne.

> **“For a given set of selected facilities, tactical decisions included selecting a transportation mode for each ground segment and establishing inventory policies such as safety stock (SS), order quantity (OQ), and reorder point (ROP).**

SCN Description

The SCN under study consisted of three echelons. The first echelon was the port echelon, which replaced the factory echelon from the typical SCN in Figure 1. The 15 largest ports in Australia were selected as candidate ports for products arriving from the ports of either Singapore or Ningbo. The SCN was constrained to select no more than three of these ports. The second echelon was the warehouse, depot, or distribution center. The Australian Bureau of Statistics (2016) defines 96 Greater Capital City Statistical Areas (GCCSAs) in Australia. Each GCCSA was considered as a potential host for a warehouse in this SCN. Based on the budget available for defending these facilities, up to five warehouses could be selected from the 96 potential sites.

The third echelon was the location of a military unit, similar to a retail location in Figure 1. Each GCCSA was represented as a single unit or retail location in the SCN. Each unit experienced stochastic demand with a mean proportional to the surrounding population.



Supplies arrived in Australia by ship at one of the hubs in standard 40-ft ISO shipping containers. The containers were transported to one of the warehouses by rail or truck load (TL) shipment. The products could be shipped from a warehouse to a retail location as a full container, or as a smaller shipment if less than a full container was required. Transportation from a warehouse to a retail location was by rail, TL, or less than truck load (LTL) freight. The mode chosen for each shipment was the least expensive considering all applicable costs, minimizing the combined shipping cost, holding cost, and ordering cost. The rates for rail and TL shipping were based on freight rates provided by BITRE (2017). The ratio between the cost of TL and LTL was used to determine the LTL rate and was varied over a range found in the literature (Kay & Warsing, 2009; Mendoza & Ventura, 2014; Özkaya et al., 2010). A cost multiplier was provided at each leg to account for required security reflected in the fully burdened cost. The time for each transportation segment was stochastic with a mean dependent on the mode selected and proportional to the distance traveled.

Strategic decisions included selecting up to three hubs from the 15 potential ports, selecting up to five depot locations from the 96 GCCSAs, assigning each depot to a servicing port, and assigning each unit to a servicing depot.

For a given set of selected facilities, tactical decisions included selecting a transportation mode for each ground segment and establishing inventory policies such as safety stock (SS), order quantity (OQ), and reorder point (ROP). The common equation for determining OQ, first proposed by Harris (1990), assumes a constant shipping price for each order. The introduction of the transportation mode decision includes a minimum cost per shipment by each mode as well as different cost per mile, resulting in a nonconvex cost function (Mendoza & Ventura, 2014; Perera et al., 2017; Tersine & Barman, 1991). Chan et al. (2002) studied this problem and proved it to be NP-hard.

Operational decisions were made for each warehouse and unit each day. The operational decisions included servicing demand and replenishing inventory. Servicing demand entails shipping the amount of product demanded up to the amount on hand. Replenishing, which is done at the end of the day, consists of comparing inventory on hand plus inventory on order to the determined ROP, and placing an order if warranted. If the inventory on hand plus inventory on backorder was below the ROP, the facility placed an order for the OQ using the TM determined at the tactical level.

The SCN attempted to meet all demand. However, out-of-stock situations were possible. A penalty was assessed for any orders that could not be filled. Orders placed at the unit level were not placed on backorder. If warehouses did not have enough inventory on hand to fulfill an order, the order was held on backorder until sufficient stock arrived.

Decisions

Quantifying the impact of considering strategic, tactical, and operational levels of decision simultaneously is a key research objective of this study. At the strategic level, the authors include facility selection and allocation. At the tactical level, the authors include two tightly coupled sets of decisions: transportation mode selection and inventory policies. Transportation model selection for each facility considers four modes of transportation, each with different capacities and cost structures. Inventory policy decisions include order quantity and reorder point for each facility. At the operational level, the authors include ordering based on realized demand, inventory on hand, and inventory on order.

The decisions at the strategic level include selecting a set of up to three port facilities to serve as maritime shipping hubs and a set of up to five GCCSAs to host depots, as well as selecting which port will supply each depot and which depot will serve each retail location. Location selections are indicated

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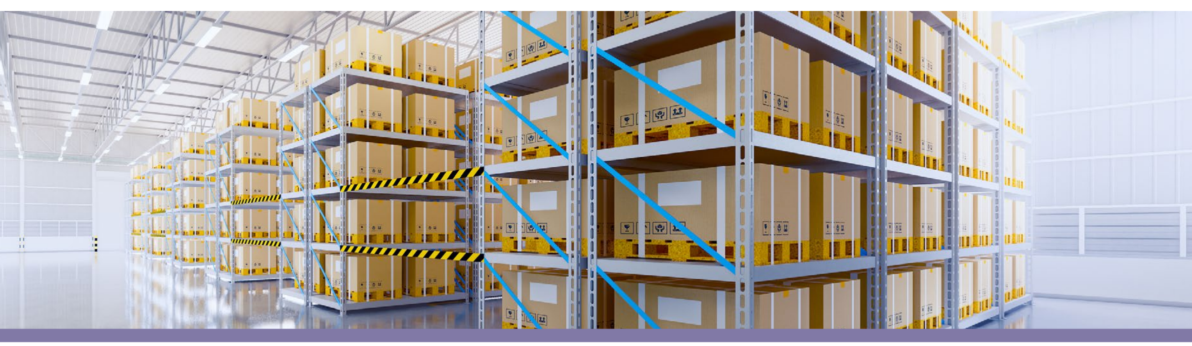
by the 8-tuple, S, where the first three values indicated selected port locations and the final five values indicated selected depot locations from the list of 96 GCCSAs. A value of zero indicates that no facility will be used. For example, SCND = (2, 5, 0, 5, 82, 93, 0, 0) indicates that only two ports will be chosen as the maritime hubs—one in GCCSA No. 2 and the other in GCCSA No. 5; and only three depots will be established—one in GCCSA No. 5, one in GCCSA No. 82, and the last in GCCSA No. 93. The set P is the set of non-zero, unique, elements from the first three elements of S. The set W is the set of non-zero unique, elements from the final five elements of S. In this example, P = {2, 5} and W = {5, 82, 93}.

Discrete Event Simulation

A discrete event simulation of this SCN was created and verified in the form of a stochastic function in MATLAB. The function was used within a script file that set the initial condition and called the function to execute the simulation. The scenario variables as well as simulation control variables were established as global variables accessible to the function. The SCND in the form of an 8-tuple of selected locations was passed to the function as an input parameter. The function simulated a warm-up period followed by a number of repetitions, each simulating one calendar year of operation. It also recorded the total operating cost as well as the individual tallies for the cost components of the elements of the fully burdened cost of the supply chain for each repetition. While a year was chosen as the replication length for this study to align with standard accounting periods, a replication length equal to the planned campaign length may be used if it is known. Upon completion of the final repetition, the function returned the sample mean and the 95% confidence interval (CI) for the total cost and each of the cost components.

This research used cost as the metric to optimize, while requiring the SCN to satisfy all demand. Each incident where demand could not be satisfied triggered assessment of a penalty. The authors recognize that cost is not the only, or even the most important, metric of concern to the military logistician. Speed of resupply and the potential loss of life must be considered. These aspects could be incorporated in future studies by increasing the cost penalty for unsatisfied demand to make such cases so expensive that the optimization routine would prevent them.

One aim of the study was to quantify the impact of making the strategic and tactical decisions together. To accomplish this, a second input variable indicated whether the function should calculate tactical decisions including the order size, reorder point, and transportation mode for each retail location, or should use existing values. Therefore, the model included two options for tactical decisions: (1) a 1-pass optimization approach in which the tactical decisions were calculated for each potential design during each simulation run, and (2) a 2-pass optimization approach. In the first pass of the 2-pass approach, the tactical decisions were made for the base line design and held constant while the strategic decisions were varied for the remaining simulation runs to optimize the SCN performance at the strategic level. Once the strategic decisions were optimized, the function was used one last time to make the tactical decisions based on the selected design and determine the final set of cost data.



Simulation-Based Optimization

Jourdan et al. (2009) divides methods for approaching complex and NP-hard optimization problems into four categories. The first category consists of tools that find an exact optimal solution, often using a gradient-following approach. This category does not scale well for complex problems that are nonconvex, such as many practical SCND problems faced by military logisticians. The second category attempts to find near-optimal solutions through approximations and subdividing the problem into smaller problems that may be solved using approaches from the first category. Again, these approaches do not scale to the required size and do not work well with a large number of nonconvex regions. The third category applies heuristics to solve certain classes of problems efficiently. This category takes advantage of specific aspects of certain classes of problems, but does not work for general problems such as the complex SCND problem. Metaheuristics, which include GAs, is the final category. A metaheuristic is a set of guidelines or strategies that predictably find reasonably good solutions to problems that may be too hard to solve with a closed-form or equation-based approach. Metaheuristics may not find the optimal solution but may find a near-optimal solution for a complex problem. Metaheuristics may be the only available solution for large scale, complex, highly nonconvex problems found in practice in military SCND where a good solution to the practical problem is better than a perfect solution to a simplified problem.

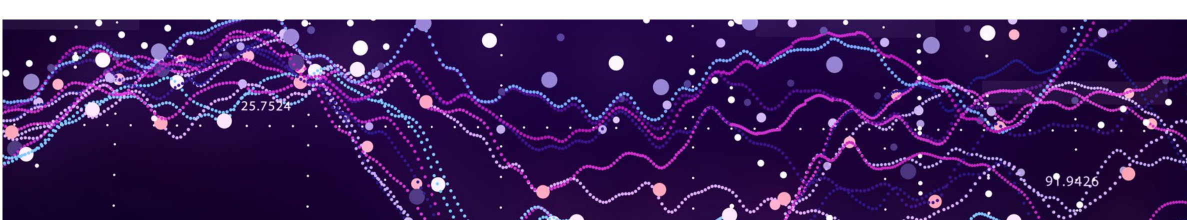
In this research, a GA was combined with the simulation model to search the tradespace of possible designs for this SCN to identify the SCND, which optimizes the objective function of the total supply chain cost. The simulation model was used to determine the total cost of the supply chain for each potential SCND as the GA altered the structure of the SCN.

Genetic Algorithm

The GA accepted the function call for the simulation model, including the constraints on the possible values of each element of the SCND, as inputs. The objective function was defined as the value returned by the simulation model for the specific SCND. The GA generated a random set of 200 SCNDs, each conforming to the constraints of the SCND definition. The GA identified the SCND with the lowest total operating cost.

In each generation, each candidate SCND was evaluated by the objective function and ranked in order of its value, with the lowest ranked SCND having the lowest total cost for a year of operation. Candidates for the subsequent generation were determined by three processes: survival, crossover, and mutation. The survival process selected the 10 lowest cost SCNDs for inclusion in the next generation. Crossover selected the 140 lowest cost SCNDs and randomly exchanged values for subsets of parameters between the SCNDs, such as the ports from design No. 8 with the warehouses from design No. 17. Mutation selected the 50 lowest ranked SCNDs and randomly changed three of the eight selected facilities.

For each new generation, the evaluation and ranking process was repeated and, potentially, a new lowest cost SCND was identified. The GA repeated the process until no improvement greater than 0.5% of the total cost occurred over the course of 50 generations, or until 1,000 generations had been evaluated.



Experimental Approach

A scenario was defined as a specific set of conditions for the SCN, including the geographic constraints such as the possible locations of cities and ports, the cost data such as the per-container cost of maritime shipping to Australia and the fixed cost of operating a warehouse, and the stochastic demand at each retail location. The DES was used to estimate the operating cost for each SCND, and the GA was used to search the tradespace of potential designs to minimize the estimated operating cost using two approaches. The 1-pass method made the tactical decisions within the simulation each time it was called, optimizing the tactical decisions along with the strategic decisions. The 2-pass method determined the tactical decisions for each unit-level or retail location: the first time before the GA was used to optimize the strategic decisions and a second time once a final strategic design was selected. The tactical decisions for each retail location were not altered while the GA optimized the strategic design. For both the 1-pass and 2-pass approaches, the final cost data were recorded for further analysis.

Results

The optimization routine was run for values of the maritime shipping rate from the maximum values to 70% of the maximum values in steps of 5% to determine the impact on the SCN. Figure 5 summarizes the results of the optimization. Each data group contains three sets of data: the performance of the base line SCN, the performance of the SCN optimized using the 2-pass approach, and the performance of the SCN optimized using the 1-pass approach. The base line SCN assumes no changes in the SCND and retains the original ground shipping costs, order costs, holding costs, and fixed costs in each set. The only difference between the base line costs in each of the groups is the reduction in the maritime shipping cost. The 2-pass approach and 1-pass approach both result in the realignment of the SCN to take advantage of the reduced shipping rate. For example, with a high maritime shipping rate, a warehouse in Sydney may be serviced by a port in Darwin using rail transport from Darwin to Sydney. At a low maritime shipping rate, the warehouse in Sydney would be serviced by the port in Sydney. Under this scenario, the maritime shipping cost would be higher due to the longer maritime distance, but the ground shipping cost is reduced by eliminating the rail transport. Figures 6 and 7 illustrate these examples.

FIGURE 5. OPTIMIZED SUPPLY CHAIN NETWORK PERFORMANCE

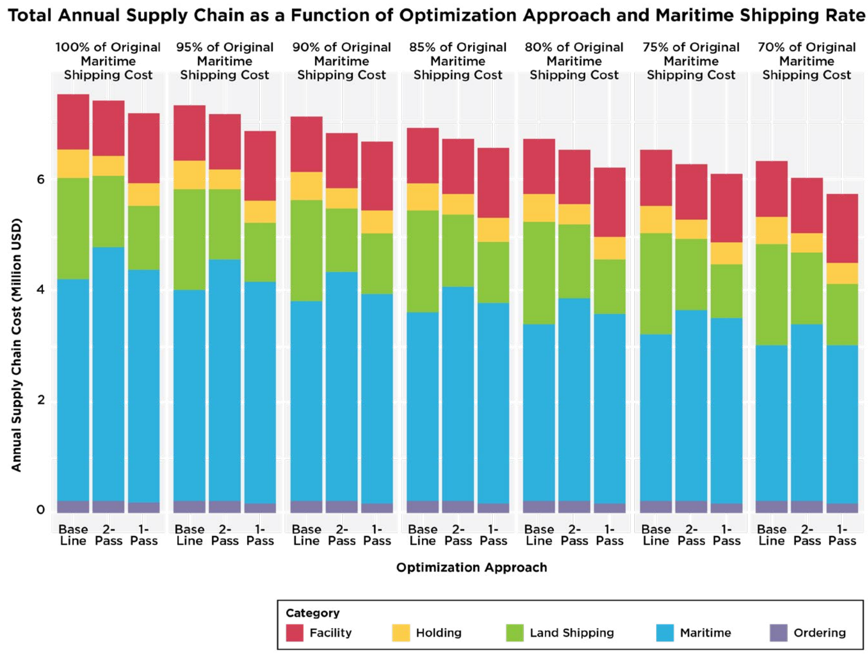


FIGURE 6. OPTIMIZED SUPPLY CHAIN NETWORK WITH HIGH MARITIME SHIPPING COST

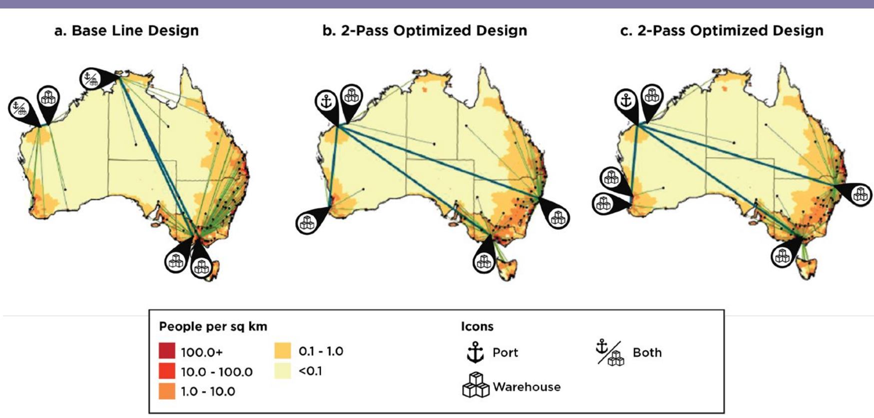


FIGURE 7. OPTIMIZED SUPPLY CHAIN NETWORK WITH LOW MARITIME SHIPPING COST

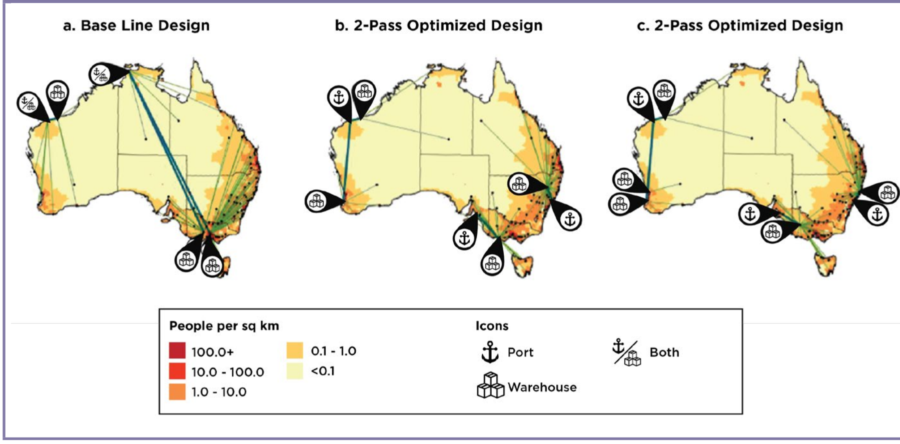


Figure 6 shows the optimal networks based on the original maritime shipping rates. These networks are represented in the far-left set of three bar graphs (Figure 5). The base line design uses the ports of Darwin and Karratha as recommended by Lee et al. (2017). Each port city held a warehouse, and two additional warehouses were included in the design as indicated in case (a), Base Line Design (Figure 6). The annual operating cost of this supply chain was estimated to be $7,519,689, with a 95% CI of $17,163, and is shown graphically in the Base Line bar of the far-left set of data in Figure 5. Employing the 2-pass approach of holding the tactical decisions constant while modifying the strategic decisions before optimizing the tactical decisions resulted in consolidating all port operations at Karratha as indicated in case (b), 2-Pass Optimized Design (Figure 6). The annual operating cost of this SCN was estimated to be $7,408,560, with a 95% CI of $79,814, and is shown in the 2-pass bar of the far-left set of data in Figure 5. The 2-pass method increased the total maritime shipping cost but reduced the land shipping cost, resulting in a net savings. The 1-pass method of simultaneously optimizing both the tactical and strategic decisions resulted in a design that was similar to the design produced by the 2-pass method, with the addition of one warehouse as indicated in case (c), 1-Pass Optimized Design (Figure 6). The annual operating cost of this SCN was estimated to be $7,169,326, with a 95% CI of $36,846, and is shown in the 1-pass bar of the far-left set of data in Figure 5. The additional cost of operating the warehouse was more than offset by a savings in transportation costs.

The final network designs incorporating the projected 30% reduction in maritime shipping rates appear in Figure 7, and they are represented in the far-right set of data in Figure 5. Case (a), Base Line Design (Figure 7), shows the unchanged base line. The estimated annual operating cost of this network is $6,320,758, with a 95% CI of $61,229, and is represented by the base line bar of the far-right set of data in Figure 5. Notably, this set of data is the same as the Base Line bar of the far-left set of data in Figure 5, with the exception that the maritime portion of the bar is reduced by 30%. Employing the 2-pass approach of holding the tactical decisions constant while modifying the strategic decisions and then optimizing the tactical decisions resulted in the network shown in case (b), 2-Pass Optimized Design (Figure 7). The transcontinental shipping from northern ports to southern warehouses has been replaced by southern ports. The estimated annual operating cost of this network is $6,021,737, with a 95% CI of $39,946, and is shown graphically in the 2-pass bar of the far-right set of data in Figure 5. Finally, the 1-pass method of simultaneously optimizing both the tactical and strategic decisions produced a result that resembled the design produced by the 2-pass method, with slightly different warehouse and port locations in the heavily populated southeastern section of the country. The difference appears in case (c), 1-Pass Optimized Design (Figure 7). The annual operating cost of this SCN was estimated to be $5,747,141, with a 95% CI of $41,595, and is shown in the 1-pass bar of the far-right set of data in Figure 5.

TABLE 2. SUMMARY FOR 30% REDUCTION IN MARITIME SHIPPING COST

	Cost with Initial Maritime Shipping Rate	Cost with 30% Reduction in Maritime Shipping Rates	Total Savings Over Base Case Initial Cost		Incremental Savings for Each Technique	
			USD	%	USD	%
Base Line Design	$7,519,689	$6,320,758	$1,198,931	15.9%	$1,198,931	15.9%
2-Pass Optimization	$7,408,560	$6,021,737	$1,497,952	19.9%	$299,021	4.0%
1-Pass Optimization	$7,169,326	$5,747,141	$1,772,548	23.6%	$274,596	3.7%

Source of Savings	USD	% of Savings
Reduced Shipping Rate	$1,198,931	67.6%
2-Pass Optimization	$299,021	16.9%
1-Pass Optimization	$274,596	15.5%
Total Savings	**$1,772,548**	**100.0%**

TABLE 3. IMPACT OF INTEGRATING STRATEGIC, TACTICAL AND OPERATIONAL DECISIONS

Maritime Shipping	Base Line		2-Pass		1-Pass		Additional Savings from 1-Pass Optimization
	Mean	95% CI	Mean	95% CI	Mean	95% CI	
100%	$7,519,689	$17,163	$7,408,560	$79,814	$7,169,326	$36,846	3.2%
95%	$7,319,867	$72,404	$7,168,658	$40,834	$6,852,341	$62,757	4.4%
90%	$7,120,045	$62,158	$6,826,267	$50,892	$6,677,605	$40,156	2.2%
85%	$6,920,223	$14,914	$6,718,078	$35,550	$6,548,704	$82,784	2.5%
80%	$6,720,401	$41,331	$6,525,380	$67,403	$6,201,325	$60,905	5.1%
75%	$6,520,580	$34,237	$6,263,597	$57,190	$6,090,412	$52,672	2.8%
70%	$6,320,758	$61,229	$6,021,737	$39,946	$5,747,141	$41,595	4.6%

Note.
2-Pass: Strategic, Tactical, and Operations Decisions are made independently.
1-Pass: Strategic, Tactical, and Operations Decisions are integrated.

The study found that the 30% reduction in the maritime shipping rate for this SCN would result in a decrease in the total SCN operating cost of 15.9%, from USD $7.5 million to USD $6.3 million. Optimizing using the 2-pass method resulted in an SCN operating cost savings of 19.9%, to USD $6.0 million. Optimizing using the 1-pass method resulted in an SCN operating cost savings of 23.6% to USD $5.7 million. Table 2 summarizes the data for the 30% reduction in maritime shipping rates.

SCN alignment and optimization has a magnifying effect on reductions in costs for any one portion of the SCN. The direct savings from reducing maritime shipping costs accounted for a savings of USD $1.2 million. SCN optimization amplified that savings to USD $1.8 million—an increased savings of 48% for the final scenario.

Table 3 highlights the impact of integrating strategic and tactical decisions while optimizing the SCN. Across the seven maritime shipping scenarios displayed, optimizing the strategic and tactical decisions concurrently, in a 1-pass approach, resulted in an additional savings of 3.5% of the SCN cost obtained by optimizing the strategic and tactical decisions sequentially in a 2-pass approach.

Conclusion

SCND has been shown to be NP-hard and mathematically complex in the general case. Many of the techniques in the literature find exact solutions to the SCND problem by making simplifying assumptions, which are driven as much by the requirements of the solution technique as the needs of the practitioner. To the authors' knowledge, no solution in the literature has been shown to solve the problem without assumptions, either exactly or in an approximate sense. No special structure has been identified in the general case, which would allow a known heuristic to be applied. Therefore, a metaheuristic solution was pursued.

> **Further analysis showed that integrating tactical and strategic solutions in a single pass provided a structurally different solution than optimizing the strategic and tactical decisions sequentially, and that this structural difference resulted in an additional 3.5% savings in total SCN operating costs.**

This study answered the primary research questions. An SBO engine composed of a genetic algorithm converged to a solution for a large SCN of the scale used to support a theater commander. The solution incorporated operational, tactical, and strategic decisions simultaneously, in the presence of stochastic input variables, without making assumptions that are inappropriate to the military logistician. While many of the approaches in the literature make simplifying assumptions such as transportation costs, which are independent of order size, or that the effectiveness of decisions made at the strategic level are independent of decisions made at the tactical level, this approach does not require these assumptions. The results showed that optimization of operational, tactical, and strategic decisions simultaneously results in a superior result to optimizing the decisions sequentially.

To demonstrate the authors' approach, the authors studied an illustrative SCN responding to a change in the threat environment. To minimize simplifying assumptions, the problem included many of the factors affecting fully burdened defense supply chains:

- The operators of the SCN will make decisions at the strategic, tactical, and operational levels and these decisions are tightly linked.
- The SCN operates in the presence of uncertainty in both demand and transportation lag time.
- The operators must make decisions that include nonconvex response functions, such as deciding between TL transportation with a maximum capacity, a minimum charge per TL plus a per-mile charge independent of the size of the shipment, or LTL transportation with a higher per-mile charge but no minimum charge or maximum capacity.
- The SCN must operate on a large scale, providing service to 96 locations distributed over a continent.

A novel SBO approach combining a DES with a GA and modifying the GA to consider port and warehouse selections as holistic entities in the crossover process, was shown to provide a solution to this problem in feasible time. Further analysis showed that integrating tactical and strategic solutions in a single pass provided a structurally different solution than optimizing the strategic and tactical decisions sequentially, and that this structural difference resulted in an additional 3.5% savings in total SCN operating costs. Therefore, optimization cannot be assured by solutions that consider strategic and tactical decisions either sequentially or in isolation.

Further research is required to compare the solutions obtained by the SBO approach to solutions obtained by exact or approximate methods, for those problems that can be solved by these means, to quantify the degree to which the SBO approach compares to the optimal solution. Additionally, the GA procedures should be further evaluated to identify optimal values or heuristics for determining values for this class of problem (Cosma et al., 2020). The effect these values have on both the time to converge on a solution and the optimality of that solution is left for future research.

Abbreviations & Acronyms

ABS	Australian Bureau of Statistics
AOR	area of responsibility
BITRE	Bureau of Infrastructure, Transportation and Regional Economics
CI	Confidence Interval
CSCMP	Council of Supply Chain Management Professionals
DES	discrete event simulation
DoD	Department of Defense
GA	genetic algorithm
GAO	Government Accountability Office
GCCSA	Greater Capital City Statistical Area
ISO	International Organization for Standardization
LTL	less than truck load
MILP	mixed-integer linear programming
MIP	mixed-integer programming
OQ	order quantity
ROP	reorder point
SBO	simulation based optimization
SCM	supply chain management
SCN	supply chain network
SCND	supply chain network design
SS	safety stock
TL	truck load
TM	transportation mode

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Quantifying THE EFFECTS OF AIRCRAFT ENGINE UPGRADES ON OPERATING AND SUPPORT COSTS

Bradford A. Myers, Edward D. White, Jonathan D. Ritschel, and R. David Fass

For fixed wing aircraft within the U.S. Air Force, Operating and Support (O&S) costs encompass a large portion of total life cycle costs. O&S costs include fuel, maintenance, and engine upgrades. To the authors' knowledge, no study to date has attempted to empirically quantify the realized effects of new aircraft engines on sustainment costs. Utilizing the Air Force Total Ownership Cost database, they focused on new engines appearing on the C-5s, C-130s, and C-135s. Although narrow in scope, results suggest newer engines have lower fuel costs. Maintenance costs for newer engines were not consistently higher or lower than the engines they replaced, although Contractor Logistics Support was not tracked by engine in this study. We found that savings from improved fuel efficiency tended to be greater than a potential increase in maintenance costs.

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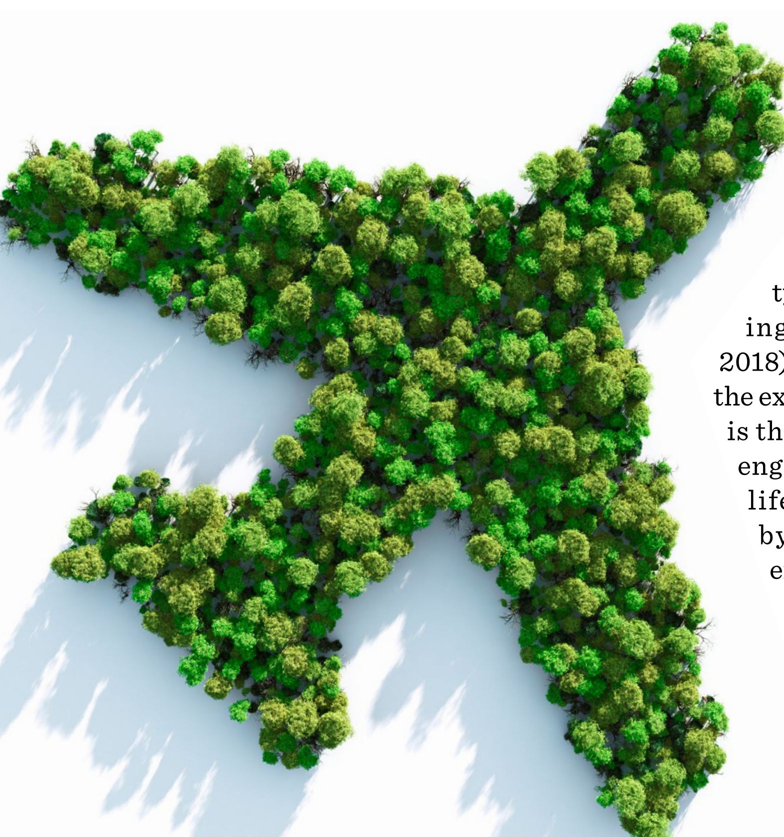
Keywords: *Engine Upgrades, Operating and Support (O&S) Costs, Contractor Logistics Support (CLS), Life Cycle Costs (LCC)*

For many Department of Defense (DoD) programs, Operating and Support (O&S) costs encompass the largest portion of Life Cycle Costs (LCC), which is a key reason why defense acquisition leadership has expressed a renewed emphasis on O&S affordability and cost management (Office of the Secretary of Defense, Cost Assessment & Program Evaluation [OSD CAPE], 2014). O&S consists of all sustainment costs, including personnel, fuel, supplies, maintenance, upgrades, etc. (OSD CAPE, 2014). For DoD aircraft, engines are expensive components to acquire, maintain, and upgrade. As such, their O&S costs need to account for perhaps the decreasing reliability and increasing maintainability costs of old engines versus the establishment and integration of newer engines. Despite O&S costs accounting for an average of 55% of total LCC (Jones et al., 2014), no study to our knowledge has attempted to empirically quantify the realized effects of new aircraft engines on sustainment costs.

Previous studies (Mouton et al., 2015; National Research Council, 2007) have analytically investigated possible ways to reduce fuel usage and the feasibility of such proposals such as engine-out taxiing strategies, optimal flight level and speed, and reducing aircraft weight. Additionally, Boito et al. (2016) discussed potential C-130 improvements, including the previous measures as well as load-balancing improvements, reduction of auxiliary power units, and installation of microvanes™. Their study suggested that full implementation of these options could save about 16 million gallons of fuel annually. These types of modifications are becoming more and more important as U.S. Air Force (USAF) systems age.



The Heritage Foundation (2020) reported that, as of 2019, the average age of USAF aircraft is over 29 years. This fact is important because the age of an aircraft typically correlates with increasing O&S costs (Hewitson et al., 2018). One way the USAF deals with the expensive issue of replacing a fleet is through modernizations, such as engine upgrades to extend service life. This is the tactic employed by the B-52 program office to extend the life of that fleet while capturing reductions in O&S costs via more fuel-efficient modern engines. On May 19, 2019, the USAF released a formal solicitation for the B-52 Commercial Engine Replacement Program.

In this article, we investigate how engine upgrades influence ongoing O&S costs, specifically fuel performance and total engine maintenance costs less Contractor Logistics Support (CLS), for a small group of USAF fixed-wing aircraft. For purposes of this article, we refer to engine upgrades as either technology insertions (modifications) into existing engines or a "re-engine," which entails replacing engines and a new Mission Designation Series (MDS).

> **"The O&S cost information collected includes unit-level manpower, fuel, depot maintenance overhaul costs, depot-level reparable costs, and other costs of major USAF aircraft and engines.**

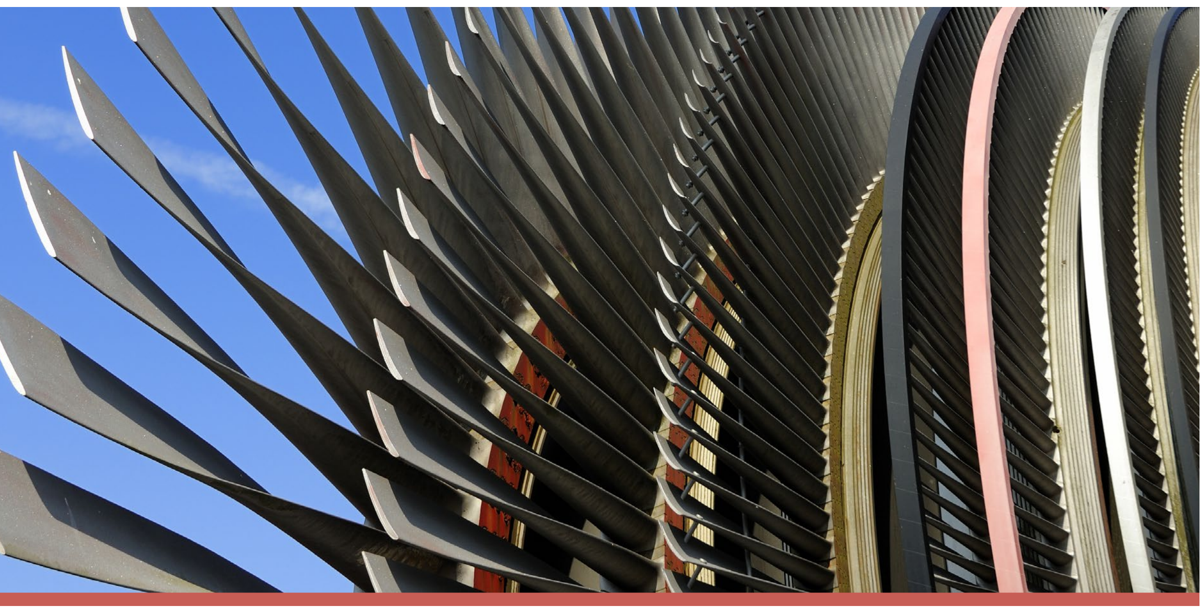
The analysis focuses on a small number of USAF aircraft because our dataset identified only three new aircraft engines introduced into the inventory in the past 20 years: the F138-GE-100 on the C-5M (in Fiscal Year [FY] 2010), the AE2100 on various C-130 "J" models (in FY2016), and the F108-GE-201 on various C-135 models (in FY2001). All three engines are for cargo aircraft. To investigate the effects of upgrading engines, the analysis requires comparable aircraft with O&S data on at least two different engines. A different engine is defined here as those engines with a separate Type Series Modification (TMS) designator.

Background and Data

The passing of the Weapon Systems Acquisition Reform Act (WSARA) in 2009 elevated the importance of O&S estimates and cost reporting. Each military department maintains its own historical O&S cost data collection system. These data systems were developed in response to an initiative known as Visibility and Management of Operating and Support Costs (VAMOSC). OSD CAPE provides broad policy guidance pertaining to the military department VAMOSC programs, but leaves the details concerning implementation to each department. Though the primary focus of VAMOSC is for future planning and the development of O&S estimates, the nature of the database allows actual O&S costs to be sorted by weapon system and by year (Ryan et al., 2012).

The Air Force system designed to be compliant with the requirements of VAMOSC is the Air Force Total Ownership Cost (AFTOC) system. It provides O&S cost information on all Air Force aircraft, space systems, and missiles. The O&S cost information collected includes unit-level manpower, fuel, depot maintenance overhaul costs, depot-level reparable costs, and other costs of major USAF aircraft and engines. AFTOC also maintains data on aircraft quantities and flying hours, number of personnel, and other noncost information (OSD CAPE, 2014). In compliance with the CAPE guidance, AFTOC also provides users with system-level data, as well as lower levels of data (major subsystems and components).

The optimal approach to compare engine performance or cost would be by aircraft tail number. This would allow accurate comparisons before and after a new engine installation for a specific aircraft, thereby minimizing any other external factors. Unfortunately, this ideal approach is unobtainable with current USAF data collection systems. Fuel consumption and flying hours are available by tail number based on the Fuel Automated System and are available within AFTOC, but not engines. Neither program offices nor USAF data systems track modifications or engine upgrades by tail number. Air Force Lines of Accounting do not isolate a particular tail number or engine. The lowest level of direct data allocation is at the aircraft, or MDS, level as captured by a combination of the data elements, namely the Program Element Code, Operating Agency Code, or Resource Center/Cost Center.



Further complicating specific costs associated with an individual aircraft tail number is the accounting of CLS. The reason CLS can be a challenge for analysis is because VAMOSC systems may collect CLS costs in aggregate, but without providing any details by cost elements such as depot maintenance (OSD CAPE, 2014). The *DoD O&S Cost Management Guidebook* states that CLS and Depot cost categories are difficult to categorize since they are likely to include costs for personnel and parts as well as other things such as overhead and facilities (DoD, 2016). Because of this, the data we used to compare the effects of replacing an older engine with a newer one do not include CLS costs.

> **"Overall, only engines that entered service between FY1997 through FY2017 are considered, for a total of 21 years of O&S data.**

AFTOC compiles data into various "data cubes," which encapsulate categories of costs. For this study, we used three principal data cubes: the CAPE14 data cube, which contains the aggregate costs from financial systems; the Engine Programmatic data cube, which reports fuel usage, flying hours, etc.; and the CAPE14 Engine data cube (hereafter just Engine data cube), which attempts to match costs reported in the CAPE14 data cube to aircraft engines using a variety of business rules. No Line of Accounting element is tied to engines, so the reported Engine data are approximated by using ratios from the REMIS (Reliability and Maintainability Information System) flying hours and comparing them to CEMS (Consolidated Engine Management System) Engine Actuarial data. The engine costs information used in this research are therefore approximations—a limitation we recognize.

Because of these limitations in how the Air Force collects source data, isolation of the effects of new and old engines is not possible unless they belong to a separate MDS. One example where this is the case is with the C-5. The C-5A, B, and C all use the TF39-GE-1 engine exclusively. The new F138-GE-100 engine was given its own MDS, the C-5M. Only because of the creation of a new MDS, which is distinguished by the new engine, is it possible to directly compare the costs of the old engine with the new engine. If a new engine is not isolated to its own MDS, costs are estimated on a proportionate basis as reported by AFTOC's Engine data cube. This second approach introduces variation into the computation since it relies on the assumption that the percentage of aircraft with newer engines equates to the same percentage of the flying hours for any given MDS.

The initial step for comparative analysis is to isolate aircraft platforms with more than one engine, generating a listing of MDS categories with more than one engine type/model/series (TMS), one of which must be a newer engine. These MDS categories were rolled up into a parent MDS family (C-5s, C-130s, C-135s) which, for purposes of this analysis, was used to identify whether the various aircraft sharing the C-130 airframe (i.e., AC-130, EC-130, etc.) would count as one MDS category under a parent MDS family of C-130s. The AFTOC helpdesk compiled a database of engine inventory by TMS, base, fixed-wing aircraft platform, and serial number that spanned from 1999 to 2019. Drones and helicopters were not considered in this article due to their distinct operating differences from fixed-wing aircraft.

Actual data for engine inventory on aircraft are used to find engine pairings. Engines put into place after FY2017 do not have at least 2 years of new O&S costs for statistical comparison. By the same logic, only those engines that have been in place since FY1997 allow for at least 2 years of premodification O&S data using AFTOC stand-up-date of FY1996. Overall, only engines that entered service between FY1997 through FY2017 are considered, for a total of 21 years of O&S data.

Aircraft with a small Primary Aircraft Authorization (PAA) (aircraft authorized to a unit for performance of its operational mission) number may have an overly influential effect in the database as errors will have a larger effect and any fixed effects within the figures will have a greater impact. Therefore, in addition to the requirement that the MDS category has more than one TMS engine, we also restricted the analysis to platforms with a PAA of five or more. After all these exclusions, only three MDS families remained—the various C-130s, C-135s, and C-5s. The MDS breakout includes three categories of cargo aircraft/refuelers—the various C-5, C-130, and C-135 variants such as the KC-135. Table 1 lists the final set of aircraft included for analysis.

TABLE 1. AIRCRAFT MDS CONSIDERED WITH 5 OR MORE PRIMARY AIRCRAFT AUTHORIZATIONS

AC-130H	EC-130E	MC-130E	C-5A	KC-135E
AC-130J	EC-130H	MC-130H	C-5B	KC-135R
AC-130U	EC-130J	MC-130J	C-5M	KC-135T
AC-130W	HC-130J	MC-130P		RC-135V
C-130E	HC-130N	MC-130W		RC-135W
C-130H	HC-130P	WC-130H		
C-130J		WC-130J		

Note. AC = Attack Cargo; C = Cargo; EC = Electronic Cargo; HC = Search and Rescue Cargo; KC = Tanker Cargo; MC = Multi-Mission Cargo; RC = Reconnaissance Cargo; WC = Weather Cargo.

It would be inaccurate to compare fuel consumption, efficiency, and cost without standardizing for operations tempo. If operations tempo increases over time, then costs will vary in accordance with that usage instead of the engine. Using the metric of gallons per flying hour (FH)—fuel consumption— mitigates the issue and creates a homogeneous comparison across aircraft in the same MDS family. Theoretically, changes in gallons/FH will be reasonably well isolated to the effects of the new engine.

> **While maintenance costs do vary by flying hour in the same way that mileage affects automotive maintenance, the number of aircraft is also important for cost standardization.**

Unfortunately, the comparison is not perfect since the data will generate errors and measuring inefficiencies. Even if these did not exist, additional variation is likely since fuel efficiency varies by altitude, atmospheric conditions, and cruise speed (Rolls Royce, 2015), none of which are captured within AFTOC data. Aircraft with few flying hours may have a distorted gallons/FH metric caused by the fuel used in takeoff and landings and taxiing, especially since flying hours are in the denominator of the metric. Since this analysis attempts to quantify the effects of average usage, aircraft with fewer than 20 reported flying hours by FY were removed. This removal represented 0.006% of the total flying hours reported.

Maintenance costs were also standardized prior to comparing the new engines to the older engines. We converted costs to Base Year 2019 dollars to remove the effects of inflation. While maintenance costs do vary by flying hour in the same way that mileage affects automotive maintenance, the number of aircraft is also important for cost standardization. Boito et al. (2015) suggested that the Primary Aircraft Inventory (PAI) is inherently more stable than flying hours and is the preferred metric by subject matter experts to standardize maintenance costs. [Note: We used PAA in place

of PAI since PAI is not available in the AFTOC data cubes; this does not meaningfully change the results of the analysis.] We use PAA to standardize maintenance costs within MDS categories. In summary, the metrics we use for comparison between new engines and older engines entail gallons/FH for fuel performance metrics; for maintenance costs we use Base Year 2019 maintenance costs/PAA/FH, excluding CLS.

We used the JMP 13 Pro statistical package for all the graphs and analyses presented in the next section. It should also be noted that our intent for the analysis was not to generate a regression model to predict fuel consumption or maintenance cost; there are simply too many uncontrolled variables for our limited dataset to adequately conduct such an undertaking. Instead, we are simply investigating the realized effects of fuel consumption and maintenance cost (minus CLS).

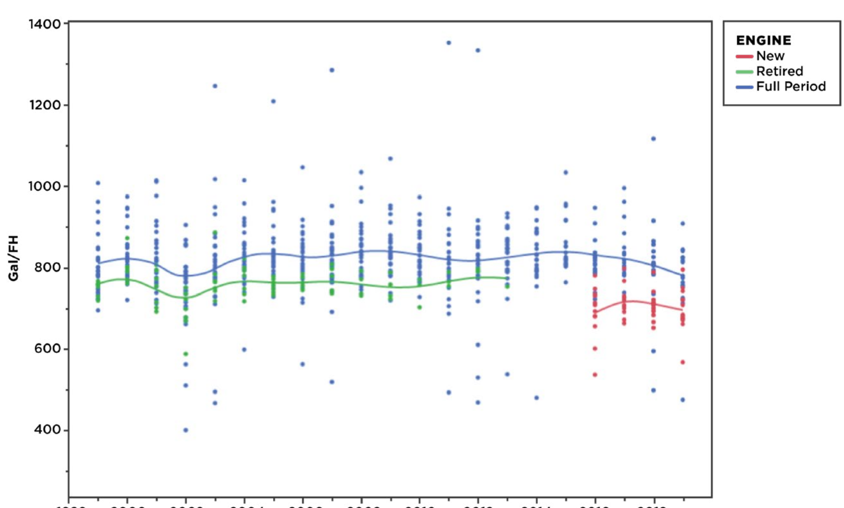
The most common test for comparing differences in means is a student *t*-test; however, this method is inappropriate when the underlying distributions are nonnormal. Therefore, we used the more conservative Wilcoxon Rank Sum test, also called the Rank Sums test, to test for statistical differences between the fuel efficiency and maintenance costs of the new versus retired engines. We also use the Hodges-Lehmann statistic (Hodges & Lehmann, 1963) to estimate the median differences and associated confidence intervals. Neither of these nonparametric methods require normality, and both provide robust comparisons in addition to being less susceptible to outliers. Since this study is exploratory and not confirmatory, we chose to minimize the chance of committing a Type II error, which is a failure to find a relationship where one exists. Therefore, we selected a level of significance of 0.1 to use for all the nonparametric tests conducted.

Analysis and Results

Except where noted, visualization patterns for engines are grouped into three broad color-coded categories: red for new engines, green for retired engines, and blue for engines that are active over the entire recorded study period (1999–2019). We first display graphs for the fuel performance metrics (gallons/FH) by MDS family to observe the effects of new engines. Following those, we present the results of the nonparametric tests with a discussion. After examining fuel performance metrics, we investigate the MDS by maintenance costs associated with their engines and limitations. The Wilcoxon Rank Sum test is used again to test and quantify the differences between the engine categories using the Hodges-Lehmann statistic.

All graphs are presented without outliers more than three standard deviations from the mean (within their respective MDS and TMS). While engine fuel performance does vary, large outliers are more likely the result of faulty data collection, such as an underreporting of flying hours instead of actual fuel performance of the engine and, as such, are excluded. For all presented figures, each dot represents a reported value from a particular command (Air Combat Command, Air Education and Training Command, Air Force Materiel Command, Air Force Reserve Command, Air Force Special Operations Command, Air Mobility Command, Air National Guard, Pacific Air Forces, and U.S. Air Forces in Europe). Since the various C-130 variants are in most of the commands, figures for that MDS have several dots. Additionally, the curves connecting the points from year to year are smoothed splines and played no role in any statistical analysis. They simply display visual trends.

FIGURE 1. MEAN GALLONS/FH CONSUMPTION RATE BY FISCAL YEAR FOR THE C-130 MDS FAMILY



Note. Gal/FH = Gallons Per Flying Hour.

TABLE 2. WILCOXON RANK SUM TEST RESULTS FOR C-130 FUEL PERFORMANCE

Comparison	Test Statistic (Z)	P-value	Hodges-Lehmann Value	Lower 90% Bound	Upper 90% Bound
Retired vs. New	3.47	0.0005	42.4	28.84	60.64
Retired vs. Full Period	-4.54	< 0.0001	-70.01	-93.01	-51.17
New vs. Full Period	-6.71	< 0.0001	-114.77	-135.32	-94.15

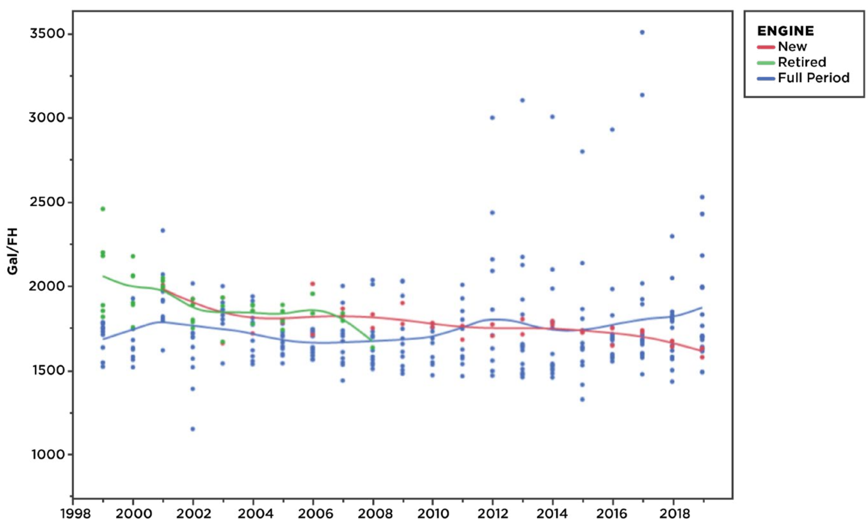
Note. Test statistic based on large sample approximation (Z-score). Values are gallons/FH. Numbers rounded to two digits after decimal place.

We begin with Figure 1, which highlights the C-130 fuel performance metrics. The new engines (belonging to the "J" models) are in red and appear to have a lower gallons/FH consumption rate than the other C-130 models. Table 2 shows the Wilcoxon Rank Sum test results. Each test is statistically significant, suggesting that a difference exists between each of the categories of engines at an α of 0.10. The Hodges-Lehmann column is the estimated median performance difference. In this case, the new engine is performing more fuel efficiently on average by 42 gallons/FH, with an associated 90% confidence interval of between 29 to 61 fewer gallons/FH in comparison to the retired engine.

The interpretation for the other two comparisons (retired or new versus engines utilized over the full study period) is comparable with the exception that the Hodges-Lehmann statistic is negative. As an example, using the Hodges-Lehmann value in the last row of Table 2, each flying hour on the full period engine (T56-A-15) is burning an additional 115 gallons/FH when compared to the new engine (AE-2100) in median fuel performance.

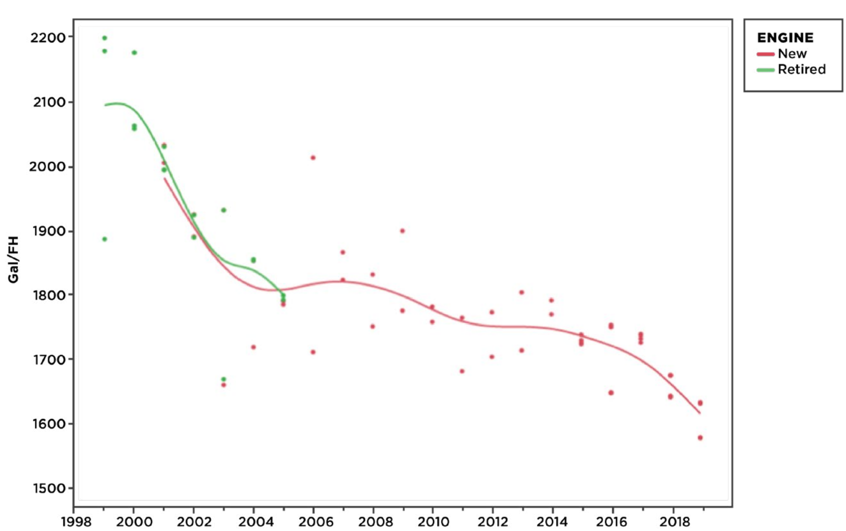
For the C-135 MDS, we chose to investigate subcategories since the missions of C-135 models are distinct (refueling versus reconnaissance) and appeared different from the rest with respect to fuel consumption. In comparison, we did not separate the C-130 models into subcategories, for there appeared to be no discernible differences except for the LC-130, which was excluded from our study due to its fundamental difference. The Lockheed LC-130 is a ski-equipped USAF variant of the C-130 Hercules used in the Arctic and Antarctic regions.

FIGURE 2. MEAN GALLONS/FH CONSUMPTION RATE BY FISCAL YEAR FOR C-135 MDS



Note. Gal/FH = Gallons Per Flying Hour.

FIGURE 3. MEAN GALLONS/FH CONSUMPTION RATE BY FISCAL YEAR FOR RC-135V/W AIRFRAME



Note. Gal/FH = Gallons Per Flying Hour.

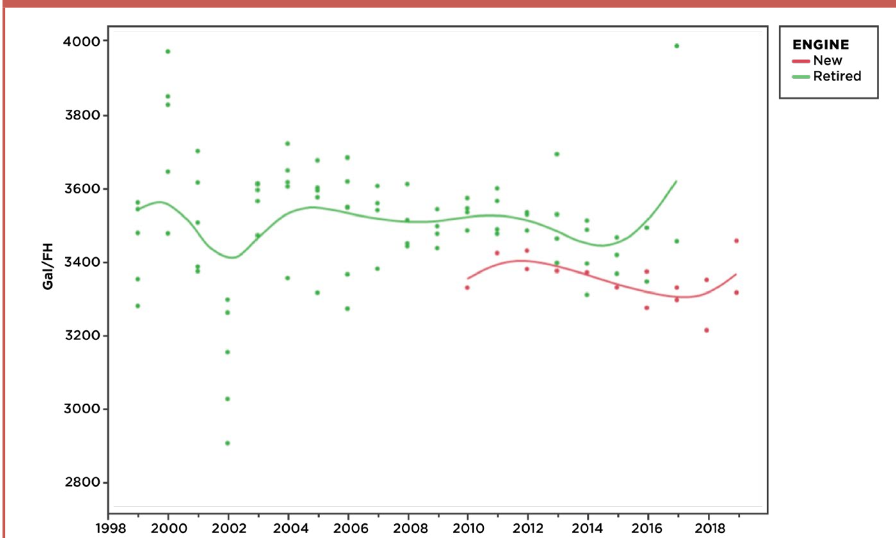
TABLE 3. WILCOXON RANK SUM TEST RESULTS FOR C-135 FUEL PERFORMANCE

Comparison (MDS)	Test Statistic (Z)	P-value	Hodges-Lehmann Value	Lower 90% Bound	Upper 90% Bound
Retired vs. New (RC-135)	4.72	< 0.0001	194.07	141.61	253.71
Retired vs. Full Period (KC-135)	4.21	< 0.0001	168.00	111.00	217.59

Note. Test statistic based on large sample approximation (Z-score). Values are Gallons Per Flying Hour (Gallons/FH). Numbers rounded to two digits after decimal place.

Figure 2 highlights the C-135 fuel performance metrics, while Figure 3 highlights just those RC-135V/W model metrics. For point of reference, only the RC-135V/W involved a new engine. Table 3 reflects the associated Wilcoxon Rank Sum tests and Hodges-Lehmann values. We can see in the fuel performance metrics that for each pair, the retired engines appear to be consuming more gallons/FH in comparison to either the full period or new engines since the green line is on top of the red line. With respect to the new engine, the estimated median performance suggests an improved engine efficiency between 142 and 254 gallons/FH in comparison to the retired engines. These results are statistically significant at the 0.1 level of significance.

FIGURE 4. MEAN GALLONS/FH CONSUMPTION RATE BY FISCAL YEAR FOR C-5 MDS CATEGORY



Note. Gal/FH = Gallons Per Flying Hour.

TABLE 4. WILCOXON RANK SUM TEST RESULTS FOR C-5 FUEL PERFORMANCE					
Comparison (MDS)	Test Statistic (Z)	P-value	Hodges-Lehmann Value	Lower 90% Bound	Upper 90% Bound
Retired vs. New	4.26	< 0.0001	167.08	116.87	216.72

Note. Test statistic based on large sample approximation (Z-score). Values are Gallons Per Flying Hour (Gallons/FH). Numbers rounded to two digits after decimal place.

Lastly, the C-5 provides the clearest comparison since there are only three MDS categories—only one of which (C-5M) corresponds precisely to just the new engine. Figure 4 shows the performance of the C-5 models. It can be observed that the new C-5 engine is performing better than the retired engine. The Wilcoxon Rank Sum statistic presented in Table 4 supports this conclusion statistically at the 0.1 level of significance. When the retired engine is compared with the new, the positive score mean difference implies that the retired engine consumed more fuel than the new one. The result is statistically significant with the estimated fuel savings being between 117 to 217 gallons/FH.

TABLE 5. DESCRIPTIVE STATISTICS OF AIRCRAFT FUEL PERFORMANCE						
MDS	Status	TMS	Mean	Median	Std Dev	CV
C-130	New	AE2100	703	708	48	0.07
	Retired	T56A7	757	759	42	0.06
	Full Period	T56A15	821	817	94	0.11
C-135	New	F108GE201	1761	1745	106	0.06
	Retired	TF33PW102	1876	1852	154	0.08
	Retired	TF33PW105	1967	1932	134	0.07
	Retired	TF33PW5	1962	1932	129	0.07
	Retired	TF33PW9	1930	1889	189	0.10
	Full Period	F108GE100	1753	1693	296	0.17
C-5	New	F138GE100	3345	3341	61	0.02
	Retired	TF39GE1	3507	3522	167	0.05

Note. Numbers given are in gallons/flying hour from 1999 through 2019. CV = Coefficient of Variation.

TABLE 6. FUEL CONSUMPTION COMPARISONS BETWEEN THE NEW ENGINES AND RETIRED ENGINES

MDS	Status	TMS	% savings (Mean)	% savings (Median)
C-130	New	AE2100		
	Retired	T56A7	7.68%	7.20%
C-135	New	F108GE201		
	Retired	TF33PW102	6.53%	6.13%
	Retired	TF33PW105	11.70%	10.72%
	Retired	TF33PW5	11.41%	10.72%
	Retired	TF33PW9	9.60%	8.25%
C-5	New	F138GE100		
	Retired	TF39GE1	4.84%	5.42%

Note. Positive percentages indicate newer engines burn less Gallons Per Flying Hour (Gallons/FH) comparisons based on both mean and median Gallons/FH.

From this exploratory data analysis, even given the relatively small sample size of new engines introduced into the inventory by the USAF over the past 20 years, the new engines appear to be more fuel-efficient than the older retired engines. With each engine comparison among the cargo aircraft, the nonparametric tests were statistically significant, suggesting better fuel efficiency of the engines. Looking at the 90% confidence intervals in an aggregate, the estimated gallons/FH of fuel saved ranged from a low of 28 (C-130s), to a high of 280 (RC-135s). Given the tens to hundreds of thousands of hours that the fleet of USAF cargo planes fly annually, the potential cost savings could be substantial. Tables 5 and 6 reflect fuel consumption metrics and estimated percentage savings comparing the retired and new engines.

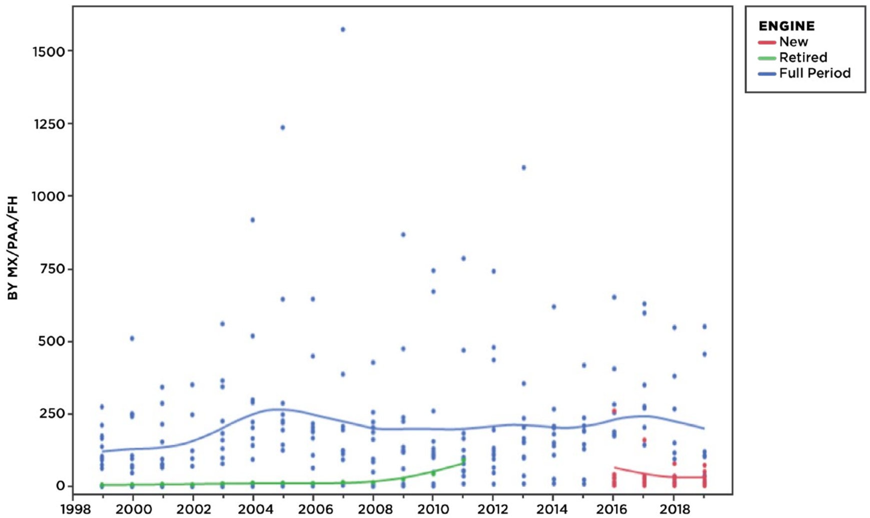
Maintenance costs are more difficult to analyze than fuel performance metrics. First, maintenance costs in general appear to vary more from year to year in comparison to fuel performance costs. Second, the AFTOC engine cost cube does not include CLS costs, thus underestimating total

“Engine maintenance costs are theorized to follow a bathtub effect, wherein costs are higher in the beginning due to initial learning or defects, reach a lower steady state, and then rise due to the aging effect.

costs—an acknowledged limitation in the data. Lastly, this is further complicated by research showing the decision to utilize CLS as a maintenance strategy is found to generally cost more than not using it as such (Ritschel & Ritschel, 2016).

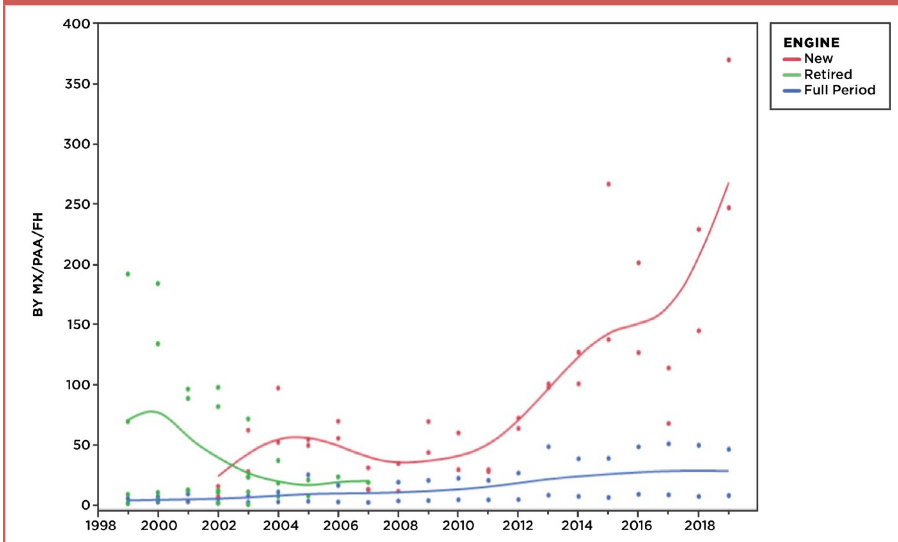
An aspect that further complicates the analysis of maintenance is the effect of aging. Over time, engines will likely cost more to maintain through the accumulation of wear and tear as well as obsolete parts and supply chains. Engine maintenance costs are theorized to follow a bathtub effect, wherein costs are higher in the beginning due to initial learning or defects, reach a lower steady state, and then rise due to the aging effect (Kiley, 2001). The best comparison of engine costs would be to compare Base Year costs from the steady state of one engine to the steady state of the other. Unfortunately, the newer engines have only been in the USAF inventory less than 10 years, decreasing the likelihood that steady state costs have fully materialized.

FIGURE 5. MEAN MAINTENANCE COSTS BY PRIMARY AIRCRAFT AUTHORIZATION BY FLYING HOUR FOR FISCAL YEARS 1999–2019 FOR THE C-130 MDS



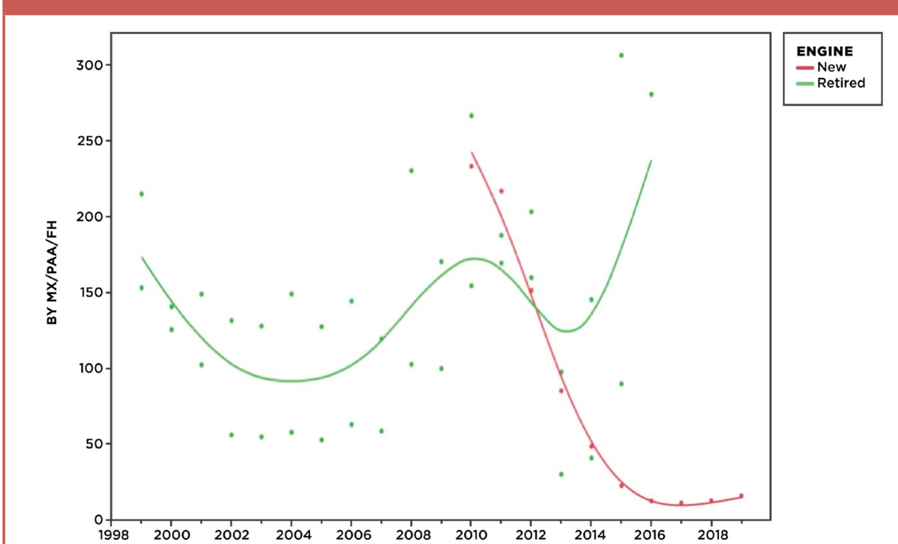
Note. MX/PAA/FH = Maintenance/Primary Aircraft Authorization/Flying Hour.

FIGURE 6. MEAN MAINTENANCE COSTS BY PRIMARY AIRCRAFT AUTHORIZATION BY FLYING HOUR FOR FISCAL YEARS 1999–2019 FOR C-135 MDS



Note. MX/PAA/FH = Maintenance/Primary Aircraft Authorization/Flying Hour.

FIGURE 7. MEAN MAINTENANCE COSTS BY PRIMARY AIRCRAFT AUTHORIZATION BY FLYING HOUR FOR FISCAL YEARS 1999–2019 FOR C-5 MDS



Note. MX/PAA/FH = Maintenance/Primary Aircraft Authorization/Flying Hour.

TABLE 7. COMBINED WILCOXON RANK SUM TEST RESULTS FOR THE C-130, C-135, AND C-5 MDS MAINTENANCE COSTS

Comparison (MDS and engine)	Test Statistic (Z)	P-value	Hodges-Lehmann Value	Lower 90% Bound	Upper 90% Bound
C-130 Full Period (T56A15) vs. Retired (T56A7)	4.39	< 0.0001	117.59	86.13	175.46
C-130 New (AE2100) vs. Full Period (T56A15)	-4.91	< 0.0001	-102.59	-141.75	-74.81
C-135 New (F108GE201) vs. Full Period (F108GE100)	6.40	< 0.0001	53.14	41.73	66.18
C-135 New (F108GE201) vs. Retired (TF33PW102)	3.96	< 0.0001	50.67	32.06	87.31
C-135 New (F108GE201) vs. Retired (TF33PW105)	3.54	0.0004	56.15	29.75	99.61
C-135 Full Period (F108GE100) vs. Retired (TF33PW5)	-3.39	0.0007	-75.91	-95.46	-34.60
C-5 New (F138GE100) vs. Retired (TF39GE1)	-2.14	0.032	-65.44	-114.14	-17.44

Note. Test statistic based on large sample approximation (Z-score). Costs are standardized to Base Year 2019. Values are dollars by Primary Aircraft Authorization by Flying Hour. Numbers rounded to two digits after decimal place.

TABLE 8. DESCRIPTIVE STATISTICS OF AIRCRAFT MAINTENANCE COSTS BY PRIMARY AIRCRAFT AUTHORIZATION BY FLYING HOUR

MDS	Status	TMS	N	Mean $	Median $	Std Dev $	CV
C-130	New	AE2100	24	43.82	30.21	57.1	1.30
	Retired	T56A7	13	20.62	12.84	23.7	1.15
	Full Period	T56A15	223	201.07	137.72	220.1	1.09
C-135	New	F108GE201	36	91.54	65.40	81.5	0.89
	Retired	TF33PW102	9	14.62	12.38	5.4	0.37
	Retired	TF33PW105	6	9.69	9.25	7.6	0.79
	Retired	TF33PW5	7	97.72	96.04	69.4	0.71
	Retired	TF33PW9	7	56.74	69.08	50.2	0.88
	Full Period	F108GE100	42	14.55	7.28	15.6	1.07
C-5	New	F138GE100	10	80.77	35.43	87.7	1.09
	Retired	TF39GE1	35	135.75	131.14	68.2	0.50

Note. Costs are standardized to Base Year 2019.

As when we compared fuel performance, we excluded outliers that were more than three standard deviations from the mean (within their respective MDS and TMS). This resulted in the removal of only nine points across all the MDS. Figures 5 – 7 illustrate the maintenance costs for the C-130, C-135, and C-5 MDS, respectively. The maintenance costs are inclusive of CAPE 1.2 (unit-level maintenance) as well the 3.0 categories recorded in AFTOC (CAPE 3.1 through 3.4; consumable materials and repair parts, depot-level repairables, intermediate maintenance [external to unit-level], and depot maintenance). Note: Figure 7 shows a large decrease in the cost of maintaining the C-5M, which can be partially explained by CLS (~23% of C-5M maintenance) and by the growth in PAA inventory from less than 10 (2011) to almost 50 (2018), which would exaggerate the effects of any fixed costs using the PAA/FH metric. Table 7 reflects the associated Wilcoxon Rank Sum tests and Hodges-Lehmann values for comparing the new engines to the retired ones and engines spanning the entire AFTOC observational window of 1999–2019. Table 8 contains the descriptive statistics of the maintenance cost data for each engine by MDS.

Overall, the maintenance results are mixed. Within the C-130 MDS family, both the retired and the new engines appear cheaper to maintain in comparison to the full period engines. Within the C-5s, the new engines were initially more expensive, but the costs quickly fell to lower levels. Although such a trend is consistent with the bathtub concept of perhaps a steady state occurring, the almost fivefold increase in PAA from 2011 to 2018 certainly contributed to this decreasing trend. The most interesting results are from the C-135 models; here, the new engine appears much more expensive to maintain with the exception that the F108GE201 tested as more expensive than the TF33PW105, but not the TF33PW5—all of which belong to the RC-135V/W. We must caution that these statistical comparisons may need to be tempered given that we excluded CLS maintenance data that could not be gathered to the engine level.

Conclusions

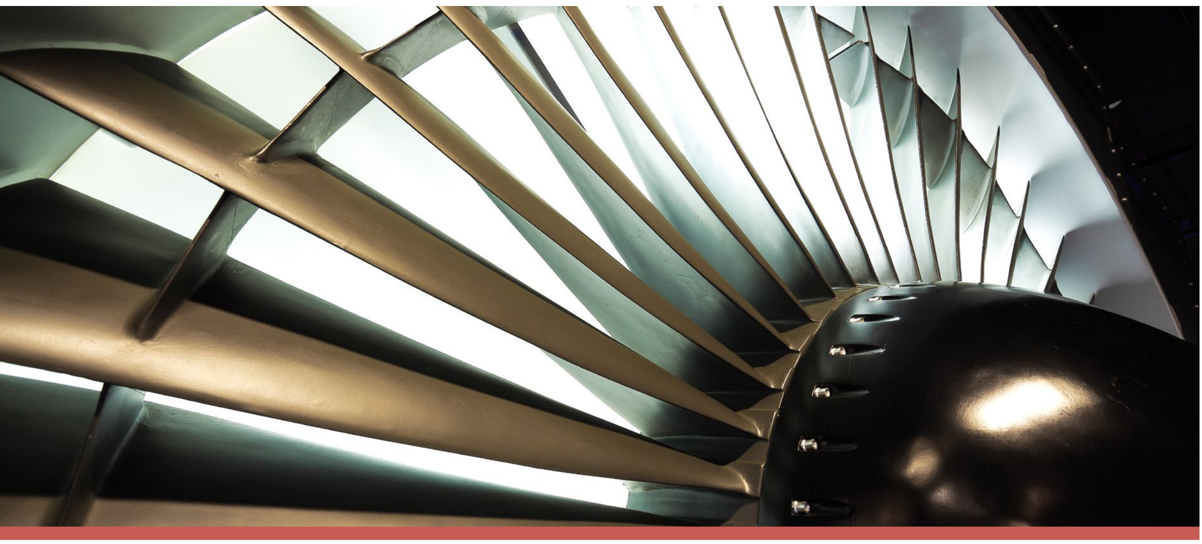
Understanding how new engines may potentially affect costs associated with fuel performance and maintenance should improve program O&S cost estimates. This is particularly important since O&S costs are historically some of the most difficult costs to correctly capture (Ryan et al., 2012). Better estimates arm decision makers with better information. Properly informed decision makers can then decide between alternatives balancing the cost or performance of an engine modification. Decision makers will likely value improved O&S estimates as evidenced by the recent increase in the focus of getting O&S costs estimates correct (Government Accountability Office, 2010).

In this article, we investigated three new engines for fixed-wing aircraft introduced into the USAF inventory in the past 20 years: the AE-2100 on the C-130 "J" models, the F138-GE-100 on the C-5M, and the F108-CF-201 on the RC135 models. For these cargo/reconnaissance aircraft, we observed improvements in fuel efficiencies. In all instances observed during the entire study period (1999–2019), statistically significant findings consistently showed the new engines had better fuel efficiency in comparison to retired engines or engines still in service. Fuel performance is rated better in the estimated range of 28 to 280 fewer gallons/FH on cargo aircraft. Maintenance costs are difficult to quantify, because costs available by engine are approximated and do not include CLS. Also, steady state to steady state comparisons are not available using AFTOC data. From the data that are available, it appears that maintenance costs on the new engines are significantly lower than the engines they are replacing for the C-5 and C-130, but higher for the C-135. We recommend that further studies address return-on-investment strategies since there will be expenses in procuring and installing the new engines, including costs associated with spares inventory, training equipment (i.e., simulators), pilot training, or possible specialized maintenance tooling/equipment, etc.

> **"While we realize this analysis is more exploratory than confirmatory in nature, we believe the potential saving is considerable when updating fixed aircraft with more modern, fuel-efficient engines.**

To conclude, we now use a case study for the cost savings that could occur using the recent re-engine efforts from the E-8 Joint Surveillance Target Attack Radar System (JSTARS) aircraft. The JSTARS was in the process of acquiring new engines, with $160 million in then-year dollars on research, development, test and evaluation from 2007 to 2011 based on the President's Budget in those years. However, the acquisition of the engines has not yet materialized. JSTARS uses the TF33-P-102C, which has similar characteristics to the TF33-PW-102 (Air Force Life Cycle Management Center, 2014) and was analyzed in this study. From our database, the median consumption rate for this engine was 1,852 gallons/FH.

If the JSTARS had new engines with similar fuel consumption as the F108-GE-201, based on our data, the median consumption rate would drop to 1,745 gallons/FH. This is a net saving of 107 gallons/FH. Using the 2020 Defense Logistics Agency standard rate for JP-8 of $2.96 per gallon, this translates into a saving of approximately $317/FH. If we use the maintenance data from Table 6 that suggests that the newer engines cost more to operate by approximately $53/PAA/FH and subtract that from $317/FH, we get a net saving of $264/PAA/FH. Using AFTOC data over the last 6 years, the JSTARS has averaged 8,100 flying hours per year, which equates to approximately a $2.1 million saved per year. Even using a conservative 2% inflation rate, this saving in present value is slightly over $51 million over 20 years. Given how long engines stay in inventory, 20 years may also prove to be conservative. While we realize this analysis is more exploratory than confirmatory in nature, we believe the potential saving is considerable when updating fixed aircraft with more modern, fuel-efficient engines. Over the lifespan of a fixed-wing aircraft, this has the potential of significantly reducing overall O&S costs.



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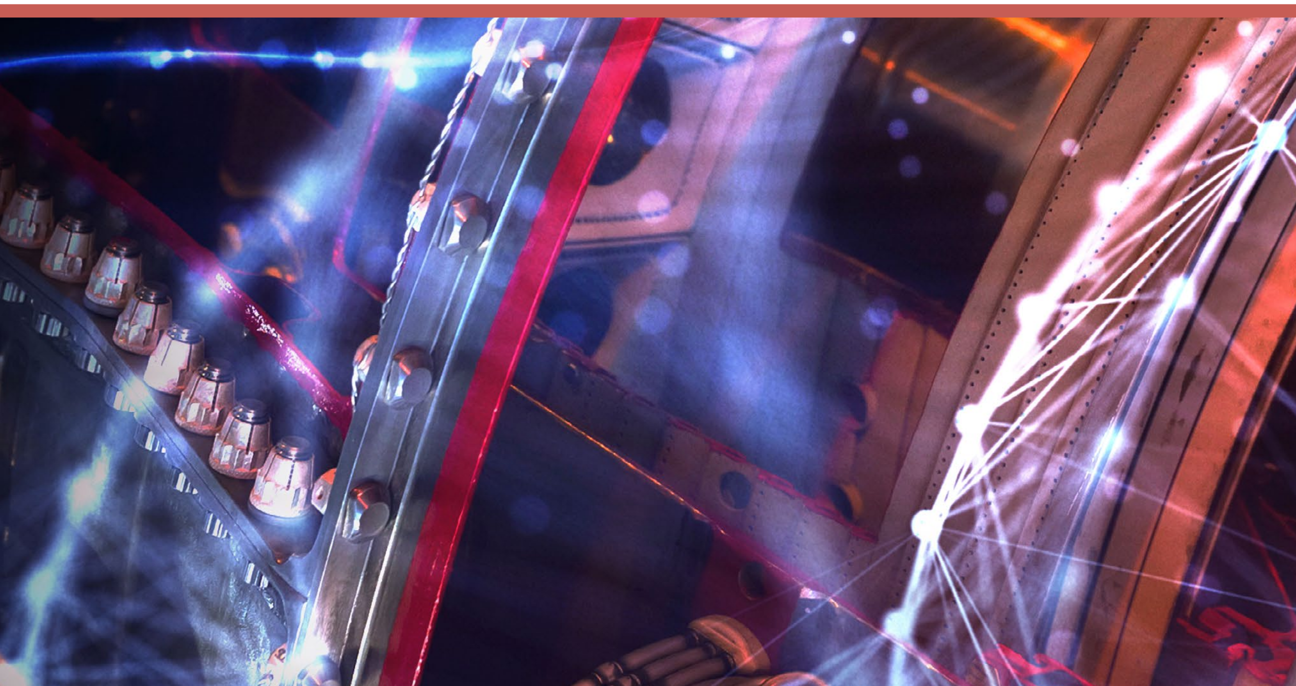

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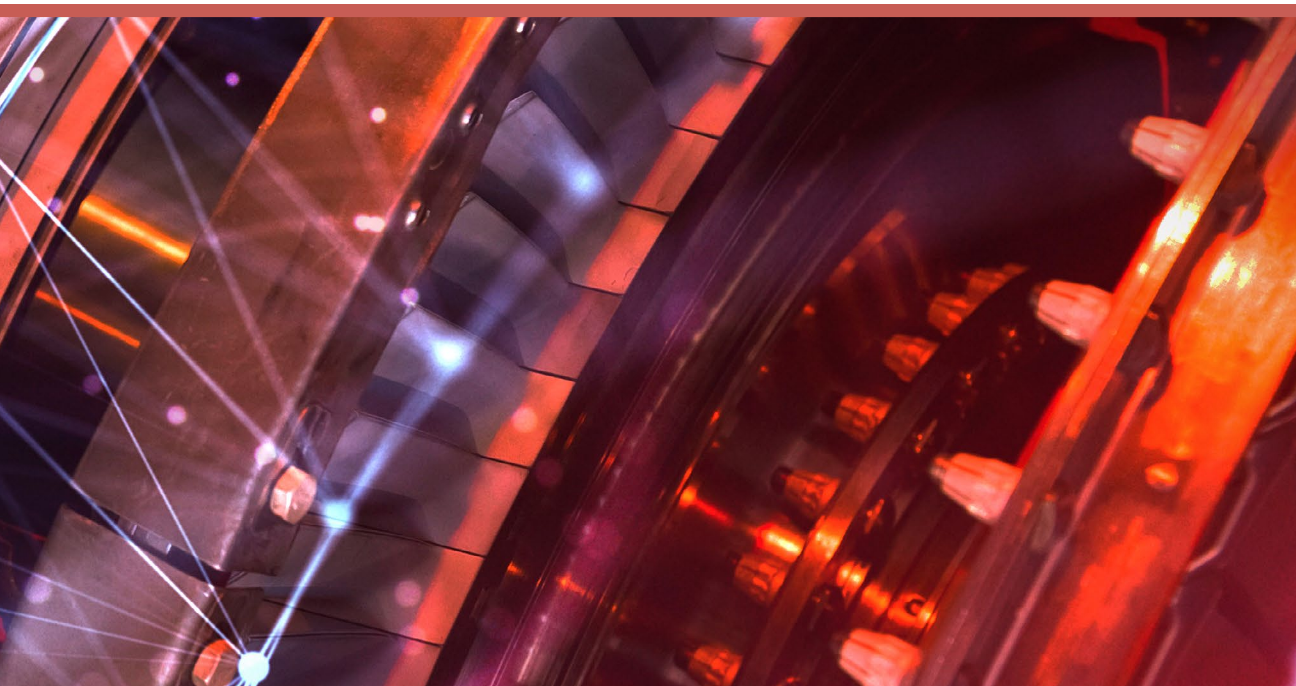


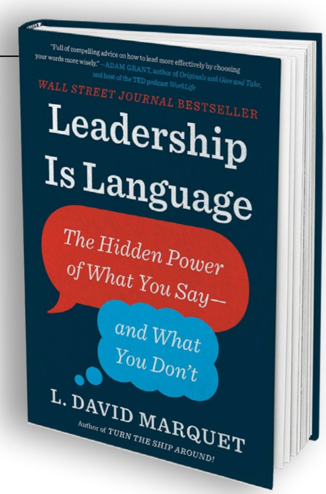
PROFESSIONAL READING LIST

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

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

Featured Book

Leadership Is Language: The Hidden Power of What You Say—and What You Don't

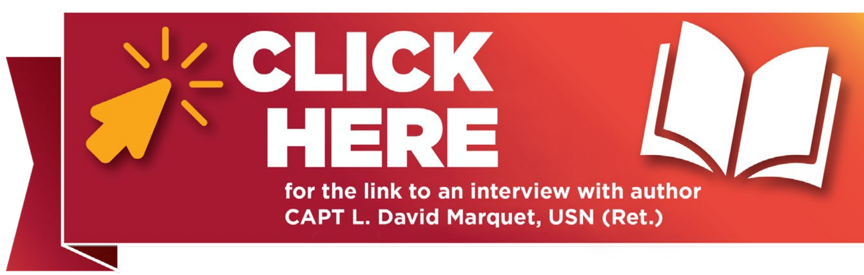


Author: CAPT L. David Marquet, USN (Ret.)
Publisher: Portfolio
Copyright Date: 2020
Hard/Softcover/Digital: Hardcover, 352 pages
ISBN-13: 9780735217539
Reviewed by: Brian J. Duddy, Professor of Program Management, DAU, Mid-West Region

Review:

The title, *Leadership Is Language*, is based on the premise that if you work with your hands, those are the tools of your job; but if you are a leader in an organization, your primary tool is language, and by extension, communication. The title is really a misnomer—it is not descriptive enough to encompass the wide range of topics covered in the book. David Marquet touches not only on leadership but really the very nature of work in the 21st century and how we need to view work differently than we have in the past. Marquet's view was shaped for decades by what he calls the "Industrial Age" approach to productivity and reducing variability. To explain his general view of work, he divides the workforce into Thinking Work, which he calls Blue Work, and Doing Work, which he calls Red Work. Each organization has its own ratio of Blue Work vs. Red Work, and learning how to integrate the two types is key to a successful organization. The thrust of his approach is that much more thinking work is going on now by more people than in the past, so organizations need to get away from the Industrial Age "assembly line" approach to everything they do and integrate thinking and doing.

Marquet analyzes a number of organizational failures and draws lessons from them that can be applied to leading thinking organizations. He presents models for integration of the Blue Work/Red Work cycle that can be tailored to the mission of each organization. Much of what he proposes with regard to the future of work might be considered obvious or "common sense," yet few have taken the time to sit down, analyze it, and write it out in such a clear and executable manner.



Marquet provides details of his approach in a new "Playbook" more tailored for how organizations—especially ones like acquisition with a predominance of Blue Work—should function for maximum effectiveness in today's world. Among those new plays are: Controlling the Clock vs. Obeying the Clock; Collaborating vs. Coercing; Committing vs. Complying; Completing vs. Continuing; Improving vs. Proving; and Connecting vs. Conforming. All those are meant to better optimize both the time available and the brainpower possessed by the members of the organization. He also highlights negative situations where an "Escalation of Commitment" seduces organizations into pouring more resources into a clearly failed strategy.

Marquet's approach offers many advantages to an array of different organizations—everything from maximizing customer satisfaction, avoiding disasters and the waste of resources, to an overall deeper buy-in and commitment from everyone throughout the organization. He really speaks to the type of work we do in acquisition and his approach will certainly resonate.

As a former military officer, Marquet's writing style will be easily grasped and digested by all currently or formerly affiliated with DoD, but he also spends a lot of time analyzing events and failures in the commercial world. Regardless of your career field, every acquisition practitioner can glean something from the universal situations described in this book.

Current Research Resources in DEFENSE ACQUISITION

Remote Work for Government and Business

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

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

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

Work-From-Anywhere: The Productivity Effects of Geographic Flexibility

Prithwiraj (Raj) Choudhury, Cirrus Foroughi, and Barbara Larson

Summary:

An emerging form of remote work allows employees to work-from-anywhere (WFA), so that the worker can choose to live in a preferred geographic location. While traditional work-from-home (WFH) programs offer the worker temporal flexibility, WFA programs offer both temporal and geographic flexibility. … We study the effects of WFA on productivity at the United States Patent and Trademark Office (USPTO) and exploit a natural experiment in which the implementation of WFA was driven by negotiations between managers and the patent examiners' union, leading to exogeneity in the timing of individual examiners' transition from a WFH to a WFA program.

APA Citation:

Choudhury, P., Foroughi, C., & Larson, B. (2021). Work-from-anywhere: The productivity effects of geographic flexibility. *Strategic Management Journal, 42*(4), 655–683. https://doi.org/10.1002/smj.3251

Remote Workforces, Expletives at Work, and Problems with Masks, Shirts, and Hats

Barbara E. Hoey, Mark A. Konkel, Maria Biaggi, and Nidhi Srivastava

Summary:

The U.S. Department of Labor (DOL) has published additional guidance addressing questions arising from the COVID-19 pandemic under the federal Fair Labor Standards Act, the Family and Medical Leave Act, and the Families First Coronavirus Response Act. This guidance is particularly apropos, as more and more employers realize that the "new normal" is a world of remote work, with some employers extending telework on an indefinite basis. Herein are some interesting questions the DOL answered and our takeaways from the guidance.

APA Citation:

Hoey, B. E., Konkel, M. A., Biaggi, M., & Srivastava, N. (2020, Winter). Remote workforces, expletives at work, and problems with masks, shirts, and hats. *Employee Relations Law Journal, 46*(3), 78–83. http://search.ebscohost.com/login.aspx?direct=true&AuthType=ip&db=bsu&AN=146209411&site=ehost-live&scope=site

Five Ways Leaders Can Support Remote Work

Donald Sull, Charles Sull, and Josh Bersin

Summary:

The COVID-19 pandemic has forced many employees to work from home, and the magnitude of the shift to remote work is staggering. Before the pandemic, about 15% of U.S. employees were working from home at least some of the time. During the first half of April, half of U.S. employees were doing all of their work remotely. Here, Sull et al. discuss the challenges with remote work.

APA Citation:

Sull, D., Sull, C., & Bersin, J. (2020, Summer). Five ways leaders can support remote work. *MIT Sloan Management Review, 61*(4), 1–10. https://search.proquest.com/scholarly-journals/five-ways-leaders-can-support-remote-work/docview/2427314594/se-2?accountid=40390

Federal Telework During the COVID-19 Pandemic: Cybersecurity Issues in Brief

Chris Jaikaran

Summary:

President Trump declared the Coronavirus Disease 2019 (COVID-19) a national emergency in March 2020. In an effort to slow the transmission of COVID-19, the Office of Management and Budget (OMB) ordered federal agencies to "maximize telework across the nation for the federal workforce (including mandatory telework, if necessary), while maintaining mission-critical workforce needs." Private sector companies are taking similar measures. This report provides information on telework in practice at federal agencies and potential effects of telework on our communications infrastructure, data, and security.

APA Citation:

Jaikaran, C. (2020, April 10) *Federal telework during the COVID-19 pandemic: Cybersecurity issues in brief*. Congressional Research Service. https://crsreports.congress.gov/product/pdf/R/R46310

What's Next for Remote Work: An Analysis of 2,000 Tasks, 800 Jobs, and Nine Countries

Susan Lund, Anu Madgavkar, James Manyika, and Sven Smit

Summary:

Remote work raises a vast array of issues and challenges for employees and employers. Companies are pondering how best to deliver coaching remotely and how to configure workspaces to enhance employee safety, among a host of other thorny questions raised by COVID-19. For their part, employees are struggling to find the best home-work balance and equip themselves for working and collaborating remotely. In this article, however, we aim to granularly define the activities and occupations that can be done from home to better understand the future staying power of remote work. We have analyzed the potential for remote work—or work

that doesn't require interpersonal interaction or a physical presence at a specific worksite—in a range of countries: China, France, Germany, India, Japan, Mexico, Spain, the United Kingdom, and the United States. We used the Materials Genome Initiative (MGI) workforce model based on the Occupational Information Network (O*NET) to analyze more than 2,000 activities in more than 800 occupations and identify which activities and occupations have the greatest potential for remote work.

APA Citation:

Lund, S., Madgavkar, A., Manyika, J., & Smit, S. (2020, November). *What's next for remote work: An analysis of 2,000 tasks, 800 jobs, and nine countries*. McKinsey Global Institute. https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Future%20of%20Organizations/Whats%20next%20for%20remote%20work%20An%20analysis%20of%202000%20tasks%20800%20jobs%20and%20nine%20countries/Whats_next_for_remote_work_F.pdf?shouldIndex=false

Our Work-From-Anywhere Future

Prithwiraj (Raj) Choudhury

Summary:

The pandemic has hastened a rise in remote working for knowledge-based organizations. This has notable benefits: Companies can save on real estate costs, hire and utilize talent globally, mitigate immigration issues, and experience productivity gains, while workers can enjoy geographic flexibility. At the same time, concerns include how to communicate across time zones, share knowledge that isn't yet codified, socialize virtually and prevent professional isolation, protect client data, and avoid slacking. Research into work-from-anywhere (WFA) organizations and groups that include the United States Patent and Trademark Office, Tata Consultancy Services, and GitLab (the world's largest all-remote company) highlights best practices and can help leaders decide whether remote work is right for their organizations.

APA Citation:

Choudhury, P. (2020, November-December). Our work-from-anywhere future. *Harvard Business Review*, 59–67. https://hbr.org/2020/11/our-work-from-anywhere-future

Federal Telework: Key Practices That Can Help Ensure the Success of Telework Programs

Michelle B. Rosenberg

Summary:

Telework offers benefits to federal agencies as well as to the federal workforce. These include improving recruitment and retention of employees, reducing the need for costly office space, and an opportunity to better balance work and family demands. In addition, telework is a tool that agencies can use to help accomplish their missions during periods of disruption, including during the current COVID-19 pandemic. Congress has encouraged federal agencies to expand staff participation in telework, most recently by passing the Telework Enhancement Act of 2010 (the Act). The Act established requirements for executive agencies' telework policies and programs, among other things. This statement provides key practices to help ensure the success of telework programs. The statement is based on the Government Accountability Office's body of work on federal telework issued from July 2003 through February 2017.

APA Citation:

Federal telework: Key practices that can help ensure the success of telework: Hearing before the U.S. Senate Subcommittee on Regulatory Affairs and Federal Management, Committee on Homeland Security and Governmental Affairs, 116th Cong. (2020) (testimony of Michelle B. Rosenberg). https://www.gao.gov/assets/gao-21-238t.pdf

Sustaining Employee Networks in the Virtual Workplace

Daniel Z. Levin and Terri R. Kurtzberg

Summary:

The coronavirus pandemic has led to a surge in virtual work across companies, with many or even all employees working from home for an extended period of time. One of the key unintended consequences of this widespread switch to virtual work is the impact on the relationships and interpersonal networks within organizations. By better understanding

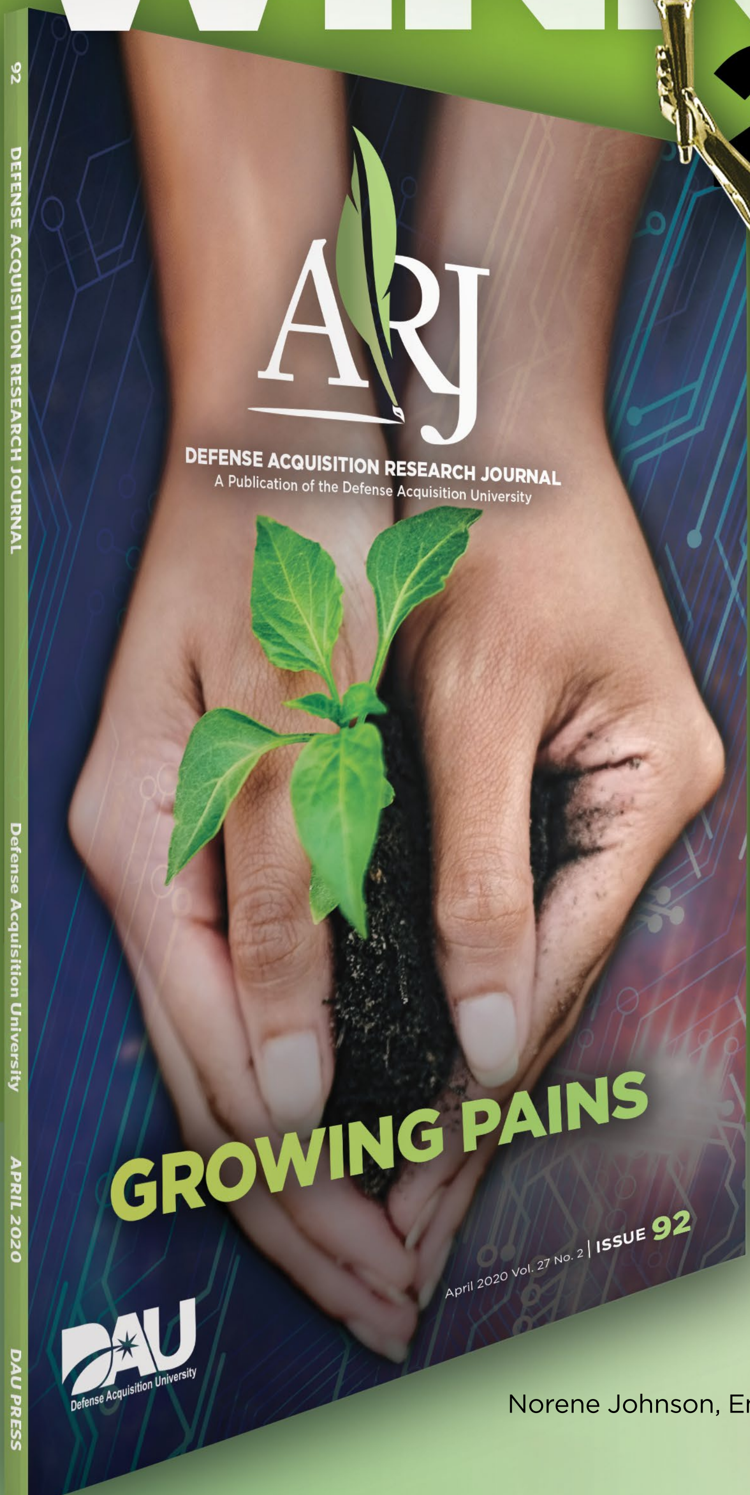
how working remotely can damage connections, trust, and cooperation, managers can act to mitigate those effects. One of the biggest drivers of who interacts with whom in organizations is physical proximity—a phenomenon that's been observed from the U.S. Senate to the Google campus. Amazingly, even a distance of a meter or two can make a big difference. When everyone goes virtual, though, employees can no longer casually run into someone in the hallway or one desk over. They do still keep in touch with the people they feel closest to, and with coworkers they're required to work with on particular tasks, but with everyone else, the level of interaction is drastically reduced.

APA Citation:

Levin, D. Z., & Kurtzberg, T. R. (2020, Summer). Sustaining employee networks in the virtual workplace. *MIT Sloan Management Review, 61*(4), 13–15. https://search.proquest.com/scholarly-journals/sustaining-employee-networks-virtual-workplace/docview/2414423277/se-2?accountid=40390

MARCOM AWARD FOR PEER REVIEWED ACADEMIC JOURNAL

WINNER 2020



Norene Johnson, Emily Beliles, and Michael Krukowski

DAU Press

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

IN GENERAL

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

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

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

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

MANUSCRIPTS

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

Research Articles

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

- clearly state the question,
- define the research methodology,

- describe the research instruments (e.g., program documentation, surveys, interviews),
- describe the limitations of the research (e.g., access to data, sample size),
- summarize protocols to protect human subjects (e.g., in surveys and interviews), if applicable,
- ensure results are clearly described, both quantitatively and qualitatively,
- determine if results are generalizable to the defense acquisition community
- determine if the study can be replicated, and
- discuss suggestions for future research (if applicable).

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

Case Histories

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

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

Each case history should contain the following components:

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

Book Reviews

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

Audience and Writing Style

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

Format

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

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

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

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

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

SUBMISSION

All manuscript submissions should include the following:

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

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

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

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

Defense ARJ
PRINT SCHEDULE

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

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

Author Deadline	Issue
July	January
October	April
January	July
April	October

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

Contributors may direct their questions to the Managing Editor, *Defense ARJ*, at the address shown below, or by calling 703-805-3801 (fax: 703-805-2917), or via the Internet at norene.johnson@dau.edu.

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Please see our guidelines for contributors for submission deadlines.

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

- Share your acquisition research results with the Acquisition and Sustainment (A&S) community.
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- Be asked to speak at a conference or symposium.

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

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

Defense Acquisition Research Journal SURVEY

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