Defense AR Journal
December 2008 Vol. 15 No. 3
A PUBLICATION OF THE DEFENSE ACQUISITION UNIVERSITY

49

Incentive Contracts
The Attributes that Matter Most in Driving Favorable Outcomes
Robert L. Tremaine

Maximizing Warfighter Capability Using Surveyed Necessity Measurement
Application to the USAF F-15C Fleet
John M. Colombi
David R. Jacques
Dennis D. Strouble

Training Architecture Practices in Army Acquisition
An Approach to Training Software Architecture Practices in U.S. Army Acquisition
Stephen Blanchette
John Bergey

The Application of Supply Network Optimization and Location Analysis to a DoD Repair Supply Chain
William R Killingsworth
David Berkowitz
John E. Burnett
James T. Simpson

Reforming How Navy Shipbuilding Contracts Adjust for Material-Cost Risk
Edward G. Keating
Robert Murphy
John F. Schank
John Birkler

Do Team Goals Affect Team Focus and Performance?
A Research Study of DAU's Program Management Office Course (PMT 352B)
Thomas Robert Edison

Frank J. Anderson, Jr.
President, Defense Acquisition University

Board of Review

Anthony Martoccia
Office of Small Business Programs
Department of Defense

Shay Assad
Director, Defense Procurement,
Acquisition Policy and Strategic Sourcing
Office of the Under Secretary of Defense
(Acquisition, Technology and Logistics)

Dr. J. Ronald Fox
Professor Business Administration, Emeritus
Harvard Business School

ADM James R. Hogg, U.S. Navy (Ret)
Director, Chief of Naval Operations, Strategic Studies Group

Scottie Knott
Director, Acquisition Management, Senior Procurement Executive, and Component Acquisition Executive, Defense Logistics Agency

John J. Young
Under Secretary of Defense
(Acquisition, Technology and Logistics)

Dr. Diane R. Murphy
Chief Executive Officer/Founder
Information Technology Management Institute

April G. Stephenson
Director
Defense Contract Audit Agency

Eleanor Spector
Vice President of Contracts
Lockheed Martin Corporation

Kathryn C. Turner
President and Chief Executive Officer
Standard Technology, Inc.

Editorial Board

Dr. Paul Alfieri
Chairman and Executive Editor

Dr. Richard Donnelly
The George Washington University

Randy T. Fowler
Curriculum Development and Support Center, Defense Acquisition University

Dr. Ned Kock
Texas A&M International University

Dr. Ira Lewis
Naval Postgraduate School

Dr. E. Johnson Marits
The George Washington University

Dr. Mark Montroll
Industrial College of the Armed Forces

Joseph Johnson
DAU Chief of Staff

Dr. Keith Snider
Naval Postgraduate School

Charles E. Tompkins III, Esq.
Information Resources Management College

Eduard H. Boyd
Director, DAU Press

Norene L. Fagan-Blanch
Managing Editor

Denise Balon and Niki Dowdell
Editorial Assistants

Paula Croisetiere
Prepress Production Manager

Harambee Dennis
Graphic Designer

Schatz Publishing Group and Collie Johnson
Technical Editing, Design, and Layout

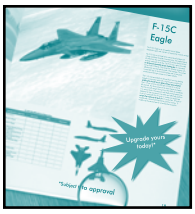
The ***Defense Acquisition Review Journal***, formerly the ***Acquisition Review Quarterly*** journal, is published quarterly by the Defense Acquisition University (DAU) Press. Postage is paid at the U.S. Postal facility, Fort Belvoir, VA, and at additional U.S. Postal facilities. Postmaster, send address changes to: Editor, ***Defense Acquisition Review Journal***, DAU Press, 9820 Belvoir Road, Suite 3, Fort Belvoir, VA 22060-5565. For free copies, mail written requests with an original signature to the above address using the subscription form provided in this journal. Articles represent the views of the authors and do not necessarily reflect the opinion of the DAU or the Department of Defense. Some photos appearing in this publication may be digitally enhanced. ISSN 1553-6408.

The ***Defense Acquisition Review Journal*** is available electronically on the DAU Home Page at
http://www.dau.mil/pubs/arqtoc.asp

TABLE OF CONTENTS

DECEMBER 2008
VOL. 15, NO. 3

DEFENSE
ACQUISITION REVIEW JOURNAL



A NOTE FROM THE EXECUTIVE EDITOR

217 **INCENTIVE CONTRACTS: THE ATTRIBUTES THAT MATTER MOST IN DRIVING FAVORABLE OUTCOMES**
Robert L. Tremaine

Incentive contracts have been in place for many years. They represent just one of many contractual tools the Department of Defense has at its disposal to drive certain performance behaviors. Lately, the usefulness of incentive contracts has come into question. The dividends have not been readily apparent. This research study set out to determine what generally afforded strong correlations between incentive-type contracts and expected performance outcomes. Twenty-five weapon system acquisition program offices were interviewed in various stages of their acquisition life cycle. A standardized questionnaire-survey was used to capture the data. This article addresses the findings and includes a few key recommendations intended to highlight learning assets available to the acquisition workforce on the use of incentive contracts.

241 **MAXIMIZING WARFIGHTER CAPABILITY USING SURVEYED NECESSITY MEASUREMENT: APPLICATION TO THE USAF F-15C FLEET**
John M. Colombi, David R. Jacques, and Dennis D. Strouble

Within the Department of Defense, with changing missions to counter dynamic and asymmetrical threats, the acquisition workforce strives to maximize capability for joint warfighting. How acquisition professionals measure and select capability improvements for the nation's weapon systems is a perpetual

challenge, made even more complex with constrained defense budgets. This study identifies a method for determining which upgrades should be purchased (production) for which aircraft in the F-15C fleet by optimizing a capability proxy measure. Each upgrade's "necessity" for a given mission area was obtained by conducting a survey of over 250 experienced F-15C pilots. The solution presented in this article should be extensible to other weapon system capability decisions.

261 **TRAINING ARCHITECTURE PRACTICES IN ARMY ACQUISITION: AN APPROACH TO TRAINING SOFTWARE ARCHITECTURE PRACTICES IN U.S. ARMY ACQUISITION**

Stephen Blanchette and John Bergey

Technology management skills in the Department of Defense (DoD) are not keeping pace with the advanced systems acquired by the DoD, especially as software becomes more prevalent in those systems. For a number of years, software architecture practices have been identified as enablers of program success, yet evidence suggests that too little attention is paid to the topic. The Army Strategic Software Improvement Program (ASSIP) seeks to dramatically improve the acquisition of software-intensive systems, in part through improved acquisition workforce skills. Through ASSIP, the Army has begun to build a level of technical expertise in modern software architecture practices within its acquisition community. This article discusses the training component of the ASSIP Software Architecture Initiative.

277 **THE APPLICATION OF SUPPLY NETWORK OPTIMIZATION AND LOCATION ANALYSIS TO A DoD REPAIR SUPPLY CHAIN**

William R. Killingsworth, David Berkowitz, John E. Burnett, and James T. Simpson

A major responsibility of the military and its suppliers is to provide an adequate supply of parts and materials to support warfighters throughout the world. This article reviews a process used by an Army global supply chain to make a location decision for a critical distribution center. Additionally, it demonstrates the applicability of network optimization techniques to a DoD supply chain location analysis problem. Finally, it investigates the feasibility of making a $15 or $25 million capital investment to provide an alternative repair facility.

293 **REFORMING HOW NAVY SHIPBUILDING CONTRACTS ADJUST FOR MATERIAL-COST RISK**

Edward G. Keating, Robert Murphy, John F. Schank, and John Birkler

This article describes how the U.S. Navy structures fixed-price and fixed-price, incentive-fee shipbuilding contracts and how labor- and material-cost indexes can mitigate shipbuilder risk in either type of contract. The Navy frequently uses the Steel Vessel material-cost index, a Bureau of Labor Statistics-derived cost index based on the mix of materials in a typical commercial cargo ship constructed in the 1950s. The Steel Vessel Index has excessive weighting on iron and steel, thereby providing shipbuilders with a mismatch between their actual and the Index-assumed material cost structure. The authors recommend the Navy use a material-cost index with more up-to-date weightings.

307 **DO TEAM GOALS AFFECT TEAM FOCUS AND PERFORMANCE? RESEARCH STUDY OF DAU'S PROGRAM MANAGEMENT OFFICE COURSE (PMT 352B)**

Thomas Robert Edison

Teams can be a significant resource to business leaders and can help lead to greater program successes. This study was conducted on student project teams in 12 classes of a Defense Acquisition University (DAU) executive-level, 6-week program management class in six different locations. The study not only underscores the significance of team focus on performance, but also highlights how team characteristics affect team focus and performance. Significant direct relationships were found in the study's 15 tested hypotheses between work team strategic intent (the team's purpose, objectives, and strategies) and team performance, as measured by team self-assessments and instructor assessments. The results of this study have applications to the successful use of project teams throughout DoD.

320 **CALL FOR AUTHORS**

321 **GUIDELINES FOR CONTRIBUTORS**

DEFENSE ARJ EXECUTIVE EDITOR

Welcome to the *Defense Acquisition Review Journal* (ARJ) Issue No. 49. Our first article in this issue is "Incentive Contracts: The Attributes That Matter Most in Driving Favorable Outcomes," by Robert L. Tremaine. This article summarizes the efforts of a DAU research team headed by the author, which was established to investigate and analyze the findings of the Government Accountability Office (GAO) regarding the use of incentives in Department of Defense (DoD) contracting. This is the second article from this research project to appear in the *ARJ*. The first article, which appeared in Issue No. 48, was a subordinate article by two members of the research team and focused on selected parts of the study. This article, which is more extensive and comprehensive, captures the entire findings from all 25 organizations participating in this Office of the Secretary of Defense-sponsored research. Incentive contracts have been in place for many years, and they represent only one of the many contractual tools the DoD has at its disposal to drive certain performance behaviors. The objective of this study was to determine what correlations exist between incentive-type contracts and expected performance outcomes.

The second article, "Maximizing Warfighter Capability Using Surveyed Necessity Measurement: Application to the USAF F-15C Fleet," by John M. Colombi, David R. Jacques, and Dennis D. Strouble, examines how upgrades and modifications to a legacy weapon system can logically be prioritized and implemented. Within the DoD, with changing missions to counter dynamic and asymmetric threats, the Services strive to maximize capability for joint warfighting. A good example is the F-15C program, for which there are a number of available capability upgrades that can markedly improve combat capability and reliability. However, the defense budget does not allow the F-15C program manager to acquire all potential upgrades for every aircraft. The purpose of this research study was to identify a methodology for determining which upgrades should be purchased for which aircraft in the fleet, by quantitatively using a capability proxy measure. In the attempt to comparatively measure capability, each upgrade's "necessity" for a given mission area was obtained by conducting a survey of over 250 experienced F-15C pilots. This "necessity" was

gauged relative to the F-15C's expected role in the Concept of Operations of Global Persistent Attack and Homeland Security. A linear programming model searched for the optimal configuration, which maximized capability of a weapon system—in this case the F-15C—constrained against an overall production budget authority. The solution to this problem is provided, as well as challenges to mathematical acquisition deciding-aiding.

In the third article, "Training Architecture Practices in Army Acquisition: An Approach to Training Software Architecture Practices in U.S. Army Acquisition," Stephen Blanchette and John Bergey examine the training concept of the Army Strategic Software Improvement Program (ASSIP) Software Architecture Initiative. Technology management skills in DoD are not keeping pace with the advanced systems acquired by DoD, especially as software becomes more prevalent in those systems. ASSIP seeks to dramatically improve the acquisition of software-intensive systems by building a level of technical expertise in modern software architecture practices within the acquisition community. The Software Engineering Institute has been working with the Army in a strategic partnership aimed at improving the ability to acquire software-intensive systems.

The fourth article is "The Application of Supply Network Optimization and Location Analysis to a DoD Repair Supply Chain," by William R. Killingsworth, David Berkowitz, John E. Burnett, and James T. Simpson. The authors discuss the responsibility of the military and its suppliers to provide an adequate supply of parts and materials to support warfighters throughout the world. Using an Army helicopter case study, this article reviews a process used by an Army global supply chain to make a location decision for a critical distribution center. Additionally, the authors demonstrate the applicability of network optimization techniques to a supply chain location analysis problem.

The fifth article, "Reforming How Navy Shipbuilding Contracts Adjust for Material-Cost Risk," is authored by Edward G. Keating, Robert Murphy, John F. Schank, and John Birkler. This article describes how the U.S. Navy structures fixed-price and fixed-price, incentive-fee shipbuilding contracts and how labor- and material-cost indexes can mitigate shipbuilder risk in either type of contract. The Navy frequently uses the Steel Vessel material-cost index, a Bureau of Labor Statistics-derived cost index based on the mix of materials in a typical commercial cargo ship constructed in the 1950s. The Steel Vessel Index has excessive weighting on iron and steel, thereby providing shipbuilders with a mismatch between their actual and the Index-assumed material cost structure. The authors recommend the Navy use a material-cost index with more up-to-date weightings. Moving toward a better index would also be an opportunity to explore a time-phased material-cost index, e.g., reflect the fact that shipbuilders typically buy keel steel early in production with on-board electronics procured much later in the construction process. The more accurately a material-cost index captures a shipbuilder's external material cost risk, the less the Navy should have to pay its shipbuilders.

The sixth article in this issue, "Do Team Goals Affect Team Focus and Performance? Research Study of DAU's Program Management Office Course (PMT-352B), is by Thomas Robert Edison. This article characterizes a study of work team per-

formance in organizations. The Department of Defense, along with many defense industry partners operating in today's complex and dynamic work environments, is becoming increasingly more dependent on *work teams* as a means of maximizing creativity and efficiency from its acquisition workforce. Work teams can be an important resource to defense/business leaders and can help optimize effectiveness of organizations resulting in greater program successes.

Dr. Paul Alfieri
Executive Editor
Defense ARJ

NOTE FROM THE MANAGING EDITOR

This note serves as a correction to the volume number for *Defense ARJ* edition 48. Instead of July 2008 Vol. 16 No. 2, the cover should read July 2008 Vol. 15 No. 2.

DECEMBER 2008

Image designed by Schatz Publishing Group

INCENTIVE CONTRACTS: THE ATTRIBUTES THAT MATTER MOST IN DRIVING FAVORABLE OUTCOMES

Robert L. Tremaine

Incentive contracts have been in place for many years. They represent just one of many contractual tools the Department of Defense has at its disposal to drive certain performance behaviors. Lately, the usefulness of incentive contracts has come into question. The dividends have not been readily apparent. This research study set out to determine what generally afforded strong correlations between incentive-type contracts and expected performance outcomes. Twenty-five weapon system acquisition program offices were interviewed in various stages of their acquisition life cycle. A standardized questionnaire-survey was used to capture the data. This article addresses the findings and includes a few key recommendations intended to highlight learning assets available to the acquisition workforce on the use of incentive contracts.

AUTHOR'S NOTE

A subordinate article regarding this research project was published in an earlier *Defense Acquisition Review Journal*, Vol. 48, by two of the seven research team members involved in the same research activity. This article is more extensive and captures the findings of all 25 organizations interviewed in the conduct of this Office of the Secretary of Defense (OSD)-sponsored research. Special thanks are extended to the entire research team, who devoted many hours developing this research approach, conducting interviews, and analyzing the detailed data: Karen Byrd, Leslie Deneault, Alan Gilbreth, Sylvester Hubbard, Leonardo Manning, and Ralph Mitchell.

In the past several years, major weapon system development programs have drawn significant attention. The reasons are varied. In some cases, costs have skyrocketed; schedules have experienced significant delays; and performance levels have failed to meet government expectations despite the employment of management tools designed to control costs, preserve schedule, and influence performance outcomes. Some of these management tools, including contractual measures as originally conceived and specified by the Federal Acquisition Regulation (FAR), can give tremendous flexibility to the implementation of government contracts. Indeed, contractual measures is only one of many handy tools in a program manager's toolkit to help drive performance behavior. However, the Government Accountability Office (GAO) recently identified an apparent disconnect between the use of certain measures like incentives and expected outcomes in weapon system acquisitions. In short, it appeared that incentives were not driving performance outcomes as originally envisioned.

The GAO looked closely at the use of incentives in the Department of Defense (DoD). It conducted structured interviews with contracting and program officials representing 92 contracts from a study population of 597 DoD *incentive-type* contracts active between 1999 and 2003. In its December 2006 report (GAO-06-66), GAO asserted that "DoD has paid billions in Award and Incentive Fees without favorably influencing performance" (GAO, 2005). In essence, the GAO found few results that could be directly traced to the award of incentives. Not surprisingly, its findings set off a few alarms including the efficacy of incentives in general. Were these incentive strategies ill-conceived? Were they poorly applied? Did they work as advertised? Have they outlived their usefulness? What went wrong? These and many other questions immediately surfaced in the Acquisition, Technology and Logistics (AT&L) community. In response to these concerns, (then) Under Secretary of Defense for Acquisition, Technology and Logistics Ken Krieg asked Defense Acquisition University President Frank J. Anderson, Jr. to conduct a research effort designed to better understand where award/incentive fee contracts had a favorable impact on performance outcomes. Consequently, DAU assembled a small team of subject matter experts from its combined regional workforce to understand the suspicious divide. Rather than search for even more verification where incentives failed, however, the research would focus on where incentives succeeded. More specifically, where have incentives specifically worked, why were they effective, and what could be done to restore confidence in incentive contracts? Invariably, confidence in incentive contracts—which has been frequently challenged in the past—would have to be restored in order to garner continued support and calm the critics. Otherwise, the usefulness of incentive strategies would weaken and their continuance become a target of increased scrutiny and uncertainty.

In late April 2006, Anderson met with members of the research team (Table 1) and challenged them to: 1) determine what generally afforded strong correlations between incentives and desired performance outcomes and why; 2) recommend which DAU curricula should be adjusted as a result of the research team's findings in both the near- and far-term; and finally, 3) make both lessons learned and best practices widely available through DAU's Community of Practice (CoP) Web site. Simply

TABLE 1. STUDY TEAM

Defense Acquisition University (DAU) Research Team Members	
Mr. Robert L. Tremaine	DAU West (Project Lead)
Mr. Alan Gilbreth	DAU Mid-West
Mr. Sylvester Hubbard	DAU Mid-West
Mr. Ralph Mitchell	DAU South
Mr. Leonardo Manning	DAU Capital and Northeast
Ms. Karen Byrd	DAU Capital and Northeast
Ms. Leslie Deneault	DAU Capital and Northeast

stated, proven techniques that drove favorable outcomes had to be made accessible to the AT&L-wide community right away; the research had to be purposeful.

RESEARCH APPROACH/METHOD

Up front, the DAU research team carefully reviewed the GAO's report and looked especially close at two of its most critical findings. The GAO had claimed that:

- DoD engages in practices that undermine efforts to motivate contractor performance and that do not hold contractors accountable for achieving desired acquisition outcomes; and
- DoD Programs frequently pay most of the available award fee for what they describe as improved contractor performance, regardless of whether acquisition outcomes fell far short of DoD's expectations, were satisfactory, or exceeded expectations (GAO, 2005).

These two declarations created a veritable research passageway into better understanding what techniques indeed drove favorable performance outcomes—the basis of DAU's research. It also addressed the fundamental problem (Table 2). The imple-

TABLE 2. PROBLEM STATEMENT NARRATIVE

Problem Statement: The implementation of Award/Incentive Fee contracts in DoD is not producing the desired/intended outcomes. In some cases, the acquisition community may not be implementing Award/Incentive Fee Contracts correctly.
Research Objective: DAU needs to understand where Award/Incentive Fee contracts made a favorable difference and why.
End State: Programs need to embrace an incentive fee strategy that achieves and sustains maximum contractor performance with a measurable value to the government.

mentation of Award/Incentive Fee contracts in DoD is not producing the desired/intended outcomes; and in some cases, the acquisition community may not be implementing Award/Incentive contracts correctly. Invariably, programs should embrace an incentive fee strategy that achieves and sustains maximum contractor performance with a measurable value to the government.

GROUND RULES AND ASSUMPTIONS

To both frame and bound the study efforts, DAU's research team developed a few imperatives. The research would not dispute the validity of incentives nor serve as a reclama to the GAO report; the research would look for both deterministic and probabilistic incentive attributes; and finally, the research would begin with a few key assumptions:

- Improved contractor performance has not always been achieved through the use of award fee/incentive fee contracts.
- Award/incentive fee contracts can be powerful tools to favorably influence contractor performance in conjunction with good acquisition fundamentals.
- Empirical evidence/measurable results could play a pivotal role in award/incentive fee determinations.
- GAO conclusions on the ineffectiveness of award/incentive fee contracting could be a result of certain ineffective practices that could be undermining policy.

These ground rules and assumptions would serve as a guidepost throughout this research project. Together, they would help keep the research focused and fixed on the target without drifting from the "end-state" research objective.

FOLLOW-UP DISCUSSIONS WITH THE GAO

For calibration purposes and in search of additional detail, DAU met with the primary authors of the GAO-06-66 Report, Tom Denomme and Ron Schwen, in mid-June 2006 and tunneled deeper into their study findings. Both individuals were very informative. They identified supplementary observations during face-to-face discussions including two striking assessments: (1) Performance outcomes were sometimes unrealistic, and (2) technical performance measures (e.g., predictors of technical progress along a program's pathway) did not seem to factor much in the overall Award Fee (T. Denomme and R. Schwen, personal communication, June 20, 2006). It also became clear that the GAO viewed incentives as a reward, not just a motivational tool.

After allowing for the GAO's additional comments and conducting a fair amount of deliberation on the DAU's research direction, the team fashioned a basic game plan. It centered on a correlational research methodology. In other words, the research study would target the relationships between certain criterion variables (e.g., the "motivators") and projected outcomes (e.g., the "successes").

Ideally, program offices would have the most effective criterion variables and help confirm what Award/Incentive Fee techniques were making a difference—a material difference. As part of their incentive strategy, program offices normally select certain criteria depending on what outcome(s) they need to achieve. Invariably, the team felt

there had to be a few invaluable practices underway. After all, program offices would probably have abandoned or significantly reduced the use of incentives if they were not making a difference and selected an alternative course of action instead.

INCENTIVES DEFINED

Contract incentives are varied, but understanding them and appropriately applying them is crucial. In its basic form, an incentive is really an extraordinary tool for certain applications. They come in many varieties. However, *all* are designed to drive some kind of desired outcome through the use of monetary awards or lack thereof. Incentives can be extremely useful when vigilantly and carefully applied, and in accordance with FAR 16.401, they are designed to drive specific acquisition objectives by:

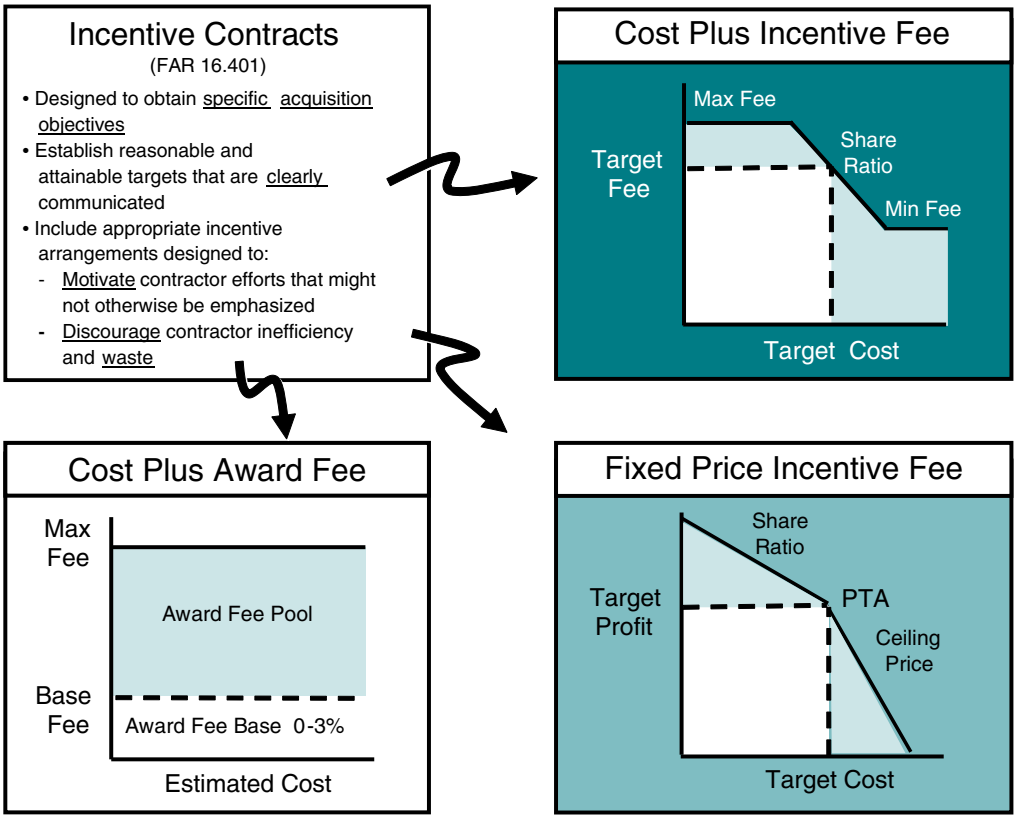
- Establishing reasonable and attainable targets that are clearly communicated to the contractor; and
- Including appropriate incentive arrangements designed to:
  - Motivate contractor efforts that might not otherwise be emphasized; and
  - Discourage contractor inefficiency and waste.

By design, incentives are also tightly integrated into overall acquisition strategies for very specific purposes in DoD contracts. They can help reduce risk; they can help combat uncertainty; and they can also help drive favorable behavior throughout a program's life cycle. By their nature, "incentives should result in expected outcomes" as Defense Procurement and Acquisition Policy Director Shay Assad reinforced at the Program Executive Officer/Systems Command (PEO/SYSCOM) Commanders' Conference held at Fort Belvoir, VA, November 7-8, 2006 (S. Assad, personal communication, November 8, 2006). Of course, understanding when and how to apply incentives is just as important and may be the tallest hurdle. More specifically and in accordance with the FAR 16.401 and 16.403:

> Incentive contracts are appropriate when a firm-fixed-price contract is not appropriate and the required supplies or services can be acquired at lower costs and, in certain instances, with improved delivery or technical performance, by relating the amount of profit or fee payable under the contract to the contractor's performance … a fixed-price incentive (firm target) contract is appropriate when the parties can negotiate at the outset a firm target cost, target profit, and profit adjustment formula that will provide a fair and reasonable incentive and a ceiling that provides for the contractor to assume an appropriate share of the risk.

Even though the concept of incentive-type contracts sounds straightforward, its execution is far from simple, especially in an environment like DoD where funding instability, technology barriers, leadership changes, and even cultural barriers frequently reign. Each element alone can potentially handicap a program as program managers would attest. The presence of all four factors can be taxing. Nonetheless, each of the incentive contract varieties (Figure 1) offers hope if they are properly

FIGURE 1. INCENTIVE CONTRACT TYPES



planned and well-executed by creating a correlation to expected outcomes; integrated within an overall acquisition strategy; and designed to meet specific program goals from the outset as often as they might vary.

Incentive contracts that use an award fee component have a very specific application especially if:

- The work to be performed is such that it is neither feasible nor effective to devise predetermined objective incentive targets applicable to cost, technical performance, or schedule;
- The likelihood of meeting acquisition objectives will be enhanced by using a contract that effectively motivates the contractor toward exceptional performance and provides the government with the flexibility to evaluate both actual performance and the conditions under which it was achieved; and
- Any additional administrative effort and cost required to monitor and evaluate performance are justified by the expected benefits.

INCENTIVES UNDER REVIEW

DAU's research phase officially began with a review of prior related work including the GAO report (e.g., its findings and potential areas of further interest) and other associated initiatives. As expected, the GAO report sounded a warning bell for incentive contracts in general, and many DoD organizations began to take a closer look at their respective portfolios to unearth any "execution" flaws.

After conducting an abbreviated literature review of incentive-type contracts, the research team found a great deal of writing on the subject. Even before the GAO published its report, a few agency, headquarters staff organizations, and field units had already initiated their own internal reviews and audits of incentives. Some even followed with specific guidance in some cases. A few examined root causes where incentive contracts failed and identified remedies to overcome what might be ineffective incentive practices. These investigations were insightful; they also validated some of the same findings that were eventually uncovered in this research. While many concentrated on various aspects of Award/Incentive fee contracts, none focused exclusively on what drives favorable outcomes.

The National Aeronautics and Space Administration (NASA) had been largely credited with successfully instituting formal incentive contracts since the early 1960s.

Interestingly enough, incentive-type contracts have been around for some time and used quite often in one form or another. Even Wilbur and Orville Wright's "Wright Flyer" contract awarded in February 1908 with the U.S. Army has been argued by some as a classic incentive contract that was based on two key objective criteria—speed and endurance (Snyder, 2001). Over the years, many other government contracts eventually contained incentive-like features. Nonetheless, the National Aeronautics and Space Administration (NASA) had been largely credited with successfully instituting formal incentive contracts since the early 1960s. In the last several years though, incentive contracts have required some further clarification. Senior Pentagon officials like (then) Assistant Secretary of the Navy for Research, Development and Acquisition John J. Young, Jr., have provided more specific direction and elucidation. On December 23, 2004, he issued specific guidance to make his stand clear. He emphasized, "If use of an award fee is appropriate, a portion of the award fee pool should be available for the contractor to earn based on objective criteria and a portion on the basis of subjective criteria." He also asserted that "contractors should have to earn fees or profits they receive based on their performance" (Young, 2004).

In 2006, the Secretary of the Air Force for Acquisition Directorate (SAF/AQX) sponsored a Contract Incentives Study under the watchful eye of its Acquisition Transformation Action Council (ATAC). After accepting some of the GAO's findings, the council formed an internal analysis group to find ways to execute the award/incentive fee process more effectively and efficiently. The analysis group sampled 43 acquisition category (ACAT) I, II, and III programs in their portfolio through the use of survey questions, divided among four specific groups. They drew a few conclusions on the award/incentive process after soliciting responses from four perspectives: 1) monitors, 2) program managers/principal contracting officers, 3) Fee Determining Officials (FDOs), and 4) award fee board members. The following points represent a high-level view of the aggregate group (Miller, 2006).

- Award Fee accomplishes its goals.
- Award Fee has a significant influence on the contractor's behavior.
- Criteria should move toward an appropriate combination of objective and subjective (e.g., 80 percent objective, 20 percent subjective).
- An overwhelming perception prevails that the Air Force accomplishes its goals with respect to award fee.

After vetting their findings, they found that incentives did not necessarily control costs nor improve performance when dealing with highly complex and technical programs with long development cycles. They were generally supportive of moving to more objective-based incentive approaches.

About the same time period, the Air Force Space Command's Space & Missile Systems Center (SMC) located in Los Angeles, CA, took a hard look at the use of incentives. A draft *Incentives Guide,* dated October 1, 2006, soon emerged. SMC's guidebook illuminated a number of ideal practices including the linkage between incentives and mission success outcomes. Its authors developed seven core principles designed to govern incentive contracts in general (Air Force Materiel Command, 2006).

- Cost-Plus-Award-Fee (CPAF) contracts, with subjective award fee criteria, will no longer be the preferred incentive approach.
- Cost-Plus-Incentive-Fee (CPIF) contracts, with a potential award fee, are highly encouraged.
- Incentives need to consider the phase of the acquisition program (National Security Space directive, NSS-03-01), the maturity of the technology, and the product line (spacecraft, launch vehicle, ground systems, and user equipment).
- Acquisition strategies need to discuss performance, schedule, and cost incentives, and their order of importance to the program.
- Award fee plans should link fees to mission success, achievements, deliverables, and objective results.
- Award fee plans should include both objective/quantitative and subjective award fee criteria.
- The incentive arrangement needs to ensure the contractor has a stake in the outcome (i.e., no fee will be earned for mission failures).

SMC's incentive guide further reinforced what many DoD organizations have increasingly begun to amplify and embed in their incentive contracts—*greater emphasis on objective criteria.*

Just recently, the 109th U.S. Congress has also taken more specific action. The John Warner National Defense Authorization Act for Fiscal Year 2007, Public Law 109–364, October 17, 2006, sec. 814, now requires the Secretary of Defense to issue guidance to:

1. Ensure that all new contracts using award fees link such fees to acquisition outcomes (which shall be defined in terms of program cost, schedule, and performance);
2. Establish standards for identifying the appropriate level of officials authorized to approve the use of award and incentive fees in new contracts;
3. Provide guidance on the circumstances in which contractor performance may be judged to be ''excellent'' or ''superior'' and the percentage of the available award fee which contractors should be paid for such performance;
4. Establish standards for determining the percentage of the available award fee, if any, which contractors should be paid for performance that is judged to be "acceptable," "average," "expected," "good," or "satisfactory";
5. Ensure that no award fee may be paid for contractor performance that is judged to be below satisfactory performance or performance that does not meet the basic requirements of the contract;
6. Provide specific direction on the circumstances, if any, in which it may be appropriate to roll over award fees that are not earned in one award fee period to a subsequent award fee period or periods;
7. Ensure consistent use of guidelines and definitions relating to award and incentive fees across the military departments and Defense Agencies;
8. Ensure that the Department of Defense:
    - Collects relevant data on award and incentive fees paid to contractors
    - Has mechanisms in place to evaluate such data on a regular basis;
9. Include performance measures to evaluate the effectiveness of award and incentive fees as a tool for improving contractor performance and achieving desired program outcomes; and
10. Provide mechanisms for sharing proven incentive strategies for the acquisition of different types of products and services among contracting and program management officials.

Whether fully justified or not, Congress became uncomfortable with the track record of incentive contracts and subsequently emphasized key factors affecting their use. The next phase of this research might become even more constructive since it centered on the collection of data that might show it influenced favorable outcomes.

DATA COLLECTION

The research team recognized certain research and resource limitations—primarily the number of programs available for interview in a limited period of time. Ultimately, the team decided to interview members from at least 25 representative weapon system acquisition programs (Table 3). Data collected from these first 25 would also serve as the starting point for best practices. The research team selected programs in various phases of the acquisition life cycle to confirm what particular award and/or incentive techniques (if any) indeed created strong correlations to performance outcomes. The interviewees would include agency directors, program executive officers, program/product managers, procurement contracting officers, and systems engineers in government program offices.

The research team considered a number of research methodologies and eventually settled on a questionnaire-survey that targeted the identification of specific techniques that drove (or heavily influenced) favorable performance. The team's data

TABLE 3. LIST OF INTERVIEWEES

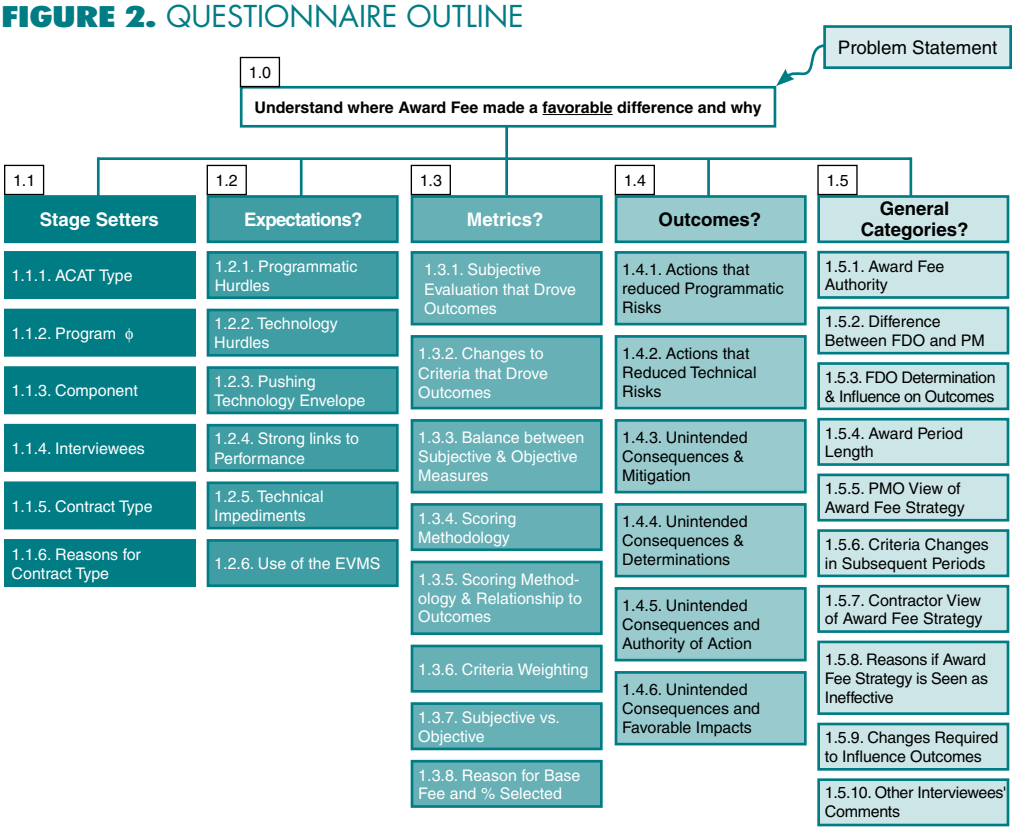
Organizations Who Supported this Research Activity through Interviews	
Space Based Infra-Red System (SBIRS)-High	Future Combat Systems (FCS)
Global Positioning System (GPS)	Total Integrated Engine Revitalization Program
Rapid Attack Identification Detection and Reporting System (RAIDRS)	Air Mobility Command (AMC) Contractor Tactical Terminal Operations
Advanced Extremely High Frequency (AEHF) System	Global Transportation Network (GTN)
Space Tracking and Surveillance System (STSS)	Biological Detection System
Air Force Satellite Control Network (AFSCN)	Missile Defense Kinetic Weapons
B-2 Aircraft-Radar Modernization Program-Frequency Change	Missile Defense Sensors
C-17 Aircraft-Sustainment	Missile Defense Targets and Countermeasures
F-15 Aircraft-Suite 6 Software Upgrade for A-D & E Models	Missile Defense C2BMC
F-16 Aircraft-Operational Flight Program Development	Multi-Mission Maritime Aircraft (MMA)
Global Hawk Unmanned Aerial Vehicle	E2D (Major upgrade to E2C)
MH-60 Black Hawk Helicopter	AV-8 (Harrier)
Marine Expeditionary Fighting Vehicle (EFV)	

collection approach afforded the simultaneous and normalized collection of key data. DAU's regional collocation with acquisition organizations created a significant geographical advantage. Each of the regional research team members could concentrate on acquisition organizations they already support within their respective locations. They knew their customer base well. The sub-division of regional teams also permitted relatively easy access to the program offices they occasionally assist.

To help chart the course for a sound questionnaire used for this research activity and limit the chance for any ambiguity, a Work Breakdown Structure (WBS) construct seemed ideal. It not only represented a very common and familiar acquisition artifact found in every DoD program, but also appeared to be a very fitting instrument. Like a schematic, it represented a high-level blueprint and easily accommodated the decomposition of survey questions into logical content categories as described by Figure 2.

The research team maneuvered the survey questions into five logical categories during three separate working sessions. The categories were: 1) Stage Setters, 2) Expectations, 3) Metrics, 4) Outcomes, and 5) a General Category. Each category contained very specific questions—all designed to narrow the search for techniques that drove expected outcomes. Even though the team built a single survey, it accommodated both incentive and award fee contracts. Figure 2 represents a rendering of the decomposition for Award Fee.

FIGURE 2. QUESTIONNAIRE OUTLINE



FINDINGS

Strongly Communicated Expectations and Feedback: Frequent and unambiguous communication/feedback made a noticeable difference for incentive contracts. Even though incentive contracts require some additional administrative burden, the outcome justified the increased workload of feedback for most programs under this research review. Continuous and open dialogue at both junior and senior levels led to early discovery and timely reconciliation of many known issues and helped keep a program on track.

- Space Based Infra-Red Surveillance System (SBIRS)-High created a specialized response team that routinely tackled issues as a result of a flight software quandary originally uncovered by monthly reports. Their team "pays a lot more attention, has a lot more discussion, and serves almost like a first level of evaluation" (personal communication, September 18, 2006).
- E2D summarized what many others echoed: "We are very open with the contractor. We have no secrets. If they win, we win. Communication is extremely important. The contractor is never surprised by what they get" (personal communication, October 12, 2006).
- Missile Defense Agency (MDA) Sensors instituted "emphasis letters" during their award periods to stress the importance of certain outcomes or "events" even more (personal communication, September 18, 2006).
- Multi-Mission Maritime Aircraft (MMA) employed what they called a "barometer report" during interim reviews to ensure that information from monitors was readily available to management at critical junctures. "Our contractor takes it very seriously. Each report is very detailed. The contractor understands well in advance what we see. If the contractor was heading in the wrong direction, early intervention was crucial" (personal communication, October 12, 2006). In some cases, sharing certain information prematurely and without a proper context could have unintended consequences.
- In one program, when the contractor received a reduced award, program office personnel were "uninvited" from a few key intermittent reviews. Program office personnel were viewed as critics, not full partners. The program office quickly instituted monthly reviews with the proviso that progress should be measured not only by results but also the agility to take any necessary corrective action(s). Things quickly turned around.
- F-15 and Global Hawk used more informal monthly feedback sessions to surface known issues or raise any potential concerns (personal communication, August 28, 2006; July 27, 2006).
- Space Tracking and Surveillance System (STSS) government and contractor program managers meet every Friday to "just talk and keep the lines of communication wide open—little issues sometimes surface and can be reconciled almost immediately" according to the government program manager (personal communication, September 27, 2006).

- Missile Defense Kinetic Weapons found communication and expectation management had a direct connection to favorable outcomes (personal communication, October 11, 2006).
- B-2 created a glossary tool to improve communication during the evaluation briefings, which proved extremely beneficial when team member changes occurred as they frequently did. This was particularly important in milestone terms, especially in the clarification of "first flight" (personal communication, August 11, 2006). Many organizations found that a strongly prepared and focused evaluation board along with upper management support were very important elements and made a difference.
- In E2D, "during the evaluation period, everyone has a binder, copy of the plan, contractor self-assessment, monitor evaluations, historical information, etc. You need this commitment to make this work" (personal communication, October 12, 2006). Ultimately, a set of expectations known by all and a disciplined award fee board structure along with refined mechanics seemed to help strengthen the viability of incentives.
- In one case, feedback had a multiplying effect. Missile Defense and Countermeasures found their contractor performing process improvement reviews based upon mid-term guidance and Air Force determinations (personal communication, September 22, 2006).

Undeniably, open and frequent communication/feedback is a driving force behind the effective execution of incentive contracts.

Key measures can validate whether or not a program achieved certain necessary intermediate milestones along a program's critical glide path.

Metrics. The selection of key and enduring measures within an evaluation period, and measures that could be connected to subsequent evaluation periods made a noticeable difference for incentive contracts. Key measures can validate whether or not a program achieved certain necessary intermediate milestones along a program's critical glide path. They confirm program momentum. They serve as an early warning system—a bellwether—and answer the age-old question, "Are we on track?" They also fill a huge role as performance benchmarks. Those interviewed under this research project said when they effectively employed key measures, it also helped them navigate their program pathway despite the unavoidable programmatic turbulence. Their measures surfaced as two types: *objective* and/or *subjective*. Without question, selecting the correct type of measure presented the biggest challenge.

The ability to hard-wire them to achievable outcomes makes objective measures like Technical Performance Measures (TPMs), Cost Performance Indices (CPIs), Schedule Performance Indices (SPIs), etc., invaluable gauges. They serve as tremendous forecasting devices when carefully connected to outcomes.

- STSS used objective measures in the form of Key Performance Events (KPEs) such as "ground contractor satellite operations (LSOC) facilities *established*, spacecraft *available* for space vehicle integration and test, and thermal vacuum test *complete*" (personal communication, September 27, 2006). According to the STSS program manager, the contractor also had to "show me that the system worked in the intended environment."
- SBIRS used objective measures in the form of Mission Success Criteria (MSI) like ITS/Increment1 *capability* and IMCSB-1 System *delivered*. They reported a significant change when they amplified the importance and subsequent inclusion of mission success in the form of tangible, measurable outcomes (personal communication, September 18, 2006).
- Missile Defense Kinetic Weapons felt technical performance outcomes were ideally suited for objective measures especially since they rely heavily on test flights where mission success is key (personal communication, October 11, 2006).
- Global Positioning System (GPS) targeted specific milestones/events that either demonstrated space-qualified processes or the completion of space-qualified parts—both critical elements since they directly supported the development of the Gallium Arsenide (GaAs) Solar Arrays used to power the spacecraft. GPS also found that its prime contractor welcomed objective measures in the form of tangible milestones such as specific task completion and scheduled deliveries (personal communication, September 20, 2006).
- MDA Sensors recognized their software development risk early on since many algorithms came from the Theater High Altitude Area Defense (now Terminal High-Altitude Area Defense) system as Government-Furnished Equipment (GFE). Consequently, they used incentives to drive integration efforts of these algorithms along a well-defined pathway (personal communication, September 18, 2006).
- STSS found cost controls to be powerful measures, especially if the contractor could share in the savings (personal communication, September 27, 2006).
- AV-8 (Harrier) made cost a primary objective criterion since the "work was known, [they] just wanted to keep costs down, and there was a firm design specification in place with expectations of little to no modification" (personal communication, September 22, 2006).
- Total Integrated Engine Revitalization tied incentives directly to the achievement of doubling *Mean Time for Depot Repair* from 700 hrs to 1400 hrs (personal communication, August 14, 2006). FCS found incentives more useful when based on delivery of critical sub-components since they were so vital to the aggregate system (personal communication, August 14, 2006).
- Many others like F-15 and GPS found that incentives became more strongly correlated to outcomes when they jointly developed incentive criteria with

their respective contractors and incorporated risk management as a major variable in the overall equation (personal communication, August 28, 2006; September 17, 2006).

- In the STSS, both the government and contractor co-developed the incentive criteria to ensure they were meaningful, achievable, useful, measurable, and enduring (personal communication, September 27, 2006).
- Subjective criteria, the more elastic of the two measure types, depend on certain factors such as judgment, beliefs, and propensity to yield specific outcomes. These measures found their way into many programs including STSS, Rapid Attack Identification Detection and Reporting System (RAIDRS), Global Hawk, and B-2. Each of these programs called for highly effective and comprehensive systems engineering processes, and strengthened their incentives to enforce it. RAIDRS also found subjective measures "afforded some freedom of action and much needed flexibility," (personal communication, September 19, 2006).
- E2D and Advanced Extremely High Frequency (AEHF) found they could "more effectively influence how their prime contractor managed subcontractor behavior through subjective means" (personal communication, September 20, 2006).
- AEHF used subjective measures to drive management responsiveness and effective communication" (personal communication, September 20, 2006).
- C-17 inserted customer satisfaction into their overall incentive equation through the use of customer surveys in the context of a CPIF contract that was primarily objective in nature (personal communication, August 16, 2006).
- In a few program offices like STSS, program personnel found the selection of key outcomes can also make evaluation periods more enduring by creating a bridge between one award fee period and the next. They employed 34 KPEs that spanned nine periods from FY02–FY06 (personal communication, September 27, 2006). In retrospect, these aggregate KPEs kept everyone who was involved with the execution of STSS focused on the goal line, which went well beyond single award fee periods (personal communication, September 27, 2006). Like others, those who structured their award fee plan also understood the delicate balance among cost, schedule, and performance incentives, which have been successful in motivating the contractor to take a long-term view of program and mission success rather than a more short-term view of performance during any specific period.

What we found particularly interesting was the increased use of objective measures in Award Fee type contracts. We noticed a strong tendency by the organizations interviewed to find more objective and tangible measures in the conduct of their incentive strategies that incorporated award fee. Objective measures that were used as criterion variables seemed to fill an air gap by demonstrating the attainment of certain intermediate milestones and irrefutable performance outcomes. Subjective measures were still important, especially since they verified qualitative characteristics; but the

combination of objective and subjective measures created some of the strongest correlations to expected outcomes.

Rollover. Rollover, the process of moving unearned award or fee into a subsequent award period, has received a generous amount of consideration lately, but STSS used it sparingly. In nine award fee periods, STSS used the rollover provision just once (personal communication, September 27, 2006). Initially, government evaluators felt the contractor took a little too much mission assurance risk with the hardware. STSS weighed the options and concluded "they were willing to forgive the fact that the contractors made them very uneasy during one period as long as the satellites worked as intended 'on orbit' in the end." Consequently, a portion of the unearned fee was rolled over to the Mission Success Fee portion of the award fee plan. STSS also felt that in periods where they did not implement the rollover provision, the contractor should be taking the appropriate corrective action anyway in order to earn the larger fees at the end of the program. Consequently, there was no reason to provide additional incentives to correct behavior that seemed to occur anyway.

The incorporation of base fee in award fee contracts made a noticeable difference. Of the 25 organizational interviews, many used some form of base fee on CPAF contracts. Numerous organizations implementing CPAF valued base fees as a leverage tool. Even though the Defense Federal Acquisition Regulation Supplement (DFARS) 216.405-2(c)(iii) allows up to 3 percent of the estimated cost of the contract exclusive of fee, a contractor could provide "best efforts" for the award fee term and still receive no award. As a result, there was some pressure on the government to provide a portion of the award fee for "best efforts."

- F-15 found themselves in such a predicament since they originally planned to only pay award fee for "excellence" (personal communication, August 28, 2006). However, during deliberations the contractor asked for consideration of a base fee based if it met discrete contractual terms and conditions. The F-15 eventually agreed and implemented a 3 percent base fee giving the Systems Program Office (SPO) ample flexibility to award the remaining balance for "excellence."
- Other CPAF program offices appeared to recognize the value of a base fee. FCS incorporated a base fee, all objective in nature (personal communication, August 14, 2006).
- Missile Defense Kinetic Weapons found base fee flexibility to be "just right for responsiveness, and timeliness and cost considerations" (personal communication, October 11, 2006).
- Biological Detection System included a 3 percent base fee that also became a source for employee bonuses (personal communication, August 14, 2006).
- Global Hawk are revising their contract to include a 3 percent base fee to distinguish excellence from best efforts (personal communication, August 28, 2006).
- Others like STSS are looking at the prospect of incorporating key performance events into base fee (personal communication, August 21, 2006).

Our research team found that senior defense industry personnel welcomed the use of base fee to better delineate the difference between "best efforts" (e.g., fee) and "excellence" (e.g., award).

Nothing seems to have a more dramatic impact in DoD than training and experience.

Trained and Experienced Personnel made a noticeable difference for incentive contracts. Nothing seems to have a more dramatic impact in DoD than training and experience. Training draws its roots from practical experience. It is systematic. We learn from our successes and failures in the field and make adjustments accordingly in the way we train. The mantra "train like we fight, fight like we train" is pervasive in warfighter training across DoD, and ultimately leads to advantages on the battlefield. Without question, practical experience helps build better training programs. It can overcome unforeseen shortfalls and the inevitable prevailing uncertainty even with proven systems. The same mindset applies to incentive-type contracts. Program managers that had formalized instruction and/or coached their personnel on the use of incentives indicated they more favorably influenced outcomes.

- F-15 felt "training and experience made a huge difference" (personal communication, August 28, 2006).
- RAIDRS instituted a robust series of Murder Boards for review of assessments generated by performance monitors prior to each Air Force Review Board (AFRB). All performance monitors were required to sit through the review of all other assessments. The process ensured consistent communication with all on the expectations for their assessments in terms of quality, format, scope, etc. (personal communication, September 19, 2006). RAIDRS found that those who go through the process once consistently provide excellent assessments in the future and pass on their lessons learned to others, resulting in a faster review in succeeding periods (personal communication, September 19, 2006).
- MDA summed up what the remaining interviewees reiterated. Aside from the specialty training a few of their personnel have received in multiple courses covering incentive contracts, everyone seems to receive the training they need to make incentive contracts work (personal communication, September 22, 2006).

INDUSTRY REINFORCEMENT

Even though the research team did not meet individually with industry representatives, contractor perspectives were considered an important element of this research. The team found an expedient method to collect industry's thoughts on award

fee incentives. During mid-summer 2006 and before the interview process started with government program offices, DAU hosted an Industry Day at Fort Belvoir, VA. With non-attribution safeguards in place, 18 senior-level defense industry representatives participated and spoke freely about their experience with incentive contracts. Their views were enlightening. In many cases, industry confirmed what data the research team found through field interviews. Table 4 captures industry's aggregate views and positions after much interactive and lively discussion.

Interestingly enough, many of the 18 statements can be associated with the four specific categories that influenced outcomes: 1) Strongly Communicated Expecta-

TABLE 4. INDUSTRY PERSPECTIVES

1.	Government construction of the award fee plan (including metrics, incentives, etc.) may not link with the offeror's proposed solution or motivations.
2.	Award fee is sometimes not the proper contract type to achieve program outcomes.
3.	In some cases, the intended goal(s) of award fee contracts are unclear.
4.	Contracts without base fee can cause problems.
5.	In some cases, the government does not follow its own policies on award fee.
6.	On occasion, award fee evaluation criteria are poorly explained or justified, and communication of award fee goals and criteria are not clearly explained.
7.	It is difficult to establish the relationship between awards for month-to-month activities to the goals of a multiple-year program. The linkage is not always apparent.
8.	Administration of award fee criteria can change post-award and create problems during contract execution.
9.	The government may not manage or evaluate the award fee criteria as agreed and planned.
10.	Post-award administration of award fee contracts is time- and resource-intensive.
11.	In some cases, government personnel are not adequately trained in managing award fee contracts.
12.	Desired outcomes are not always driven by the award fee because of insufficient funds available and subjectivity of the final evaluation.
13.	Inconsistency in the timing of the award in line with the evaluation criteria and uncertainty of expected profitability before award pose additional problems.
14.	Contracting parties and stakeholders have different perceptions of the purpose of award fees.
15.	In some cases, there is government failure to understand the economics of defense contracting and its impact on government contractors.
16.	From time to time, there is inappropriate use of award fee contracts.
17.	Award fee is not targeted at creating fair shareholder value (or financial advantage to the private company) in line with actual performance. Metrics are sometimes not meaningful and are "fuzzy" in line with "fuzzy" requirements. Sometimes they are too subjective and do not measure outcomes that are sought by DoD.
18.	Award fees that require the contractor to exceed the requirements of the contract motivate requirements creep or "gold-plating."

tions and Feedback; 2) Relevant, Achievable, and Enduring Measures within an Evaluation Period; 3) Base Fee; and 4) Training and Experience. Industry comments can also be further subdivided into two general categories—Planning and Execution.

SUMMARY

So, what about incentives? Are they still a good tool to drive performance behaviors despite the recent criticism and doubt? Have organizations found a way to effectively apply incentives and demonstrate the usefulness of incentives? The answer to all of these questions is "yes." There is no "one size fits all," but the incentive attributes that seemed to matter the most in influencing performance outcomes for the 25 programs, and generally afforded strong correlations between incentives and desired performance are outlined in Table 5.

Ideally, an optimal incentive strategy features these and perhaps other attributes in the context of cost, schedule, and performance factors forged together as a unified accord. In practice, cost, schedule, and performance are strongly interdependent and tend to interfere with one another's outcomes. Influencing all three, while not at the expense of one another, becomes a delicate balancing act and the challenge for any incentive strategy. For example, emphasizing technical performance could come at the expense of cost and scheduled deliveries. Emphasizing schedule and/or cost could easily come at the expense of technical performance. Nonetheless, all our interviewees developed incentive strategies that carefully considered the weighting aspect of these three attributes depending on certain program priorities, distinctive program phases, and certain aim points.

One prevailing element distinguishes DoD and other U.S. Government agencies from general industry. Unlike simple commercial development efforts, DoD builds and sustains many "one-of-a-kind" systems that count on "cutting-edge" technologies, operate in unforgiving or threatening conditions, and come under enemy fire. Invariably, motivational contracting tools like incentives can help organizations managing those systems overcome numerous obstacles and reach very definitive outcomes. Incentives provide tremendous flexibility for the implementation of certain government contracts. Incentives are certainly no panacea, but, if used wisely and judiciously, can help programs either achieve difficult milestones and/or recover lost ground by allowing organizations to make the necessary course adjustments as they navigate the inevitable turbulent programmatic waters.

RECOMMENDATIONS

What DAU curricula should be adjusted as a result of the research team's findings in both the near- and far-term; and how can DAU make both lessons learned and best practices widely available? First, the acquisition contracting workforce, particularly contract specialists working with incentive contracts, must possess a certain understanding of incentive contracts. Therefore, it seems reasonable that every functional area should have or at least consider an introductory lesson on incentive contracts

TABLE 5. KEY ATTRIBUTES, DIFFERENTIATION, AND APPLICATION INCENTIVE

Key Attributes	**Relevant, Achievable and Enduring Measures**	
	Frequent and Unambiguous Communication/Feedback	
	Trained and Experienced Personnel	
	No Base Fee	**Base Fee**
Differentiation	**Cost Plus Incentive Fee (CPIF)** **Description** Provides for the initially negotiated fee to be adjusted later by a formula based on the relationship of total allowable costs to total target costs; specifies a target cost, a target fee, minimum and maximum fees, and a fee adjustment formula. After contract performance, the fee payable to the contractor is determined in accordance with the formula. The formula provides, within limits, for increases in fee above target fee when total allowable costs are less than target costs, and decreases in fee below target fee when total allowable costs exceed target costs. This increase or decrease is intended to provide an incentive for the contractor to manage the contract effectively. When total allowable cost is greater than or less than the range of costs within which the fee-adjustment formula operates, the contractor is paid total allowable costs, plus the minimum or maximum fee.	**Cost Plus Award Fee (CPAF)** **Description** Provides for a fee consisting of (1) a base amount fixed at inception of the contract and (2) an award amount that the contractor may earn in whole or in part during performance and that is sufficient to provide motivation for excellence in such areas as quality, timeliness, technical ingenuity, and cost effective management. The amount of the award fee to be paid is determined by the Government's judgmental evaluation of the contractor's performance in terms of the criteria stated in the contract. This determination and the methodology for determining the award fee are unilateral decisions made solely at the discretion of the Government.
Application	Incentive Contracts • Motivate contractor efforts that might not otherwise be emphasized • Discourage contractor inefficiency and waste	

that incorporates lessons learned and best business practices during the many training opportunities that abound. In the meantime, and before the curricula development teams make their respective determinations, a number of learning assets are already available for immediate review and required updates. Aside from a couple of specialized incentive contract lessons embedded in a few Defense Acquisition Workforce Improvement Act (DAWIA) contracting and budgeting courses, DAU offers two 24/7, online Continuous Learning Modules (CLMs) that can help guide organizations with their incentive selection and subsequent development pathway. The first, Contractual Incentives (CLC 018), "focuses on understanding the balance between government

and industry goals and objectives in crafting an effective incentive strategy … that effectively motivates and incentivizes the contractor to deliver what the government needs, when it needs it, and within budget." The second, Provisional Award Fees (CLC 034), addresses the 2003 rule that permits award fee payments to be made anytime prior to the interim or final evaluation.

Both CLMs are useful, but do not address the execution "essentials." An "Incentive Contracts" CLM that is more comprehensive and readily available to the acquisition community is necessary to provide much more assistance on the mechanics and implementation of incentive contracts. Additionally, exploiting the knowledge of seasoned professionals through the increasingly popular collaborative medium called Communities of Practice (CoPs) on the DAU Acquisition Community Connection (ACC) Web site can offer access to a wide array of current experiences and lessons learned regarding incentives ranging from the general to the specific. DAU has already established a site rich in information on the ACC—Award and Incentive Fee Contracts, at https://acc.dau.mil/CommunityBrowser.aspx?id=105550. Access to these and other collaborative training aids is critically important because once an incentive strategy is in place, its maximum value truly depends on its ability to implement known techniques that can drive favorable outcomes. No better source of experts exists than those who face contract incentive challenges every day—the acquisition workforce professionals who are charged with appropriately implementing the techniques that drive outcomes—appreciably.

Mr. Robert L. Tremaine is associate dean at the DAU West Region. Prior to joining DAU, he served over 26 years in the U.S. Air Force in acquisition assignments that spanned air, missile, and space. He holds a B.S. from the U.S. Air Force Academy and an M.S from the Air Force Institute of Technology. He graduated from the Canadian Forces Command and Staff, and U.S. Army War Colleges. He is level III certified in Program Management and Systems Planning, Research, Development and Engineering.

(E-mail address: robert.tremaine@dau.mil)

AUTHOR **BIOGRAPHY**

REFERENCES

Air Force Materiel Command. (2006). *Draft Incentive Guide.* Space and Missile Systems Center. Wright-Patterson Air Force Base, OH: Author.

Department of Defense (DoD), General Services Administration & National Aeronautics and Space Administration. (2005, March). Federal Acquisition Regulation. Washington, DC: U.S. Government Printing Office.

Miller, J. (2006, August 7). *Contract Incentives Transformation Initiative Group (TIG) Brief for the Acquisition Transformation Action Council (ATAC).* Pentagon, Washington, DC: Office of the Secretary of the Air Force (Acquisition).

Snyder, T. J. (2001, Summer). Analysis of Air Force contract implementation. *Air Force Journal of Logistics*, *25*(2), 14–21.

United States Congress. (2006, October 17). National Defense Authorization Act for Fiscal Year 2007. H.R. 5122, 109th Congress. Washington, DC: U.S. Government Printing Office.

United States Government Accountability Office. (2005, December). *Defense acquisitions: DoD has paid billions in award and incentive fees regardless of acquisition outcome.* GAO Report 06-66. Washington, DC: U.S. Government Accountability Office.

Young, J. J. (2004, December 23). *Contract profit and incentives arrangements.* Policy Memorandum. Assistant Secretary of the Navy for Research, Development and Acquisition. Retrieved October 2006 from http://acquisition.navy.mil/content/view/full/3868

Image designed by Schatz Publishing Group

MAXIMIZING WARFIGHTER CAPABILITY USING SURVEYED NECESSITY MEASUREMENT: APPLICATION TO THE USAF F-15C FLEET

John M. Colombi, David R. Jacques, and Dennis D. Strouble

Within the Department of Defense, with changing missions to counter dynamic and asymmetrical threats, the acquisition workforce strives to maximize capability for joint warfighting. How acquisition professionals measure and select capability improvements for the nation's weapon systems is a perpetual challenge, made even more complex with constrained defense budgets. This study identifies a method for determining which upgrades should be purchased (production) for which aircraft in the F-15C fleet by optimizing a capability proxy measure. Each upgrade's "necessity" for a given mission area was obtained by conducting a survey of over 250 experienced F-15C pilots. The solution presented in this article should be extensible to other weapon system capability decisions.

With the planned addition of the F-22A into the United States Air Force (USAF) inventory, the Service developed plans to draw down the F-15 fleet to 179 total aircraft (F-15 C/D models only) by 2013, eventually transitioning most aircraft to the Air National Guard (ANG). However, as a result of decisions made by the Base Realignment and Closure (BRAC) Commission (DoD, 2005) and the 2006 Quadrennial Defense Review (QDR) (DoD, 2006), as well as a reduced F-22A buy, the USAF and ANG will keep an additional number of aircraft in service through 2024. Since current plans and budgets have been based on a fleet of 179, the budgets will not support installation of all planned upgrades to a larger F-15 fleet.

This research demonstrates a method for determining the optimal mix of production upgrades for the future F-15 fleet (including C and D models, but not E models,

which are managed separately) within a constrained budget. To make this determination, the following three questions had to be answered:

- Which upgrades (modifications) are most needed for the F-15 to perform its mission(s)?
- How can these upgrades be compared on a common scale?
- Can we maximize a fleet's capability for a fixed budget authority?

The study thus seeks to provide an optimized solution for keeping a large number of aircraft beyond the 179 relevant for combat duty for one to two additional decades of service.

BACKGROUND

The F-15 is an all-weather, maneuverable tactical fighter designed to gain and maintain air supremacy over the battlefield. This superiority is achieved through a mixture of maneuverability, acceleration, range, weapons, and avionics. The weapons and flight control systems are designed so one person can safely and effectively perform air-to-air combat. But as the Advanced Tactical Fighter (ATF) program was conceived, this new aircraft was seen to be a replacement for the F-15 fleet, all A-D variants. However, as the program evolved to the F-22A, the planned buy was cut from 750 aircraft to 442 aircraft to 339 aircraft. It soon became apparent that some F-15C/Ds would need to remain in service alongside the F-22A for the foreseeable future. Prior to 2001, plans were developed to reduce the F-15 fleet size to 179 aircraft by 2013. These "long-term" aircraft, also known as "Golden Eagles," were scheduled to receive a large number of modifications and upgrades that would extend their combat relevance out to 2025 and beyond. (Due to a crash, there are now only 178 Golden Eagles.) However, in 2002, the F-22A buy was further reduced to 183 aircraft, and the results of the 2005 BRAC mandated keeping a larger ANG F-15C force size than the Air Force had planned. Further, after September of 2001 the air superiority forces of the DoD have been tasked with an additional mission of homeland defense, a mission largely abandoned after the Cold War ended in the early 1990s. This combination of factors has resulted in a need for additional F-15Cs over the next 20 years.

Since little trade space exists in the fleet size, largely mandated by BRAC, QDR, and political considerations, and given the current tightly constrained fiscal environment, some sort of decision support process was needed to choose which upgrade(s) will be purchased for which aircraft and in which year. This decision in the past would often have been made in a non-scientific manner, attempting to balance conflicting though professional recommendations by multiple stakeholders in the acquisition, budget, and operational environments. The complexity of this planning decision is daunting; a number of related factors must be considered, some of which include:

- Fleet size over time including retirement schedules
- A- and B-Model retirement plans

- Sundown Rule, restricting upgrade spending on aircraft to be retired within 5 years
- Prior upgrades (Golden Eagles already have many of these upgrades)
- Acquisition costs, including unit price per lot, startup production costs, research and development cost, installation costs, and timing, testing, and certification, etc.
- Funding profiles across Future Years Defense Plan (FYDP) and appropriation type
- Squadron-specific missions, including Deployed Combat within an Air Expeditionary Force (AEF), Homeland Security, and Training
- System upgrade interdependencies

This research was sponsored by the F-15 system program office and was focused on previously approved modifications. The 11 modifications examined have been vetted through all appropriate requirements and capability reviews. Thus, the challenge was to find the number of each modification to maximize fleet capability over time to perform the F-15 missions. A tool and method was requested to support this complex acquisition decision.

METHOD

The method used to solve this problem first started with a set of 11 upgrades, provided and currently managed by the program office, which added to F-15 capability. To establish a measure of capability improvement for all upgrades, an online survey of experienced F-15 pilots was released. The survey data were averaged, scaled, and combined with various fleet and acquisition constraints. All this was input to a linear programming model that searched for the best set of modifications and their respective production quantities, constrained primarily by budget authority.

CANDIDATE UPGRADES AND COSTS

The list and description of 11 current upgrades is shown in Table 1. The cost of each upgrade (per aircraft) is shown in Figure 1. Admittedly, there could be some variability in these costs due to variations in total quantity purchased and the quantity purchased per year, but for purposes of this study these costs are representative.

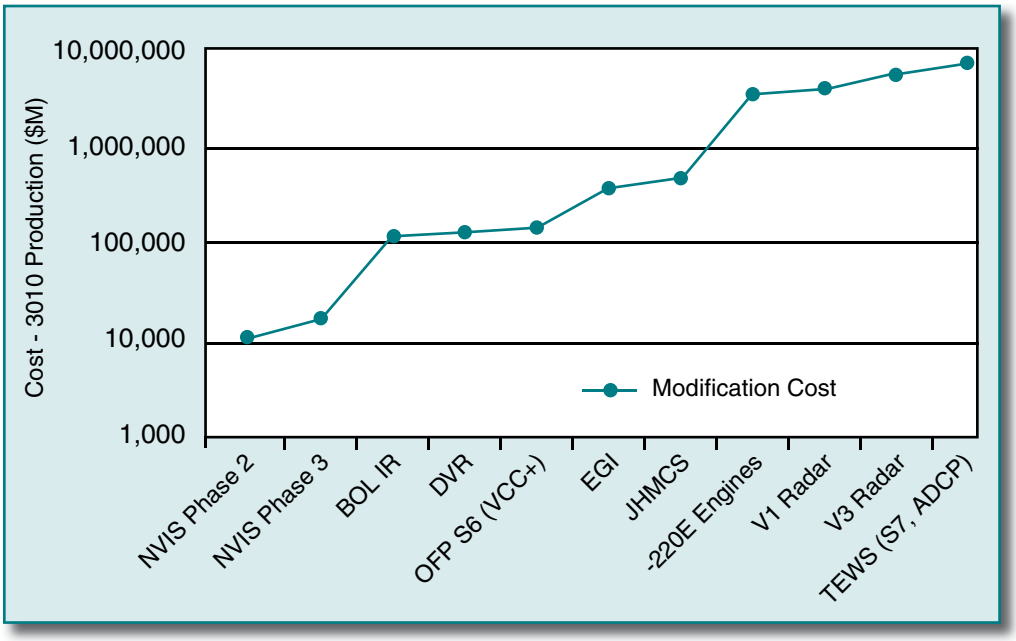
COMPARING UPGRADES ON A COMMON SCALE

A method was needed to evaluate all the candidate upgrades on a common scale that described their "value added" to the aircraft's capability. Similar techniques have been tried on other Air Force platforms, such as comparing upgrades on a "Mission Availability" improvement scale, a technique used to evaluate Air Warning and Control System (AWACS) upgrades during the Extend Sentry program. As a desired acquisition practice stemming from DoD's ongoing Capability Based Acquisition

TABLE 1. F-15 MODIFICATION/UPGRADES AND DESCRIPTION

Modification/Upgrade	Brief Description
220E Engines	Replaces the 30-year old F100-PW-100 engine's analog fuel control with a digital fuel control unit. This results in faster afterburner ignition, more power, increased reliability, and greater maintainability.
APG-63v1 Radar	Replacement of the entire air-to-air radar (except for the dish) with more advanced components, reducing the number of Line-Replaceable Units (LRU) from seven to five. Offers increased radar performance in addition to improved reliability and maintainability.
APG-63v3 Radar	Combines the new "back end" processors of the APG-63v1 radar with an active electronically scanned array (AESA) radar dish, providing vastly improved detection, identification, and target tracking ability and increased Mean Time Between Failures (MTBF).
Joint Helmet-Mounted Cueing System (JHMCS)	A helmet-mounted display and cueing system allowing the pilot to assess aircraft and weapons status while maintaining "eyes out" of the cockpit. Allows visual cueing of high-off bore sight (HOBS) weapons like the AIM-9X.
Night Vision Imaging System (NVIS) Phase II	Aircraft's interior lighting modified to be Night Vision Goggle (NVG) compatible.
Night Vision Imaging System (NVIS) Phase III	Aircraft's exterior lighting modified to be Night Vision Goggle (NVG) compatible.
Embedded GPS/INS (EGI)	Adds a Global Positioning System (GPS) receiver to the aircraft and integrates it with the aircraft's existing Inertial Navigational System (INS).
BOL IR	Defensive system providing for continuous covert employment of IR countermeasures for increased survivability in the visual arena
Digital Video Recorders (DVRs)	Upgraded recording devices that capture sensor and display parameters digitally, eliminating the unreliable 8mm recording system
Upgraded Tactical Electronic Warfare Set (TEWS)	Upgrades to the F-15's 1970s-era Radar Warning Receiver (RWR), Internal Countermeasures Set (ICS), Electronic Warfare Warning System (EWWS), and Countermeasures Dispenser (CMD) Systems.
Suite 6 Operational Flight Program (OFP)	Upgraded radar software offering improvements in target detection, weapons employment, target identification, and signal security. Suite 6 development is already funded; however, to run Suite 6 the F-15 requires an updated central computer called the Very High Speed Integrated Circuitry Central Computer Plus (VCC+). There is a unit cost for the VCC+.

FIGURE 1. F-15 UPGRADE COSTS PER AIRCRAFT (3010 PRODUCTION) ON LOGARITHMIC SCALE



initiative, the Department favors measuring all upgrades on capability delivered. However, to put the candidate upgrades on a common capability scale was difficult due to the varied performance parameters and mission applicability of each upgrade. Consider performance parameters for upgraded radar. They include search range, search volume, and target-tracking ability. But the Key Performance Parameters for an upgraded engine might include maximum thrust, fuel consumption, and spool-up time. The wide variety of parameters could not be transposed onto a common scale. Instead, the method selected evaluated candidate upgrades on a common "necessity" scale. Thus, capability improvement of a candidate upgrade is the measure of how *needed* it is to accomplish the mission.

SURVEY OF SUBJECT MATTER EXPERTS

The next step was to quantify which of the upgrades were actually needed for the F-15 to perform its mission. Admittedly, this was and is a matter of considerable debate in the F-15 community. The study required a scientific way to collect and quantify this information so that it would be accurate, useful, and defensible. The researchers decided to conduct an online survey of experienced F-15 pilots in the USAF and ANG, and use the survey results to establish the necessity of each particular upgrade.

In choosing the survey pool, the expert opinions of the most accomplished F-15 pilots in the USAF and ANG were deemed most valuable. At the same time, enough survey responses were required to be statistically valid. A survey pool was chosen consisting of only "Experienced" F-15 pilots, both current and non-current. Experienced is defined in Vol. I of Air Force Instruction (AFI) 11-2F-15 and normally

TABLE 2. SURVEY TARGET POPULATIONS

Operational Active Duty Bases	Langley AFB, VA; Mountain Home AFB, ID; Eglin AFB, FL; Elmendorf AFB, AK; Kadena AB, Japan; RAF Lakenheath, UK
Operational Air National Guard Bases	Jacksonville IAP, FL; New Orleans JRB, LA; Portland IAP, OR; Otis ANGB, MA; St. Louis IAP, MO; Hickam AFB, HI
F-15 Training Bases	Tyndall AFB, FL, Kingsley Field OR
Misc. F-15 Locations	Nellis AFB, NV; Edwards AFB, CA; Keflavik NAS, Iceland
Non-F-15 Operating Locations	Holloman AFB, NM; Sheppard AFB, TX; Moody AFB, GA; U.S. Air Force Academy
Resident PME Locations	Wright-Patterson AFB, OH; Maxwell AFB, AL; Fort Leavenworth, KS; Naval Postgraduate School, CA
Staff Locations	HQ USAF, HQ ACC, HQ PACAF, HQ USAFE, HQ AETC, HQ AFMC, 9th AF (ACC), 12th AF (ACC), 19th AF (USAFE), 7th AF (PACAF), HQ NGB, HQ JFCOM

is when a pilot reaches 500 hours in the F-15. Responses were sought from those actively flying in operational units, both Active Duty (AD) and ANG, training units (AD and ANG), and the test community. Responses were also sought from F-15 pilots currently serving on staff, in other airframes, and enrolled full-time in designated Professional Military Education (PME) schools. Additionally, responses were sought from F-15 test engineers who have worked closely with these programs. An efficient, inexpensive way to distribute the survey and collect responses was needed. A distribution method was also needed that would maximize the number of responses received and minimize the time required for a person to take part in the survey.

Excellent guidance for developing a survey and writing specific survey questions can be found in many references (Weisberg & Bowen, 1977; Meyburg & Stopher, 1979; Dillman, 2000).

All survey-related activities were conducted in accordance with AFI 36-2601, Air Force Personnel Survey Program. An Internet-based survey was developed with responses solicited via e-mail. The survey required approximately 15 minutes to complete. Survey responses were sought from the various locations, shown in Table 2.

To capture the qualifications, background, and experience of survey respondents, the first survey section collected demographics, including: rank, years flying the F-15, hours flying the F-15, current flying status, duty assignment (operational flying, Replacement Training Unit [RTU] instructor, full-time PME, etc.), AD or ANG, qualifications earned (instructor pilot, flight examiner, weapons school graduate, etc.), and combat experience. In accordance with AFI 36-2601, no attempt was made to correlate individual survey responses or demographic information specific to individuals participating in the survey.

The survey sought how necessary a particular upgrade would be for pilots to accomplish their mission. Three mission types considered were Deployed Combat, Homeland Defense, and Replacement Training Unit. The deployed combat mission correlates closely with the Concept of Operations (CONOPS) for Global Persistent Attack (Department of the Air Force, 2004a). The Homeland Defense mission correlates closely with the Homeland Security CONOPS (Department of the Air Force, 2004b). These missions were described to the survey respondents.

NECESSITY RATINGS

Survey respondents were asked to rate the necessity of each modification to accomplish each of the three missions. The upgrades considered were very diverse—some offered an increase in offensive capability (lethality), some defensive capability (survivability), while some offered both. As discussed earlier, the researchers could not find a way to rate all upgrades on a common *capability* or *utility* scale. Via the survey, the researchers were able to rate all the upgrades on a common necessity scale.

Survey respondents rated each upgrade's necessity using the following Likert psychometric scale:

0 – N/A – Don't Know – Not enough information to answer
1 – Not necessary to accomplish the mission
2 – In rare circumstances may be necessary to accomplish the mission
3 – Sometimes necessary to accomplish the mission
4 – Usually necessary to accomplish the mission
5 – Absolutely necessary to accomplish the mission

The survey respondents rated the necessity of each upgrade against each of the three mission areas—Deployed Combat, Homeland Defense, and Replacement Training Unit. Respondents were instructed to rate an upgrade with respect to its necessity only; they were to ignore the cost or perceived reliability of the upgrade. It was anticipated some survey respondents would rate many or all of the upgrades as "Absolutely Necessary" or "Usually Necessary," not providing enough stratification to accurately evaluate the necessity of those systems. For this reason, when a respondent rated multiple upgrades as "Absolutely Necessary," the respondent was asked to rank-order those upgrades in importance, and then do the same for all the upgrades ranked as "Usually Necessary." These rank orders were then used to adjust the necessity ratings.

NECESSITY COEFFICIENTS (N_C)

The survey necessity ratings needed to be converted to numeric Necessity Coefficients (N_C). A simple method would be to simply use the numerical Likert scale and average the results. In his book *The Engineering Design of Systems*, Buede cites the work of Craig Kirkwood that found exponential functions are most commonly used to approximate the value functions of stakeholders (Buede, 2000). In other words, when user preferences are stated, their highest preferences are preferred many times over to their lower preferences. In some cases, the highest preferences can be orders of magnitude greater in desirability than the lowest preferences. For these reasons,

an exponential function was used to both adjust each person's Necessity Ratings for the rank order and then convert the Adjusted Necessity Ratings to numeric Necessity Coefficients. Table 3 summarizes the conversion of survey data.

For example, if a respondent rated three upgrades as "Absolutely Necessary," the survey then asked the respondent to rank-order those as No. 1, No. 2, and No. 3. The study used these *rank orders* to further stratify the upgrades by necessity. The upgrade ranked as No. 1 necessity would be given a higher Adjusted Necessity Rating than the upgrade ranked No. 2, which would have a higher Adjusted Necessity Rating than the upgrade the respondent ranked No. 3. Assuming an exponential user preference, the Necessity Rating was adjusted for rank using the following formulas:

Adjusted Necessity Rating = $4.5 + [e / e^{(\text{rank}/2)}]$, for a Necessity Rating of "5"
Adjusted Necessity Rating = $3.5 + 0.5[e / e^{(\text{rank}/2)}]$, for a Necessity Rating of "4"
Adjusted Necessity Rating = 3, for a Necessity Rating of "3"
Adjusted Necessity Rating = 2, for a Necessity Rating of "2"
Adjusted Necessity Rating = 1, for a Necessity Rating of "1"

So the Adjusted Necessity Rating is scaled *upward* on an upgrade for which a respondent ranked first, second, or third. Conversely, the Adjusted Necessity Rating is scaled *downward* for upgrades a respondent ranked fourth, fifth, or lower. For upgrades a respondent rated as 1, 2, or 3, the respondent was not asked to rank order them, thus the Adjusted Necessity Rating is simply the same as the Necessity Rating. From there, the Necessity Coefficient was calculated for each response on an exponential scale. The exponential function used was:

If Adjusted Necessity Rating = 1, Necessity Coefficient = 0
If Adjusted Necessity Rating > 1, Necessity Coefficient = $e^{(\text{Adjusted Necessity Rating})}$

Table 3 summarizes the conversion of survey data.

TABLE 3. USER SURVEY RATING CONVERSION TO NECESSITY COEFFICIENT

Original Survey Rating	Conversion	Necessity Coefficient
0 – N/A, Don't Know	Thrown Out	N/A
1 – Not Necessary	Set to Zero	0
2 – Rarely Necessary	$e^{(\text{Rating})}$	7.39
3 – Sometimes Necessary	$e^{(\text{Rating})}$	20.08
4 – Usually Necessary	$e^{(\text{Adjusted Rating \& rank})}$	33.16 - 75.52
5 – Absolutely Necessary	$e^{(\text{Adjusted Rating \& rank})}$	90.24 - 468.12

CAPABILITY OPTIMIZATION AND CONSTRAINTS

The study merged Necessity Coefficients (derived from survey responses), costs, and many other limiting factors involved in purchasing the upgrades. Linear Programming was the method chosen based on its applicability, simplicity, and modeling

assumptions (Ragsdale, 2004). The solution used a Simplex algorithm with two-sided bounds on all variables (Frontline, 2006). The algorithm moves up and down the bounds of a feasible region defined by an optimization objective, manipulating the value of the variables, until it reaches its maximum or minimum value subject to any defined constraints. The objective function, J, used in this research was the summation of all modifications to all aircraft weighted by the modification's Necessity Coefficient.

$$\max J = \Sigma_{i=1}^{M} N_{C_i} X_i \qquad \text{(Eq. 1)}$$

where: M is the number of different types of modifications

X is the number of modifications, of type i, chosen to buy

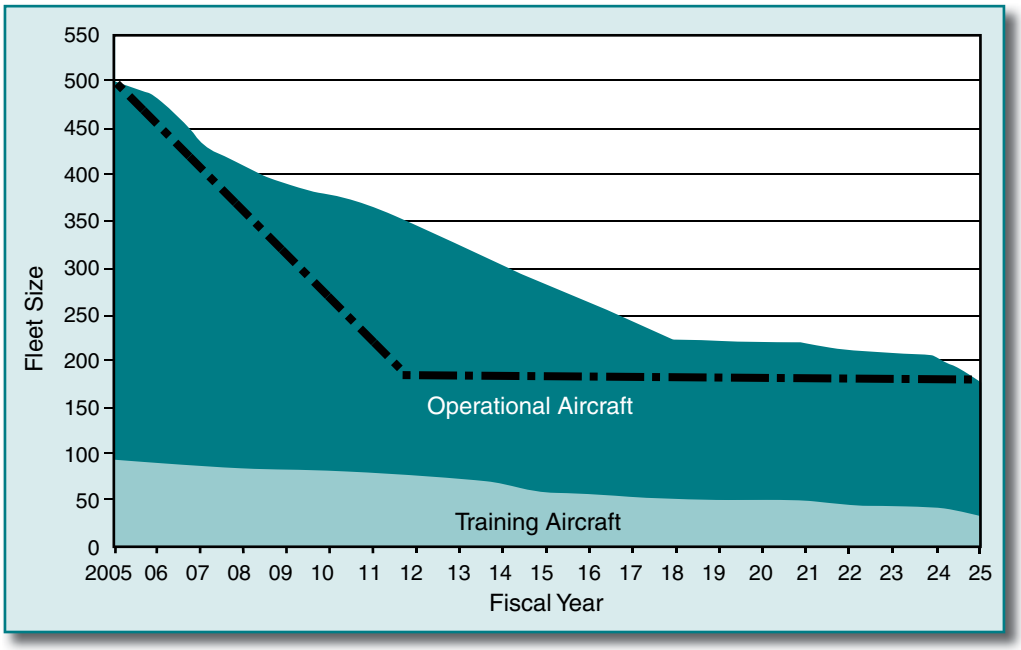
N_{C_i} is the Adjusted Necessity Coefficient for the *ith* modification.

The objective function was then constrained in several ways. The most obvious and primary constraint was a fixed budget authority, but other constraints included budget appropriations, the designated combat fleet size, designated training fleet size, upgrade interdependencies, and upgrade purchase limitations.

Like the program budget, the overall F-15 fleet size is subject to changes based on USAF, DoD, BRAC, or QDR directives. Current plans call for the F-15 fleet to gradually draw down from the current level of over 480 aircraft over the next 20 years. The total planned fleet size (broken into operational and training components) by fiscal year is shown in Figure 2.

The potential upgrades sometimes can not be installed on their own—they require other upgrades to be installed prior to or concurrently with the upgrade in question.

FIGURE 2. F-15 FLEET SIZE NOW EXCEEDS EARLIER DOWNSIZING PLANS (DASHED LINE) FOR THE NEXT 20 YEARS



This adds cost and further constrains the solution. One example is the APG-63v3 radar dish: it requires the "back-end" processors of the APG-63v1 radar.

The number of upgrades is also constrained by several other factors. First, we have already outfitted part of the fleet with some of these upgrades. An example is Embedded Global Positioning System/Inertial Navigation System (EGI). The USAF has already purchased EGI for 232 F-15s, so no money needs to be spent on EGI until the Service decides to upgrade the 233rd aircraft with EGI. Table 4 shows the current number of aircraft in the fleet already possessing a candidate upgrade.

TABLE 4. NUMBER OF AIRCRAFT CURRENTLY UPGRADED

Upgrade	Number of Aircraft
220E Engines	282
V1 Radar	178
V3 Radar	18
JHMCS	200
NVIS Phase II	178
NVIS Phase III	0
EGI	232
BOL-IR	114
OFP S6 (VCC+)	232
DVR	0
TEWS (S7, ADCP)	0

Another funding constraint occurred in cases where Research and Development (R&D) was not completed (or perhaps not even started) on a particular upgrade. In these cases, *3600 money* (R&D dollars) must be spent before *3010 money* (aircraft production dollars) can be spent. If a decision is made to buy a quantity of an upgrade, no matter how small, all associated 3600 money required to get that system ready for production must also be allocated.

Two other constraints applied were purely mathematical in nature: integer and non-negative constraints. Integer constraints applied to this F-15 problem ensure the solution can not buy a fraction of an upgrade—i.e., half of a new radar. Upgrades are only bought in integer quantities. Also, non-negative constraints ensured the algorithm would not try to "sell" certain upgrades to fund purchases of different ones—a mathematical solution but not a practical one in reality.

Since F-15s are being retired each year, there was a need to check the number of years left in a particular aircraft's life when deciding what upgrades to purchase for that aircraft. Obviously, spending a lot of money to upgrade a jet that may only have a couple years until retirement is undesirable. That money could otherwise be spent on an aircraft that will remain in service for 20 more years. The study decided

TABLE 5. MAXIMUM MODIFIABLE FLEET SIZES OVER TIME

	Short-Term (2007-11)	Mid-Term (2012-16)	Long-Term (2017-21)
Operational Fleet Size	282	204	169
Training (RTU) Fleet Size	81	56	48

to split the retirement and optimization plan into five-year blocks. Thus, the FY07 President's Budget provides an estimate of the upgrade budget available for the first five-year period of FY07–FY11. Budget estimates for subsequent five-year periods are current-year estimates based on the first five-year period. The fleet size in the optimization is thus divided into three parts: aircraft that will be around through the first five-year period, aircraft that will be around for the second five-year period, and finally aircraft that will be around for the third five-year period and beyond. Aircraft that will be retired in the next five years are not considered for upgrades. Modifiable aircraft numbers used are shown in Table 5.

All the above constraints were then added to the optimization model, resulting in the following:

$$\max J = \sum_{i=1}^{M} N_{Ci} X_i \qquad \text{(Eq. 2)}$$

such that:

$X_i \le CA_i(\text{period})$, (number $\le$ max number F-15 Combat Aircraft at end of period)

$X_i \le TA_i(\text{period})$, (number $\le$ max number F-15 Training Aircraft at end of period)

$X_i \le M_i$, (i.e. number $\le$ max number of Mods needed - many already installed)

$X_i \ge 0$, (number of mods selected is a non-negative number)

$X_i \in$ Integer

$\sum_{i=1}^{M} Cost_{3600}(X_i) \le BA_{3600}(\text{period})$, (one time R&D Cost $\le$ 3600 Budget Authority in period)

$\sum_{i=1}^{M} Cost_{3010}(X_i) \le BA_{3010}(\text{period})$, (one time Production Cost $\le$ 3010 BudgetAuthority in period)

$\sum_{i=1}^{M} Cost_{3010}(i) \cdot X_i \le BA_{3010}(\text{period})$, (total Production Costs $\le$ 3010 BudgetAuthority by period)

$X_i = X_j$, if modification i requires (enabled by) modification j

In general, this study did not investigate the cost or feasibility of moving upgraded systems from aircraft to aircraft as jets are retired. The added cost and logistic requirements are prohibitive in many cases. In some cases, upgraded systems on retired aircraft will re-enter the fleet as spare parts. Further, Air Force planners assumed that as the combat fleet is reduced in size, aircraft with many upgrades installed will be transferred to the training fleet, and the trainer aircraft with fewer upgrades will be the ones actually removed from service. Lastly, no attempts were made to include Operations and Sustainment costs to this model.

RESULTS

SURVEY RESULTS

A total of 278 F-15 pilots participated in the survey. A significant number of survey responses were received from all facets of the F-15 community including operational pilots (both AD and ANG), RTU instructors, the test community, and F-15 pilots serving on staffs and at full-time PME. A demographic summary of the survey participants is shown in Table 6.

Figure 3 shows the necessity coefficients that were derived from the survey results using the formulas discussed above for two missions. Of note, the scores for a given upgrade in the Combat mission are generally much higher than for Training, representing the higher necessity of most of the listed systems to do that mission. Also, while the Homeland Defense survey results were collected, it was decided that a separate Homeland Defense F-15 configuration would not be feasible to implement,

TABLE 6. F-15 USER SURVEY—RESPONDENT DEMOGRAPHICS

Average number of years flying F-15C	8.4
Average number of hours flying F-15C	1362
Number of respondents currently performing flying duties	222
Number of respondents currently performing other duties	54
Number currently operationally flying with the active duty Air Force	108
Number currently operationally flying with the Air National Guard	37
Number of respondents who were/are Training (RTU) instructors	92

FIGURE 3. NECESSITY COEFFICIENTS *(N_C)* PER MODIFICATION FOR COMBAT AND TRAINING MISSIONS

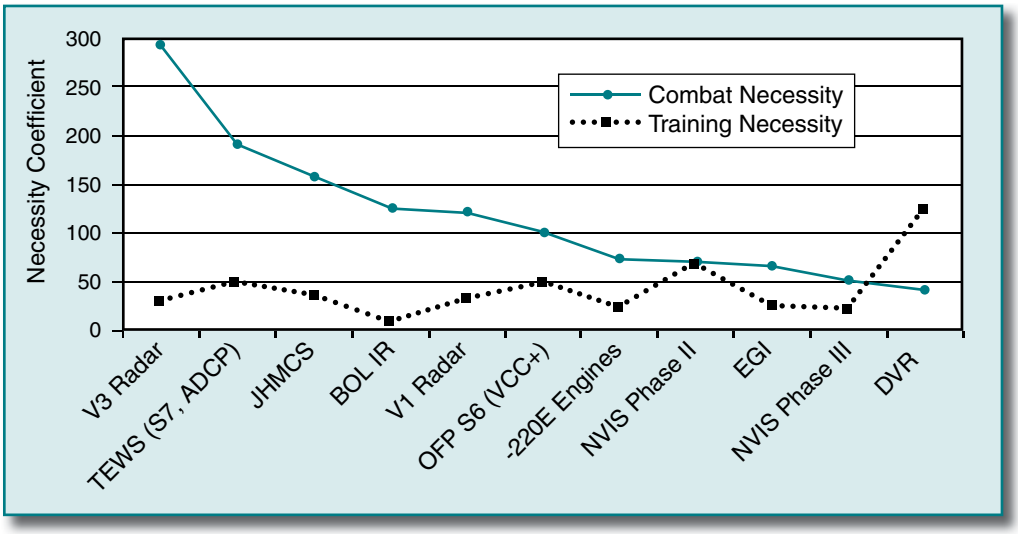


TABLE 7. TIME PHASED OPTIMIZATION SOLUTION

	Short-Term		Mid-Term		Long-Term		Total
Upgrades	Number to Buy (Combat)	Number to Buy (RTU)	Number to Buy (Combat)	Number to Buy (RTU)	Number to Buy (Combat)	Number to Buy (RTU)	Number to Buy
220E Engines	0	0	0	0	0	0	0
v1 Radar	0	0	0	0	0	0	0
v3 Radar	0	0	1	0	14	0	15
JHMCS	26	0	0	34	0	0	60
NVIS Phase II	104	81	0	0	0	0	185
NVIS Phase III	282	81	0	0	0	0	363
EGI	0	0	26	56	0	0	82
BOL-IR	168	0	0	0	0	0	162
OFP S6(VCC+)	104	0	0	0	0	0	104
DVR	0	81	179	0	0	0	260
TEWS (S7, ADCP)	0	0	0	0	0	0	0

so the optimization program eliminated this option and focused on the two remaining missions—Combat and Training.

OPTIMIZATION RESULTS

The optimization was run with the best current estimates of fleet size, budget authority, and upgrade-specific cost. The model was test-run for several different scenarios to check its validity and also to evaluate its sensitivity to some of the assumptions made earlier. Due to the funding environment today, the recommendations are based on a fairly constrained budget across each of the next three FYDPs. Table 7 shows the purchase recommendations of the model for the short-, mid-, and long-terms using a modest budget and having only two configurations—Combat and Training.

OPTIMIZATION OBSERVATIONS

At first glance, the optimization results generated one major question: Why isn't the model recommending immediate purchase of the item(s) rated as most necessary in the survey? As a specific example, why do the results recommend immediately buying Digital Video Recorder (DVR) and Night Vision Goggles (NVG)-compatible interior and exterior lights for the fleet instead of the APG-63v3 radar when the radar

ranked so highly on the survey? Perhaps the reader will think it is because of the *relative cost* of the items. The v3 radar certainly has a much higher Necessity Coefficient than DVR (7 times), but it also has a per-unit cost over 450 times that of the Night Vision Imaging Sensor (NVIS) Phase II. Several striking examples of relative cost can be calculated. For the price of only four v3 radars, it would be possible to upgrade all the remaining combat-coded jets in the short-term fleet (168 aircraft) with BOL-IR; and for the price of equipping three aircraft with the Joint Helmet Mounted Cueing System (JHMCS), it would be possible to install NVIS Phase II lighting in the 104 aircraft remaining in the short-term fleet without it. Recall that the optimization is trying to maximize capability for the entire fleet, not just an individual aircraft.

EXAMINATION OF OPTIMIZATION METHOD

Is this a flaw with the model—maximize fleet capability constrained by budget? Initially, assume that the approach is correct. Each modification made to an aircraft provides a measurable (through exercises, simulation or survey) increase in capability. So how does the model, using Linear Programming, search for a solution? To illustrate this, we limit the problem to only 2 of the 11 modifications, for example NVIS III and -220 Engines. This will allow a two-dimensional examination of the objective curves and constraint lines. For this simplified example, looking at one time period and one type of appropriation, the optimization model becomes:

$$\max J = \sum_{i=1}^{2} N_{Ci} X_i$$

such that:

$$\sum_{i=1}^{2} Cost_{3010}(X_i) \leq BA$$

Cast as a linear combination of modifications:

$$\max J = N_{C1} X_1 + N_{C2} X_2$$

such that:

$$Cost_1 X_1 + Cost_2 X_2 \leq BA$$

While J is typically the dependent variable, we can rearrange and write as the number of modifications of Engines, X_2, with respect to J and the number of NVIS III modifications (external lighting), X_1. Putting in actual necessity coefficients from the survey and cost (3010 $) values, the number of Engines can be written as:

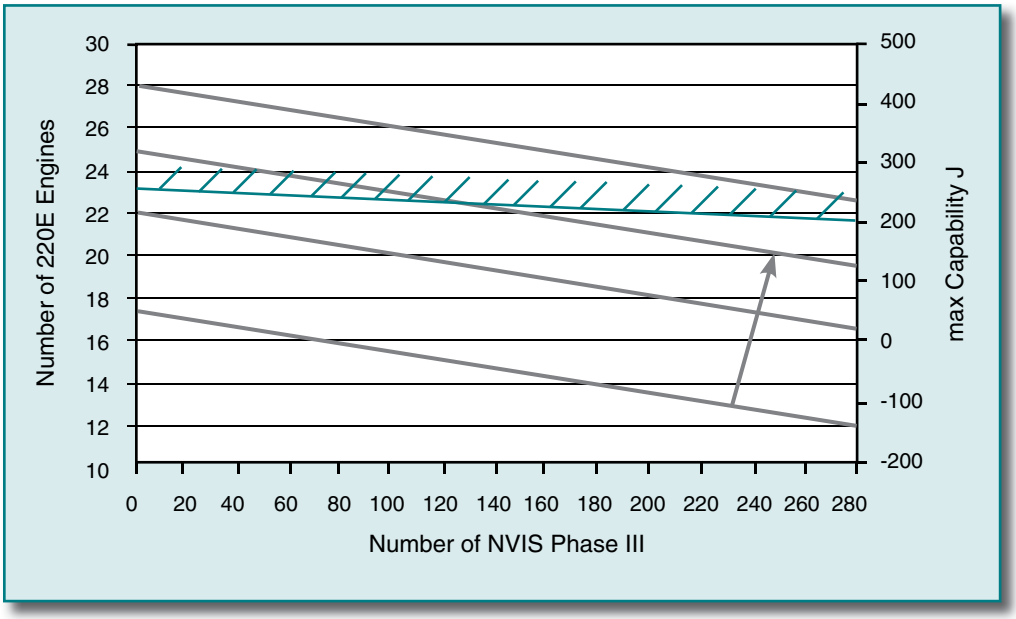
$$X_2 = -(N_{C1} / N_{C2}) X_1 + (J / N_{C2}) = -(74.2 / 51.2) X_1 + (J / 51.2)$$

such that (when the constraint is active),

$$X_2 = -(Cost_1 / Cost_2) X_1 + (BA / Cost_2) = -(\$17K / \$3.34M) X_1 + (\$77M / \$3.34M)$$

This can be graphically portrayed for varying maximums, J. In Figure 4, note that the cost constraint has a slope (with crosshatch), while the optimization of capability

FIGURE 4. OPTIMIZATION MODEL



Note: The cost constraint slope (blue with crosshatch) is a function of the cost ratios. Likewise, the objective function has a slope, a function of necessity coefficient ratios.

provides a series increasing objective lines with a second slope. To maximize *J*, the optimization algorithm will search for changes in X_2 and X_1, which increase *J*. Visually, the algorithm moves from the lowest *J* isoline up to higher contours. When the algorithm meets a constraint, it will move along it until reaching another constraint or finding a vertex (circle in figure). In this example, the design point moves toward the right (increasing NVIS) until the side constraint is reached, indicating that no more NVIS upgrades are feasible.

This type of behavior is well understood (Hazelrigg, 1996) and linear programming problems of this type will either find one optimal solution, may not find any solution if the parameters are unbounded, or find an infinite number of equally valid solutions. For the first solution to exist, it will occur at a vertex of constraint lines. The second solution is not applicable for this research, as all parameters are bounded based on maximum number of F-15 combat and training aircraft in a particular time period, as well as further constrained by budget authority and number of modifications already installed. The last solution, an infinite number of valid solutions, will be true if the active constraint line and the objective have exactly the same slope.

Thus, the behavior can be understood completely, for these two modifications, by the examination of the two slopes. The first is the slope of the Cost (constraint) line of $Cost_2/Cost_1$, or $Cost_{ENGINE}/Cost_{NVIS}$. The second is the slope of the Objective (necessity) line of N_{C2}/N_{C1}, or $N_{C\text{-}ENGINE}/N_{C\text{-}NVIS}$. The decision to buy more (all) NVIS modifications will occur if the slope of the necessity ratio is less than the slope of the cost ratio.

$$N_{C\text{-}ENGINE}/N_{C\text{-}NVIS} < Cost_{ENGINE}/Cost_{NVIS}.$$

TABLE 8. BALANCING COST BY EXAMINING SCALE OF NECESSITY COEFFICIENTS. FIRST QUANTITY REFERS TO OPTIMIZATION SOLUTION WITH α=100. SECOND QUANTITY USES A MORE BALANCED α=50

	Short-Term		Mid-Term		Long-Term		Total
Upgrades	Number to Buy (Combat)	Number to Buy (RTU)	Number to Buy (Combat)	Number to Buy (RTU)	Number to Buy (Combat)	Number to Buy (RTU)	Number to Buy
220E Engines	0	0	0	0	0	0	0
v1 Radar	0	0	0	0	0	0	0
v3 Radar	10/0	0	11/1	0	14/14	0	34/15
JHMCS	0/26	0	0/ 0	0/34	0	0	0/60
NVIS Phase II	0/104	0/81	0	0	0	0	0/185
NVIS Phase III	0/282	0/81	0	0	0	0	0/363
EGI	0	0	0/26	0/56	0	0	0/82
BOL IR	0/168	0	0	0	0	0	0/168
OFP S6(VCC+)	0/104	0	0	0	0	0	0/104
DVR	0/55	0/81	0/179	0	0	0	0/315
TEWS (S7, ADCP)	1/0	0	1/0	0	0	0	2/0

Another observation of these ratios can be made by examining the extremes across the set of 11 modifications. By examining the largest ratio of necessity coefficients and the corresponding cost values, one can see that the v3 radar and the DVR have the following relationship:

$$6.94 = N_{C\text{-}V3\ RADAR}/N_{C\text{-}DVR} < Cost_{V3\ RADAR}/Cost_{DVR} = 40.7. \qquad \text{(Eq. 3)}$$

This would indicate that linear programming would choose buying DVR to maximize capability.

Likewise, by examining the largest ratio of cost coefficients and the corresponding necessity values, the Tactical Electronic Warfare Set (TEWS) and NVIS II have this relationship.

$$2.78 = N_{C\text{-}TEWS}/N_{C\text{-}NVIS}\ II < Cost_{TEWS}/Cost_{NVIS}\ II = 630. \qquad \text{(Eq. 4)}$$

This would indicate that the optimization would tend to buy NVIS II modifications.

To remedy this situation of always buying low-cost, lease-capable modifications, one should examine the spread of Necessity Coefficients, N_C, and their relation to the spread of cost and budget authority. While the cost scale and constraints must remain on a linear scale, the Necessity Coefficients could be further spread, using a larger base. Recall the current scale of N_C uses $e^{\text{(Adjusted Rating \& rank)}}$. One could better balance cost using $\alpha^{\text{(Adjusted Rating \& rank)}}$, where α is chosen in the range that satisfies both Equations 3 and 4. For example, using an α of 100 and 50, the following results comparable to Table 7 are produced in Table 8.

CONCLUSIONS

This article documents an effective approach to compare system modifications in terms of capability provided, through the use of surveying experienced pilots and extracting their assessment of upgrade "necessity" to successfully conduct various missions. Necessity proved to be a novel way to compare, on a common scale, candidate upgrades with widely different system parameters. Additionally, scaling necessity on an exponential scale should better represent a user's true relative preferences. While a linear programming model can combine cost and necessity (capability), incorporating a myriad of complex constraints and relationships, one must understand the limitations of these models. In particular, one should balance scales of necessity and cost by examining point ratio extremes. These ratios (slopes) guide the search algorithms in linear programming to solutions. Results provide recommended modification purchases for the USAF F-15 fleet for combat and training aircraft across three FYDPs. This approach should be extensible across DoD programs, to extract quantitative measures of capability, constrained by budget authority, to provide those capabilities.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the work of several people who made significant contributions to this article, especially students Joseph Beahm, Bret Anderson, and Robert White. Thanks to the sponsors, Dan Marticello and John McLaughlin, as well as Terry Sampson for survey Web design. Thanks also to the editors/ reviewers for strengthening this work. Finally, thanks to the hundreds of F-15 pilots who took the time to respond to the survey.

Lt Col John Colombi, USAF (Ret.), is an assistant professor of Electrical Engineering at the Air Force Institute of Technology (AFIT). He holds a Ph.D. in Electrical Engineering from AFIT. Currently, he teaches graduate courses and leads sponsored research in support of the Systems Engineering program. Dr. Colombi led Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance systems integration activities, including systems engineering for the Airborne Warning and Control System at Hanscom AFB, MA.

(E-mail address: john.colombi@afit.edu)

Lt Col David Jacques, USAF (Ret.), is an assistant professor of Aerospace Engineering on the faculty of the Air Force Institute of Technology (AFIT). He holds a Ph.D. in Aeronautical Engineering from AFIT. Dr. Jacques is currently curriculum chair of the Graduate Systems Engineering Program. His research interests are in the areas of concept definition and evaluation, architecture modeling, and optimal system design. Dr. Jacques led the activation of the Air Force Center for Systems Engineering.

(E-mail address: David.Jacques@afit.edu)

Dr. Dennis Strouble is an assistant professor of Systems Engineering Management at the Air Force Institute of Technology. He holds a Ph.D. in Management and a J.D. from Texas Tech University. Currently, he teaches graduate courses in Systems Engineering Management, Information Resource Management and Law, and leads sponsored research in support of the Systems Engineering and Information Research Management programs. Dr. Strouble has taught at several universities, has remained active in the practice of law, and has founded and managed several businesses.

(E-mail address: dennis.strouble@afit.edu)

AUTHOR **BIOGRAPHY**

REFERENCES

Buede, D. M. (2000). *The engineering design of systems, models and methods.* New York: John Wiley & Sons.

Department of Defense. (2005, September 8). 2005 Defense Base Closure and Realignment Commission Report to Congress.

Department of Defense. (2006, February 6). Quadrennial Defense Review Report.

Department of the Air Force. (2004a, May 24). Global Persistent Attack CONOPS.

Department of the Air Force. (2004b, September 15). Homeland Security CONOPS.

Dillman, Don A. (2000). *Mail and Internet surveys: The tailored design method* (2nd ed.). New York: John Wiley & Sons.

Frontline Systems, Inc. (2006). *Frontline systems solver technology for optimization.* Retrieved May 2006 from www.solver.com/

Hazelrigg, George A. (1996). *Systems engineering: An approach to information-based design.* Upper Saddle River, NJ: Prentice Hall.

Meyburg, Arnim H., & Stopher, Peter R. (1979). *Survey sampling and multivariate analysis for social scientists and engineers.* Toronto: Lexington Books.

Ragsdale, Cliff T. (2004). *Spreadsheet modeling & decision analysis: A practical introduction to management science* (4th ed.). Mason, OH: South-Western, a division of Thomson Learning.

Weisberg, Herbert F. & Bowen, Bruce D. (1977). *An introduction to survey research and data analysis.* San Francisco: W. H. Freeman and Company.

Image designed by Harambee Dennis

TRAINING ARCHITECTURE PRACTICES IN ARMY ACQUISITION: AN APPROACH TO TRAINING SOFTWARE ARCHITECTURE PRACTICES IN U.S. ARMY ACQUISITION

Stephen Blanchette and John Bergey

Technology management skills in the Department of Defense (DoD) are not keeping pace with the advanced systems acquired by the DoD, especially as software becomes more prevalent in those systems. For a number of years, software architecture practices have been identified as enablers of program success, yet evidence suggests that too little attention is paid to the topic. The Army Strategic Software Improvement Program (ASSIP) seeks to dramatically improve the acquisition of software-intensive systems, in part through improved acquisition workforce skills. Through ASSIP, the Army has begun to build a level of technical expertise in modern software architecture practices within its acquisition community. This article discusses the training component of the ASSIP Software Architecture Initiative.

Since late 2002, the Software Engineering Institute (SEI), a federally funded research and development center operated by Carnegie Mellon University, has been working with (then) Assistant Secretary of the Army for Acquisition, Logistics & Technology (ASA[ALT]) Claude Bolton,[1] in a strategic partnership aimed at improving the Army's ability to acquire systems that are highly dependent on software (often called software-intensive systems [SIS]).[2] Through this partnership, known as the Army Strategic Software Improvement Program (ASSIP), the Army and

the SEI are engaged in several initiatives designed to enhance the Army's ability to be a "smart buyer" of software-intensive systems.

The need for ASSIP is readily apparent. Much has been made about the lack of technical depth demonstrated by the Department of Defense (DoD) in managing ever more complex system development programs (Government Accountability Office, 2007; Government Accountability Office, 2008). In fact, in 2007 the Pentagon initiated a study of the skills of its acquisition workforce (Erwin, 2007). One contributing factor to the shortage of technical skills is the growing presence of software in virtually every major system, from tanks to bombs to bullets, procured by DoD.

Early ASSIP investigations into Army SIS acquisition indicated, among other things, that while software architecture practices were deemed important for SIS programs, methods and skills to carry out those practices were perceived to be inadequate. Hence, the ASSIP formulated an initiative to raise the organic capabilities of Army acquisition in this important software development area. This article describes the work done to begin developing a foundation for an organic Army software architecture capability.

WHY SOFTWARE ARCHITECTURE?

One might question the focus on software architecture capabilities within the Army's acquisition workforce, but the reason becomes obvious when viewing architecture in terms of program success. First, a software architecture is the set of system structures that consist of "software elements, the externally visible properties of those elements, and the relationships among them" (Bass, Clements, & Kazman, 2003, p. 21). The software architecture underpins a system's software design and code; it represents the earliest design decisions—ones that are often difficult to change later (Bass et al., 2003), so getting the architecture "right" has enormous implications for the software and for systems reliant upon that software. It then follows that solid software architecture practices are essential to successful software-intensive programs.

In 2000, the DSB pointed to software architecture as "a central theme for software reuse, product lines, and greater exploitation of commercial technology and practices" (Defense Science Board Task Force, 2000, p. 3).

In fact, the importance of software architecture practices has been known for quite some time. In 1994, the Defense Science Board (DSB) highlighted the potential for software architecture and product line techniques to reduce cost and cycle times

(Defense Science Board Task Force, 1994). In 2000, the DSB pointed to software architecture as "a central theme for software reuse, product lines, and greater exploitation of commercial technology and practices" (Defense Science Board Task Force, 2000, p. 3). Further, a 2001 Army lessons-learned workshop focusing on software upgrade programs concluded, in part, that architecture is "a key technical focus for the system" (Anderson et al., 2001, p. 14), making special note of the criticality of the architecture in determining the future ability to upgrade the system (Anderson, et al., 2001).

Given that software architecture practices have been linked to successful SIS acquisition as noted above, one might have expected that such practices would be prevalent in Army (and other Services') acquisition programs. However, such is not the case. In 2002, the DoD Tri-Service Assessment Initiative (TAI) highlighted poor software architecture practices as one *systemic causal factor* of software-intensive systems issues, based on TAI assessments of 21 DoD programs (Charette, McGarry, & Baldwin, 2003; McGarry, 2002). Simply performing a task called "software architecture" is insufficient to leverage the benefits of software architecture. In fact, the act of producing an architecture is inadequate; both acquirer and supplier should also conduct an evaluation of the architecture's quality and robustness to ensure suitability for current and future needs as the system evolves. Indeed, a few of the larger defense contractors routinely employ some form of architecture evaluation (Bass, Nord, & Wood, 2006).

A recent SEI analysis of 18 software architecture evaluations performed by the Institute between 2000 and 2005 showed that over half of the evaluations revealed significant program risks driven by an organization's failure to appreciate the extent of the software architecture effort, as evidenced by lack of training, lack of tools, and poor planning. Further, about two-thirds of the risks discovered were risks of *omission* (architectural decisions either not made or not captured, for example) (Bass, Nord, & Wood, 2006). These observations are consistent with earlier reports that indicated organizations pay insufficient attention to software architecture practices, and suggest that architecture evaluators must be experienced enough to probe the architecture in detail rather than accept it at face value.

A review of findings from initial ASSIP data gathering efforts proved consistent with the studies noted above. For instance, acquisition professionals held the general impression that prime contractors' software architecture abilities were about average (Kasunic, 2004), suggesting a need for architecture evaluations to reduce associated program risk. Yet, according to interviews with some key programs and with the Army's Program Executive Officers (PEOs), government program office staffs were not sufficiently skilled to evaluate software architectures (Keeler, 2005; Blanchette, 2005).

Thus, software architecture is an acknowledged good practice in SIS programs, but one that is rarely executed effectively or evaluated rigorously.

SOFTWARE ARCHITECTURE INITIATIVE

Given that software architecture was one of the technical challenge areas facing Army program management offices (PMOs), the logical next step was to consider

what could be done to help PMOs use software architecture to their advantage. The SEI had been working with a few Army PMOs individually on software architecture issues (Bergey et al., 2005; Clements & Bergey, 2005; Clements, Bergey, & Mason, 2005), and while these efforts were successful, they were point solutions to a more systemic problem.

Understanding the significance of the studies discussed above for Army acquisition as a whole, Bolton charged the SEI to develop an ASSIP initiative to address the problems noted in software architecture. The resulting Software Architecture Initiative was approved by the ASSIP Action Group for implementation in fiscal year 2004. A training component formed the core of the initiative.

THE TRAINING PROGRAM

The SEI already had available a training curriculum for software architecture and, since it was designed to be taught either at SEI facilities or onsite at customer locations, it easily served as the basis of the ASSIP Software Architecture Initiative. The curriculum consists of six courses:

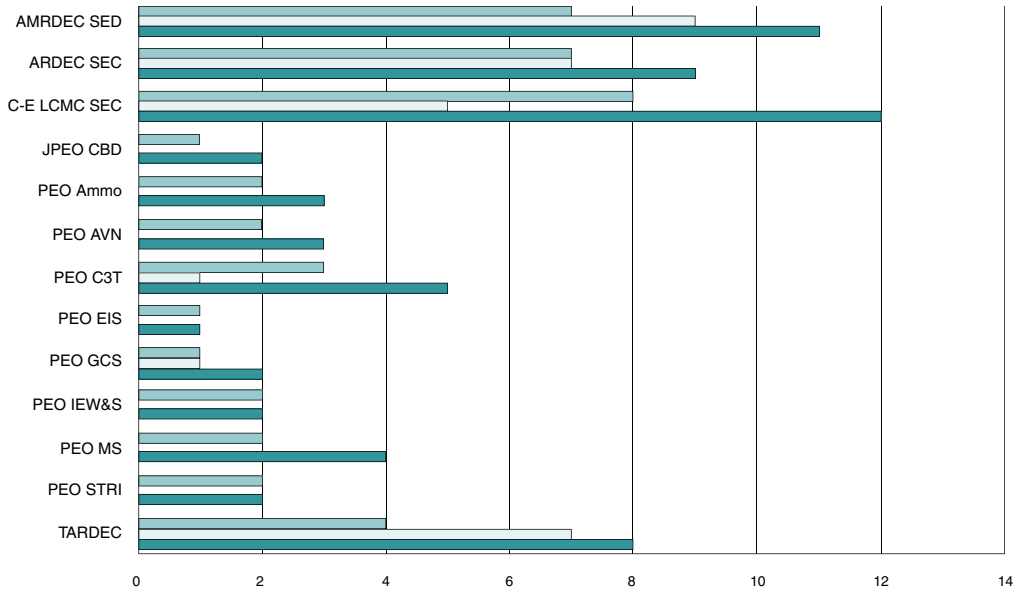
- Software Architecture: Principles and Practices
- Documenting Software Architectures
- Software Architecture Design and Analysis
- Software Product Lines
- SEI Architecture Tradeoff Analysis Method® (ATAM®) Evaluator Training
- ATAM Leader Training

Through a series of special offerings, the SEI delivered the curriculum at the Army software engineering centers (SECs) using the same materials and instructors as the publicly offered classes. The SECs provided the most central location for many participants since most of the Army's program offices are located in close proximity to one of the SECs. Students who completed the prescribed course sequences earned certificates just as if they had attended the regular public offerings.[3]

Generally, each course had 30 slots available to Army personnel engaged in acquisition or acquisition support roles. The ASSIP allocated the slots equitably among the PEOs, PMOs, and SECs. Due to the nature of the coursework, the more advanced ATAM Evaluator and Leader courses had a limit of 15 students. To better serve the specific needs of the Army, the ASSIP made those slots available to the SECs first because they are positioned to provide evaluation support across many programs. The PEOs and PMOs took advantage of the few slots in the courses not filled by SEC personnel.

The training program enjoyed strong participation, a good indication of both need and interest within the Army acquisition community. In fact, demand exceeded expectations and forced the waiving of class size restrictions in a few instances. Additionally, participation was broad: 9 of the 11 PEOs (including subordinate PMOs) and all of the Army's software centers had students who took part in the program. Sixty-four Army technical professionals attended at least part of the curriculum, with most earning at least one certificate. Figure 1 summarizes these results.[4]

FIGURE 1. SUMMARY OF ASSIP ARCHITECTURE TRAINING RESULTS



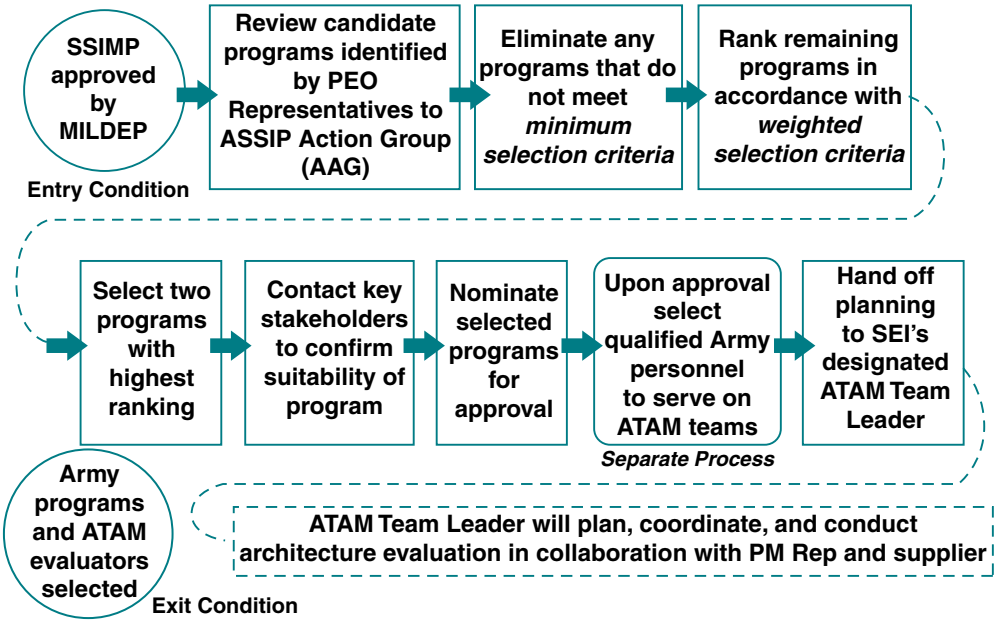
	TAR-DEC	PEO STRI	PEO MS	PEO IEW&S	PEO GCS	PEO EIS	PEO C3T	PEO AVN	PEO Ammo	JPEO CBD	C-E LCMC SEC	ARDEC SEC	AMRDEC SED
Software Architecture Professionals	4	2	2	2	1	1	3	2	2	1	8	7	7
ATAM Evaluators	7	0	0	0	1	0	1	0	0	0	5	7	9
Total Participants	8	2	4	2	2	1	5	3	3	2	12	9	11

OPPORTUNITIES FOR PRACTICE

Obviously, training is a necessary step toward building a skill level. However, training alone is not sufficient; to truly develop competence, trainees must be able to practice their newly acquired skills. To that end, the ASSIP Software Architecture Initiative added a limited skill-building component in FY05. The initiative sponsored several ATAM-based software architecture evaluations, and as a prerequisite, required the participation of trained Army evaluators on the evaluation teams.

As one might imagine, more programs were nominated for ATAM evaluations than could be accommodated, which made selecting among them a non-trivial task. As Figure 2 shows, once programs had been nominated, two experienced SEI staff members followed a process to rank the programs based on a set of criteria developed for ASSIP. The process consisted of two passes. The first pass pre-screened the nominated programs to ensure that they were ready and able to participate in an ATAM evaluation. Those that were not were eliminated from further consideration. The second pass ranked the remaining programs, with preference given to those where the

FIGURE 2. SELECTION PROCESS FOR PROGRAMS PARTICIPATING IN ASSIP-SPONSORED ATAMS



potential impact to the Army would be relatively higher and that presented the best opportunities to promote broad application of architecture practices (Blanchette & Bergey, 2007).

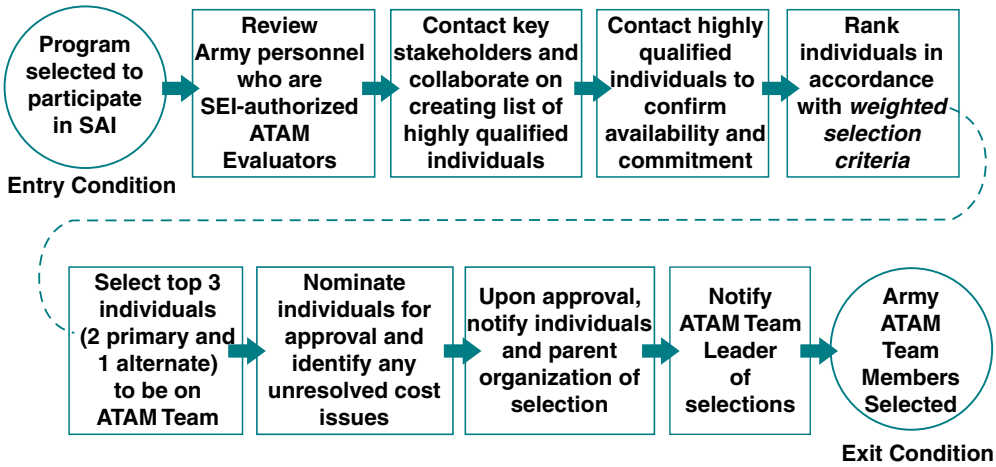
No less challenging was the effort to select evaluation team members from the pool of newly trained Army personnel; there were far more volunteers than slots available. The SEI used a process similar to the program selection process to select Army participants for the evaluation teams. Figure 3 depicts the participant selection process. Screening criteria for Army participants emphasized general technical competence in architecture practices as well as domain knowledge in the type of systems being evaluated. Ranking criteria focused on individuals who had knowledge of the program to be evaluated and who planned to become ATAM Lead Evaluators (because ATAM participation is one of the steps to becoming a Lead Evaluator) (Blanchette & Bergey, 2007).

To ensure the integrity of the ATAM, each Lead Evaluator had the final vote on whether a program was ready for an evaluation and whether the selected Army team members were adequately prepared. From FY05 through FY06, five ASSIP-sponsored evaluations provided seven students with the opportunity to hone their skills.

TAKING STOCK—A WORKSHOP

A key factor in any training program is evaluating effectiveness. Obviously, educating 30 technical professionals per year and providing practice opportunities for only one quarter of them[5] represents only a small step towards building and sustain-

FIGURE 3. SELECTION PROCESS FOR ARMY PERSONNEL PARTICIPATING ON ATAM TEAMS



ing a significant software architecture capability within the Army. Thus, gauging the relative success of the training and determining the necessary follow-on actions were important next steps in the process.

In May 2007, the ASSIP conducted a software architecture workshop designed to determine the need for additional investment and actions in order to develop a sustained and truly organic software architecture capability within Army acquisition. Hosted by the SEI, the workshop enjoyed strong attendance, with nearly 20 government representatives participating. Moreover, participation was broad—5 of the 11 PEOs were represented by at least one of their programs, and two of the Army's software engineering centers were represented, as was the office of the ASA(ALT). In addition, both the office of the assistant secretary of the Navy for research, development, and acquisition chief engineer, and the office of the secretary of the Air Force for acquisition participated in the workshop.

The workshop allowed participants to learn about recent developments in software architecture and to hear from each other about their respective experiences in applying software architecture practices. More importantly, participants actively discussed the enablers and barriers to broadening adoption of software architecture practices within the Army and brainstormed the necessary steps to achieve that broadening.

Workshop attendees eagerly discussed their ideas and suggestions, several of which centered on training. One particularly hot topic was the DoD Architecture Framework (DoDAF). The DoDAF describes a six-step, data-focused approach to developing system architectures. Attendees expressed a need to understand how they could evaluate DoDAF architecture products in a rigorous manner. They also indicated a desire to understand the linkage between DoDAF architectural views and software architectures (Bergey et al., 2007).

Since it is desirable to be proactive and introduce software architecture practices early in the acquisition process so that they are appropriately applied and coordinated throughout the development life cycle, attendees suggested that training for contract

officers would be beneficial. Doing so would allow them to be familiar enough with the risk reduction concepts to incorporate many of the practices into a request for proposal or contract at the beginning of an acquisition. Attendees also noted that while training was good and necessary, it needed to be augmented with guidelines and support materials that would help government personnel apply the knowledge effectively (Bergey et al., 2007).

Finally, several attendees voiced the need to have software architecture practices incorporated into the Defense Acquisition University (DAU) curriculum in order to promulgate the practices more widely and ultimately achieve risk reduction in the software component of system acquisitions across the Services (Bergey et al., 2007). It should be noted that DAU does address software architecture practices and issues in its intermediate and advanced courses in software acquisition management; workshop attendees simply felt that a greater degree of technical depth was needed in those courses.

SOME LESSONS LEARNED

Based on results to date of the ASSIP Software Architecture Initiative, several lessons may be gleaned for organizations contemplating a similar educational program.

TRAINING

The training curriculum itself was the simplest part of the initiative to implement since it already existed in a format that lends itself to this application. In hindsight, though, the manner in which the training was offered and the overall planning for it could have been improved.

The Lead Evaluator course should have been offered only to those individuals who not only had an interest in becoming Lead Evaluators but who had the support of their organizations in satisfying all the criteria.

For instance, the initiative made the entire software architecture curriculum, including the ATAM Lead Evaluator course, available to all participants. However, actually becoming a Lead Evaluator requires satisfaction of several criteria beyond simply attending the course. In particular, candidates must satisfy course instructors that they possess not only the requisite technical skills but also the necessary leadership acumen to be an effective Lead Evaluator. They must have participated on an evaluation team. They must also undergo observation while leading an ATAM evalu-

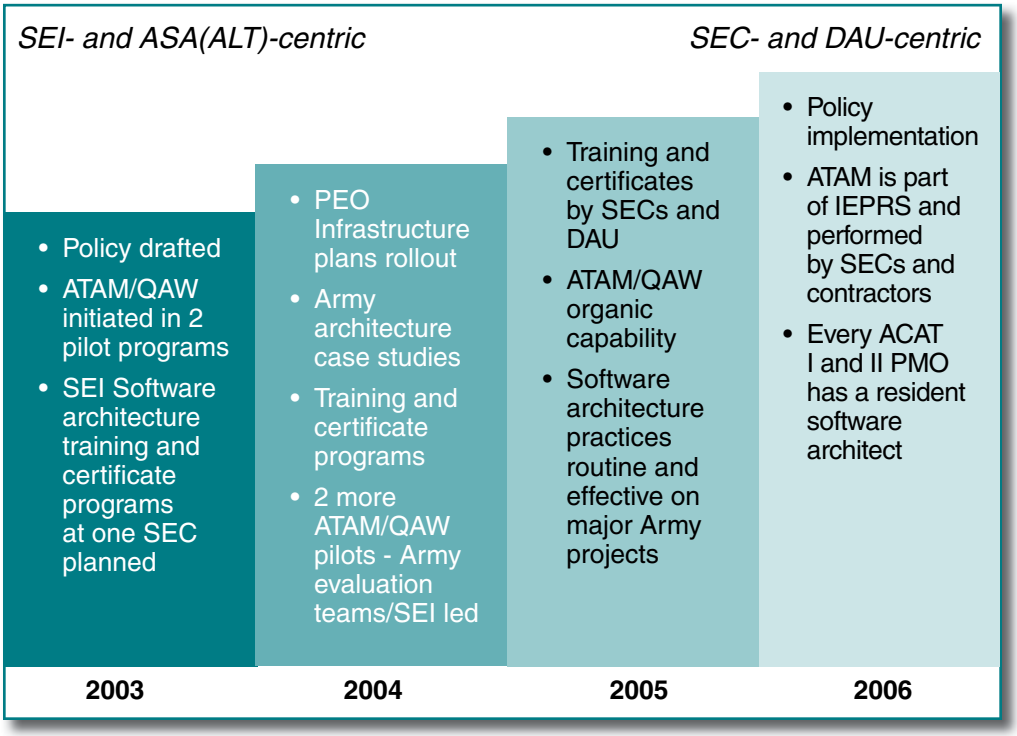
ation. Since there is a fee for the observation, the commitments of each individual's organization and supervisor are also required. Through the initiative, however, individuals were permitted to take the ATAM Lead Evaluator course without consideration for commitment to follow through with these additional steps. The Lead Evaluator course should have been offered only to those individuals who not only had an interest in becoming Lead Evaluators but who had the support of their organizations in satisfying all the criteria. An effective means of establishing organizational commitment is for prospective Army Lead Evaluators to include participation on an ATAM evaluation team (as an observed Lead Evaluator or as a regular team member) in their Individual Development Plans (IDPs).

As originally envisioned in FY03 and depicted in Figure 4, the ASSIP Software Architecture Initiative would have transitioned responsibility for the architecture training from an ASSIP-sponsored effort to the Army SECs and DAU by FY05. In retrospect, that schedule was too ambitious. Realistically, it was necessary to build a small cadre of trained professionals first and then demonstrate the utility of their training in order to develop the sort of groundswell of interest in software architecture practices that would support such a transition. In addition, transitioning the curriculum to external organizations requires careful planning.

PRACTICE

Arranging practice opportunities for students was one of the more challenging aspects of the initiative. For instance, although all of the nominated programs were in-

FIGURE 4. ORIGINAL TIMELINE



terested in receiving a free software architecture evaluation, a few were initially hesitant about having personnel from their PEO or SEC participate, while others objected to having Army personnel from unrelated or external commands on the team. Still others did not want the participation of *any* Army personnel. Although the objections were handled during the personnel selection process, the requirement for Army personnel to be involved needed to be more explicit in the program nomination process.

A focus of the ATAM evaluation is the actual on-site meetings, and it is easy to forget the other activities, such as pre-evaluation teleconferences and post-evaluation report development, that draw on a participant's time. These tasks are as essential to a successful outcome as the evaluation meetings, but are easily overlooked if there is a lengthy period between taking the ATAM Evaluator class and participating on a team. There were a couple of instances of misunderstanding about these points when recruiting participants for the ATAM evaluations. Although they were resolved without difficulty, reinforcing the requirements for participation up front, which is now part of the recruitment process, is a better approach.

The key difference between acquisition organizations is the manner in which they perceive software in their systems.

Finally, having the flexibility to adjust plans when situations dictate a change is essential; it is not in anyone's interests to cancel the limited practice opportunities. If a program selected for an architecture evaluation turns out not to be ready for the evaluation as planned, fallback options can be explored. For instance, if the architecture is not yet matured to a state where an evaluation would make sense, a quality attribute workshop, in which a team works with the program and its stakeholders to develop and prioritize non-functional requirements, might be substituted. The benefit of this approach is that evaluation team members are still able to practice techniques that they have learned through training, because eliciting quality attributes is an important step in an ATAM evaluation. Alternatively, if a program's architecture is sufficiently mature but not adequately documented for an evaluation, it is possible to postpone the evaluation while working with the program to improve its documentation.

PARTICIPATION

Not surprisingly, the SECs, due to their explicit focus on software, had the highest participation in the training program. The acquisition organizations were distributed relatively evenly in their course attendance, but at a much lower level than the SECs. When it came to nominating programs for architecture evaluations, however, those organizations that acquire software systems, communications systems, or electronics were more inclined to take advantage of the opportunity than those organizations that

chiefly acquired weapons systems (despite the fact that weapon systems were likely to contain large amounts of software, communications, and electronic components).

The key difference between acquisition organizations is the manner in which they perceive software in their systems. Weapon systems acquirers tend to focus on the system in its totality; they view software as an *enabler* rather than a *driver* of system behavior, and perceive it as relatively less important. Acquirers whose systems are dependent on software for functionality were quick to appreciate the importance of software and the need for software architecture evaluations. These differences suggest that extra effort is necessary to reach out to organizations that tend to treat software as a less important implementation detail in their systems.

In the case of the Army, the workshop validated the need and importance of the architecture training program while also demonstrating a need to expand Army investment in it.

Perhaps the most significant outcome of the workshop was that a number of program offices indicated that they were only willing to pursue evaluation of their software architectures because ASSIP paid for the evaluations, yet *all* recognized the value of the evaluation afterwards (Bergey et al., 2007). The ability to turn "nay-sayers" into "yea-sayers" is powerful evidence of the architecture initiative's success. However, such findings also suggest that similar education programs must be prepared to counter lack of awareness among program managers about architecture evaluations through funding, policy, or both.

Additionally, it is important to evaluate the effectiveness of the program. In the case of the Army, the workshop validated the need and importance of the architecture training program while also demonstrating a need to expand Army investment in it.

WAY AHEAD

The success of the software architecture initiative led to a number of tasks for ASSIP in FY08 that seek to build on successes as well as to address the lessons learned and workshop results. Among the tasks in progress are the continued offering of the software architecture curriculum, the expansion of opportunities for students to apply techniques in several ASSIP-funded ATAM evaluations, and the introduction of opportunities for selected promising students to advance toward becoming SEI-certified ATAM Lead Evaluators. Additionally, a new course, aimed at acquisition executives to increase their awareness of the benefits of the disciplined use of software architecture practices, is being developed. The ASSIP also will conduct interviews of

program office personnel to collect lessons learned and develop case studies regarding software architecture practices, and will hold a workshop to explore and make clearer the relationships amongst different kinds of architecture, including software, systems, and enterprise architectures. Lastly, the SEI will collaborate with DAU in seeking opportunities to enhance the software training available to the Army (and DoD) technical workforce.

SUMMARY

There is no shortage of reasons for wanting to improve the technical skills of the government's acquisition practitioners, especially for those individuals who acquire software-intensive systems. Sound software architecture practices are widely recognized as helpful in developing such systems successfully, yet they represent one of the key areas where government expertise is lacking.

Through the ASSIP Software Architecture Initiative, the U.S. Army has succeeded in training a cadre of its acquisition professionals in the necessary skills to understand and evaluate software architectures. The initiative provided hands-on experience opportunities in addition to the classroom-based training.

In assessing the results of the Software Architecture Initiative, clearly more work remains to be done to achieve a truly organic software architecture capability in the Army. That work is underway as the Army continues its emphasis on improving the skills of its acquisition workforce.

Mr. Stephen Blanchette, Jr., is a senior member of the technical staff at the Software Engineering Institute, specializing in acquisition improvement initiatives for the U.S. Army. A graduate of both Norwich University and Embry-Riddle Aeronautical University, he has over 20 years' experience in the defense industry. He is a senior member of the American Institute of Aeronautics and Astronautics and the Institute of Electrical and Electronics Engineers.

(E-mail address: sblanche@sei.cmu.edu)

Mr. John Bergey is a senior member of the technical staff at the Software Engineering Institute, specializing in transitioning SEI product line and architecture-centric practices into acquisition practice across the Armed Services. Mr. Bergey is a graduate of Pennsylvania State University and the University of Michigan. Prior to joining SEI, he served over 25 years as a software division manager with the U.S. Navy.

(E-mail address: jkb@sei.cmu.edu)

AUTHOR **BIOGRAPHY**

ENDNOTES

1. Claude Bolton, ASA(ALT) retired in January 2008, but the ASSIP continues under Dean Popps, Acting ASA(ALT).
2. According to the Defense Acquisition University (DAU), a software-intensive system is one in which software represents the largest segment in one or more of the following criteria: system development cost, system development risk, system functionality, or development time (Defense Acquisition University, 2005).
3. Three certificates—Software Architecture Professional, ATAM Evaluator, and ATAM Lead Evaluator—are available to students who complete the required courses.
4. Participants shown for PEO Missiles and Space were part of the predecessor organizations PEO Tactical Missiles and PEO Air Space and Missile Defense.
5. Only a limited number of contractual engagements provided a suitable opportunity to apply the skills learned in collaboration with the development contractor without being intrusive (i.e., significantly disrupting cost and schedule).

REFERENCES

Anderson, W., Bergey, J., Fisher, M., Graettinger, C., Hanson, W. J., Obenza, R., et al. (2001, November). *Army workshop on lessons learned from software upgrade programs.* Special Report (CMU/SEI-2001-SR-021). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Bass, L., Clements, P., & Kazman, R. (2003). *Software architecture in practice* (2nd ed.). Boston: Addison-Wesley.

Bass, L., Nord, R., & Wood, B. (2006, April). *Risk themes from ATAM data: Preliminary results.* Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Bergey, J., Blanchette, S., Gagliardi, M., Klein, M., Little, R., Morrow, T., et al. (2007). *Army software architecture workshop: Reporting on Army experiences.* Special Report (CMU/SEI-2008-SR-003, Limited distribution). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Blanchette, S. (2005, March). *U.S. Army acquisition – the Program Executive Officer perspective.* Special Report (CMU/SEI-2005-SR-002). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Blanchette, S., & Bergey, J. (2007, June). *Progress toward an organic software architecture capability in the U.S. Army.* Special Report (CMU/SEI-2007-TR-010). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Charette, R., McGarry, J., & Baldwin, K. (2003, January). *Tri-Service assessment initiative phase 2 systemic analysis results.* Tri-Service Assessment Initiative. Retrieved August 1, 2007, from http://www.splc.net/programs/acquisition-support/conf/2003-presentations/charette.pdf

Clements, P., Bergey, J., & Mason, D. (2005, September). *Using the SEI Architecture Tradeoff Analysis Method to evaluate WIN-T: A case study.* Special Report (CMU/SEI-2005-TN-027). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Clements, P., & Bergey, J. (2005, September). *The U.S. Army's Common Avionics Architecture System (CAAS) product line: A case study.* Special Report (CMU/SEI-2005-TR-019). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Defense Acquisition University. (2005, July). *Glossary of defense acquisition acronyms and terms* (12th ed.). Fort Belvoir, VA: DAU Press.

Defense Science Board Task Force. (1994, June). *Acquiring defense software commercially.* Retrieved August 1, 2007, from http://www.acq.osd.mil/dsb/reports/commrecialdefensesoftware.pdf

Defense Science Board Task Force. (2000, November). *Defense software.* Retrieved August 1, 2007, from http://www.acq.osd.mil/dsb/reports/defensesoftware.pdf

Erwin, S. I. (2007, April). Pentagon begins broad review of acquisition workforce skills. *National Defense, 91*(641), 18.

Government Accountability Office. (2007, June). *Defense acquisitions: Role of lead systems integrator on future combat systems program poses oversight challenges.* (GAO-07-380). Washington, DC: Author.

Government Accountability Office. (2008, January). *Defense acquisitions: DoD's increased reliance on service contractors exacerbates long-standing challenges.* Statement of David M. Walker, Comptroller General of the United States, in testimony before the Subcommittee on Defense, Committee on Appropriations, House of Representatives. (GAO-08-621T). Washington, DC: Author.

Kasunic, M. (2004, March). *Army Strategic Software Improvement Program (ASSIP) survey of Army acquisition managers.* Special Report (CMU/SEI-2004-TR-003). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Keeler, K. L. (2005, October). *U.S. Army acquisition—The program office perspective.* Special Report (CMU/SEI-2005-SR-014). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University.

Image designed by Harambee Dennis

THE APPLICATION OF SUPPLY NETWORK OPTIMIZATION AND LOCATION ANALYSIS TO A DoD REPAIR SUPPLY CHAIN

William R. Killingsworth, David Berkowitz, John E. Burnett, and James T. Simpson

A major responsibility of the military and its suppliers is to provide an adequate supply of parts and materials to support warfighters throughout the world. This article reviews a process used by an Army global supply chain to make a location decision for a critical distribution center. Additionally, it demonstrates the applicability of network optimization techniques to a DoD supply chain location analysis problem. Finally, it investigates the feasibility of making a $15 or $25 million capital investment to provide an alternative repair facility.

A major responsibility of the military and its suppliers is to provide an adequate supply of parts and materials to support warfighters throughout the world. The exploitation of supply chains has proven to be critical to the efficient delivery of these resources. One of the major decisions for supply chain managers is to determine the most appropriate location for supply chain facilities such as distribution centers.

Traditional business firms routinely make location decisions. Decisions about where to locate retail outlets, warehouses, offices, and manufacturing facilities are common supply chain decisions (Byrom, Bennison, Hernandez, & Hooper, 2001). Nevertheless, these decisions can become rather complicated as the firm attempts to optimize supply chain performance. The selection of the appropriate blend of proximity to customers, vendors, suppliers, materials, and labor resources while managing financial goals such as lower shipping costs is a significant task for any supply chain

manager (Hernandez & Bennison, 2000). The purpose of this article is to: (a) review a process used by an Army global supply chain to make a location decision for a critical distribution center, and (b) provide a prescriptive procedure for other agencies with similar location decision requirements.

We begin this study by briefly reviewing two relevant location theory frameworks. We then describe the situation underlying the study and the critical supply chain issues. Next, the method and software used in the study are discussed. Following the presentation of the results of the study, we summarize the study and discuss its implications.

LOCATION DECISION THEORY

Two distinct frameworks are used in location theory to describe location decision making in supply chains. The first framework focuses on minimizing cost, while the second framework focuses on market area and demand location. All other approaches to location decision making are combinations of these two major frameworks.

Minimizing cost and, by proxy, maximizing profit is the first framework in location decision theory.

Minimizing cost and, by proxy, maximizing profit is the first framework in location decision theory. This approach focuses on transportation as the major driver of cost. Nevertheless, transportation must be segmented into the inbound and outbound logistics to gain a complete understanding of its impact on the overall transportation cost. Inbound logistics include all the necessary parts for the production or overhaul of the product. The outbound logistics include all the work in process or final products being shipped to an end consumer or warehouse for storage. Additionally, any items stored at an intermediate storage facility incur additional costs such as transportation cost and carrying cost. Carrying cost includes costs such as storage, re-handling, and in many cases, accounts receivable (Stock & Lambert, 2001).

The second framework is a contrast to the low-cost approach and is based on being customer-centered. The market area or demand-oriented framework proposes that the least-cost approach is only one of multiple approaches to profit maximization (Stock & Lambert, 2001). This argument is based on the notion that customers and suppliers are unevenly dispersed. Hence, a firm can be better served by locating close to its suppliers. Moreover, the firm can better serve its customers by locating close to the customers. This approach would suggest that better serviced firms can better serve their customers, which should yield better satisfied customers. The results should be more repeat customers and greater profits. Of course, maximizing revenue would rarely be the primary objective for a government application. More relevant objectives might include warfighter/customer satisfaction, coverage, or cost minimization.

While both location decision frameworks have their distinct advantages, location decisions in supply chains with complex products and widely dispersed customers require the analyst to account for multiple suppliers and varying supply chains. Therefore, multiple perspectives must be included in a complete analysis of a location decision. Most effective location analyses require that the analyst consider both the cost minimization framework and the customer service framework.

The analysis in this study considers the trade-offs between logistics pipeline costs, in transit time, and the potential capital investment required for a new overhaul facility. The analysis includes the shipment, repair, and return of damaged helicopter blades to and from all key global demand areas to include South Korea, Europe, Southwest Asia (SWA), and installations within the Continental United States (CONUS). Specifically, we use one helicopter platform and its respective blade repair and replacement needs for our analysis. For the purpose of this article, we use the name *Algonquin* rather than the actual name of the helicopter platform.

This study demonstrates the applicability of network optimization techniques to a DoD supply chain location analysis problem. The focus of the study is to determine an estimate of the total annual cost of a particular helicopter platform supply chain operation under several different scenarios. This particular analysis is designed to determine the feasibility of making a $15 or $25 million capital investment to provide an alternative repair facility.

SITUATION AND DECISION PROCESS

The U.S. Army currently operates and maintains a global fleet of approximately 1,700 Algonquin (not the actual name) helicopters of which about 100 belong to the U.S. Air Force. The operating aircraft are equipped with approximately 9,800 blades, which include four main rotor blades on each helicopter and blades that are in the supply system. Over 1,000 (12 percent) of these blades will need maintenance or repair above the field level. The distribution of Algonquin aircraft and the FY06 demand for blade repairs are shown in Table 1.

TABLE 1. GLOBAL DISTRIBUTION AND BLADE REPAIR REQUIREMENTS

Algonquin 2006 Global Distribution and Blade Repair Requirements		
Location	Air Craft	Blades Requiring Repair
CONUS	1076	550
Europe	133	50
Japan	54	11
Hawaii	5	64
Korea	64	22
SW Asia	286	450
Total	**1618**	**2**

The Army Aviation and Missile Command (AMCOM) Integrated Material Management Center (IMMC) manages the transportation, repair, and procurement of Algonquin blades. In FY06, this consisted of 8,300 blades including those installed on helicopters, those in the repair pipeline, and serviceable blades in inventory. Blades removed from helicopters during routine maintenance undergo a comprehensive evaluation. Currently, blades are either repaired at Corpus Christi Army Depot (CCAD), returned to the Original Equipment Manufacturer (OEM) for repair, or scrapped.

As shown in Figure 1, in FY05, CCAD completed repairs on 785 blades and the OEM completed 110. Since some blades are lost or scrapped due to damage or excessive wear, customer demand requires that the overhaul process must be supplemented by the procurement of new blades. Figure 1 also includes the relationships between the number of blades repaired at the CCAD, the number repaired by the OEM, and the number of new blades from procurement contracts for FY04–FY06. Figure 2

FIGURE 1. BLADE REPAIRS AND PROCUREMENT

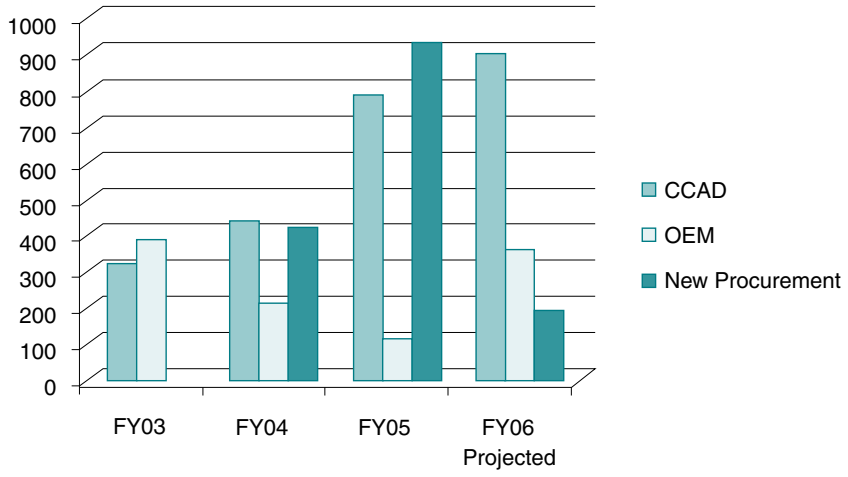


FIGURE 2. GLOBAL REGIONAL DEMAND FOR BLADES

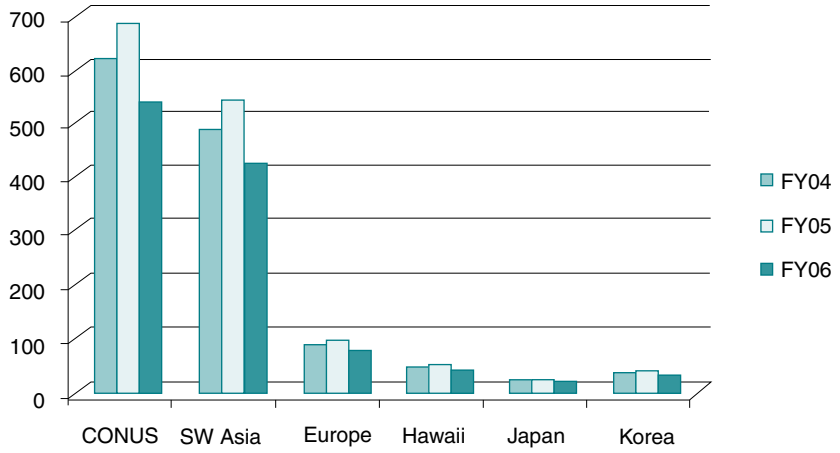


FIGURE 3. ALGONQUIN GLOBAL SUPPLY CHAIN NETWORK

provides a sense of the geographical distribution of blade demand by reporting the global regional demand for blades.

Figure 3 presents an overview of the Algonquin global supply chain network. While the need to return costly blades to the field, the need for good stewardship of the taxpayer's money, and the need to plan for unexpected demands as the military responds to global crisis were the key drivers for the analysis, our effort to identify the optimal supply chain required that we specifically address each of the following issues:

- Where should manufacturing, overhaul/repair, and distribution facilities be located?
- How many facilities are required? Which customers are sourced by which facilities?
- What are the trade-offs between:
  - inbound and outbound transportation costs
  - fixed and variable facility costs?

Responses to these questions require an assessment of several critical input factors:

- customer demand, location, transportation
- production capacities and limitations
- cost differentiation between locations:
  - transportation, distribution, and inventory costs
  - asset limitations.

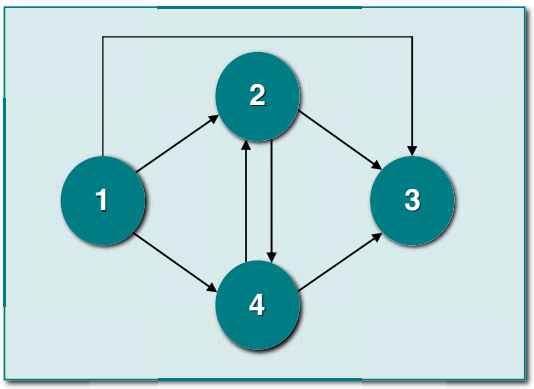
METHOD

THE NETWORK FLOW PROBLEM

The problem to be solved falls within a class of problems known as network flow problems. Network flow problems are essentially an extension of the classic

transportation (and assignment) problem where the task is to determine a feasible transportation pattern for shipping items from a set of origins to a set of destinations in a way that minimizes the total transportation cost. Hitchcock (1941) is generally credited with the original formulation and solution of the transportation problem. The extension to more general network flow problems was a natural progression. Since that time, the fundamental network flow problem and solution techniques have been applied and extended to problems in many areas, including transportation planning (Magnanti & Wong, 1984), location analysis (ReVelle & Eiselt, 2005), production management (Brown, Geoffrion & Bradley, 1981), cash management (Srinivasan, 1974), patient flows in hospitals (Mitropoulos, Mitropoulos, Giannikos, & Sissouras, 2006), and shop floor flows in manufacturing (Stafford, Tseng, and Gupta, 2005).

FIGURE 4. SAMPLE NETWORK



In order to conceptualize the fundamental minimum cost network flow problem, consider a directed network, G, that consists of a finite set of nodes, $N = \{1, 2, \ldots, m\}$ and a set of n directed arcs, $S = \{(i,j), (k,l), \ldots, (s,t)\}$ that join pairs of nodes in set N. Arc (i,j) is said to be incident with nodes i and j, and is directed from node i to node j. As an example, Figure 4 illustrates a network with four nodes and seven arcs. A number, b_i, is associated with each of the nodes in G. A $b_i > 0$ represents an available supply of an item, and $b_i < 0$ represents the required demand for the item. Nodes with $b_i > 0$ are sometimes called sources, and nodes with bi < 0 are sometimes called sinks. If $b_i = 0$, then none of the item is available at that node and none is needed. A node with $b_i = 0$ is sometimes referred to as a transshipment (or intermediate) node. The best example of a transshipment node is a warehouse. Items pass through the node but it is neither their source nor destination. For each arc (i,j), let x_{ij} be the amount of flow on the arc, and c_{ij} be the unit shipping cost along the arc.

Simply stated, the basic problem is to transport the available supply through the network to satisfy demand at minimal cost. Mathematically, the problem can be expressed as:

$$\textit{Minimize} \quad \sum_{i=1}^{m} \sum_{j=1}^{m} c_{ij} x_{ij}$$

$$\textit{Subject to} \quad \sum_{j=1}^{m} x_{ij} - \sum_{k=1}^{m} x_{ki} = b_i \qquad i = 1, \ldots, m$$

$$x_{ij} \geq 0 \qquad i, j = 1, \ldots, m$$

This basic formulation of the problem can be generalized and extended in many ways to include other aspects of network optimization problems. See Hillier & Lieberman (2001) and Winston (1994) for excellent treatments of various applications and solution techniques.

Commercial Off-the-Shelf (COTS) network design software is widely available to design, solve, and analyze many different types of complex network flow problems. LogicNet Plus® was used to perform the optimization modeling for this project. The software is developed by LogicTools Inc. LogicTools specializes in supply chain planning and has a variety of tools in its supply chain suite of software. The LogicNet Plus® software is a design tool that is capable of modeling many aspects of network flow problems, including facility location, warehousing, service requirements, transportation modes, production capacities and limitations, and multiple time periods. The model input requirements include variables related to inbound and outbound transportation costs; fixed facility costs; customer demand, location, and service requirements; and transportation lane constraints.

BASELINE PROBLEM DEFINITION

Recall that the baseline problem in this application assumes the Army Depot at Corpus Christi, Texas (CCAD), is the only repair facility used. As previously discussed, each of the Algonquin helicopters has four main rotor blades. Approximately 12 percent of these blades must be removed each year for maintenance and overhaul. Each blade removed must be shipped from key global demand areas around the world (South Korea, Europe, SWA, and installations within CONUS) to CCAD.

The first step is to develop the basic network configuration. In the baseline problem, the network consists of 11 nodes and 10 arcs, or transportation lanes. A geographical representation of the Algonquin global supply chain network was shown in Figure 3.

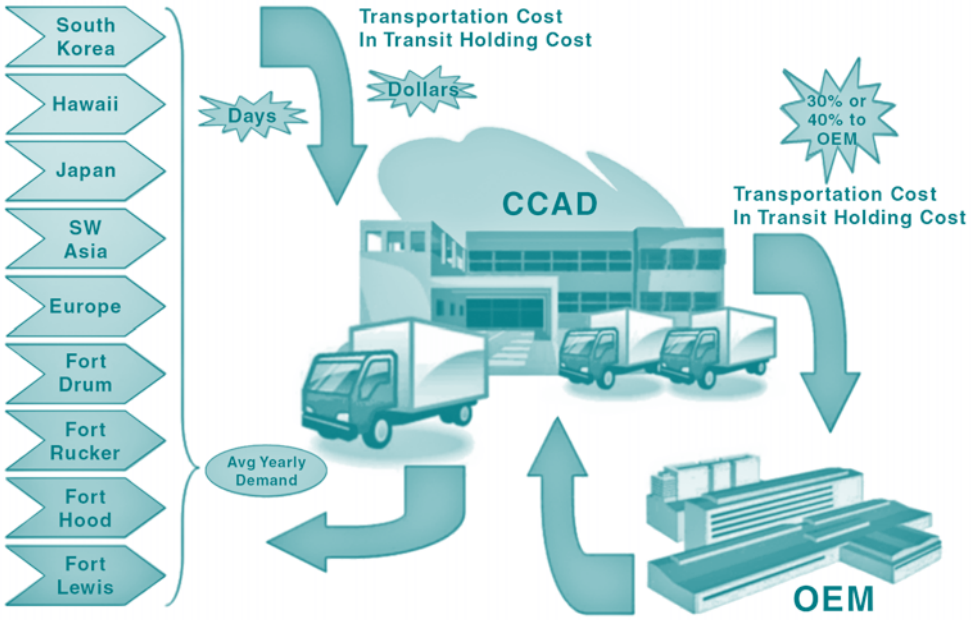
In FY06, the source of blades shipped to CCAD for inspection and repair included approximately 550 blades from installations in CONUS; over 450 blades shipped from SWA; 50 blades from Europe; and about 130 blades from Hawaii, Japan, and Korea. Blades removed during routine maintenance undergo a comprehensive evaluation resulting in the repair categories listed in Table 2.

Currently, blades are repaired at CCAD, the Original Equipment Manufacturer (OEM), or are scrapped. All inspections and all CAT II and CAT III repairs are completed at CCAD. All main rotor blades needing major repairs above the CAT III level

TABLE 2. ARMY REPAIR CATEGORIES

■ CAT I: Unserviceable or waiting inspection
■ CAT II: Repairs up to, but not including, the heat mat
■ CAT III: Candidate for the A3 (RECAP) repair program. *(The difference between the CAT II and CAT III helicopter blade repair is the heater mat for de-icing is replaced at the CAT III level.)*
■ CAT IV: Beyond repair at the Army Depot level, candidate for commercial repair by the OEM on a commercial specification commonly known as strip and rebuild

FIGURE 5. ALGONQUIN GLOBAL BLADE TRANSPORTATION PROCESS



are forwarded from CCAD to the OEM in the northeast United States. A graphical overview of the Algonquin global blade transportation system is illustrated in Figure 5.

Having established the basic supply chain network, there are four principal input data elements to the model:

- **Transportation Cost** represents the cost to ship one helicopter blade from point A to point B. It is based on actual data from historical sources or from direct communication with commercial transport carriers.
- **Transportation Time** represents the time a blade spends in transit. It is based on actual data in the Logistics Information Warehouse (LIW), a database hosted by the U.S. Army Materiel Command, Logistics Support Activity (LOGSA). The segments and time frames are well defined within LOGSA's parameters, and thus are consistent in their development and representation.
- **Demands** are the number of blades demanded by each installation. The demands for a particular region are based upon the total demand worldwide and pro-rated based upon the number of aircraft in that region. For aircraft in SWA, demands are based upon an increased flying hour funding program of three times the level of other regions.
- **Location of Aircraft** is a destination site (i.e., node) where a blade is being shipped. Japan, Hawaii, South Korea, Europe, SWA, and CONUS were determined to be the key destination locations for the blades since they are the locations from which most of the demands originate. CONUS is allocated into four regions with a central location for each of the regions. The central sites were the heavy user sites for helicopters.

The two key sources of data were the LOGSA and U.S. Army Aviation and Missile Command (AMCOM). From AMCOM, the main provider was the Integrated Materiel Management Center (IMMC). LOGSA provided most of the transportation times, and the IMMC provided most of the transportation costs.

Two important additional parameters must be specified for this application. First, recall that not every blade must be returned to the OEM to be refurbished. Therefore, the supply and demand of units across the transportation lane from CCAD to the OEM is a parameter of the model. In the base case scenario, it was assumed that 30 percent of the blades require shipment to the OEM. Second, the number of aircraft stationed in a particular geographic region affects the supply and demand of units across various transportation lanes. Therefore, a second parameter of the model is a reallocation of the number of aircraft across geographical regions. The base case represents the current allocation, but different scenarios are investigated that consider substantial troop withdrawals and redistributions across the world.

Having established the basic network structure with flows and transportation lanes, identified the transportation costs, and defined the transportation times, LogicNet Plus® performs the mathematical optimization that analyzes the various trade-offs between costs and service requirements. LogicNet Plus® is capable of analyzing and displaying a number of solution variables. The purpose of this study is to demonstrate the applicability of network optimization techniques to a DoD supply chain location analysis problem. Hence, we are primarily interested in determining an estimate of the total annual cost of the Algonquin supply chain operation under several different scenarios. The differential annual costs will allow us to determine if making a $15 or $25 million capital investment to provide an alternative repair facility is feasible.

RESULTS

BASELINE PROBLEM

Network optimization software such as LogicNet Plus® is a useful tool for analyzing different network alternatives, as well as the impact of changes in different parameters such as demand, transit times, transportation costs, location, or capital investment costs. Several critical factors are important to the decision in this application. The baseline problem represents the current state of operations where all repairs are handled at CCAD and 30 percent of repairs must be sent to the OEM (i.e., CAT IV repairs). Table 3 summarizes the relevant input variables and parameters of the baseline problem. The per blade transportation costs represent the cost of transporting a single blade from a base facility to CCAD. Retrograde costs correspond to the cost of shipping a blade back to the base from CCAD. Recall that a certain percentage of the blades must be returned to the OEM for repairs. The baseline scenario estimates this percentage at 30 percent. The baseline scenarios also reflect the current allocation of aircraft across the global arena. No reallocation of aircraft is considered. Since no new repair facilities are proposed in the baseline case, there is no capital investment. According to the network model, the baseline supply chain operation for Algonquin rotor blades has an annual cost of $17,990,558. Scenario 1B simply increases the

TABLE 3. BASELINE NETWORK CONFIGURATIONS/DATA/PARAMETER

Model Input Variables	Scenario 1A		Scenario 1B	
Per Blade Transportation Cost	**Forward**	**Retrograde**	**Forward**	**Retrograde**
Fort Lewis	$1714	$1915	$1714	$1915
Fort Hood	$733	$730	$733	$730
Fort Rucker	$1092	$1035	$1092	$1035
Fort Drum	$1604	$1693	$1604	$1693
Hawaii	$6118	$6118	$6118	$6118
Japan	$3811	$3811	$3811	$3811
Korea	$4436	$4915	$4436	$4915
Europe	$3568	$3568	$3568	$3568
SW Asia	$5415	$5415	$5415	$5415
CCAD to OEM	$1599	$1599	$1599	$1599
Days in Transit	**Forward**	**Retrograde**	**Forward**	**Retrograde**
Fort Lewis	9	9	9	9
Fort Hood	1	1	1	1
Fort Rucker	4	4	4	4
Fort Drum	6	6	6	6
Hawaii	50	50	50	50
Japan	42	42	42	42
Korea	42	42	42	42
Europe	196	132	196	132
SW Asia	128	90	128	90
CCAD to OEM	5	5	5	5
Average Yearly Demand				
Fort Lewis	250		250	
Fort Hood	250		250	
Fort Rucker	250		250	
Fort Drum	250		250	
Hawaii	64		64	
Japan	21		21	
Korea	42		42	
Europe	128		128	
SW Asia	788		788	
Study Parameters				
Percent of Blades Sent to OEM for CAT IV Repairs	30%		40%	
Global Aircraft Allocation	Current Allocation		Current Allocation	
Capital Investment	0%		0%	
TOTAL ANNUAL COST	**$17,990,558**		**$18,666,050**	

TABLE 4. ALTERNATIVE NETWORK SCENARIOS

Study Parameters	Repair Location(s)	Percent of Blades Sent to OEM for CAT IV Repairs	Global Aircraft Allocation	TOTAL ANNUAL COST	Annual Cost Savings	Capital Investment	Discounted Payback Period
Scenario 1A (Baseline)	CCAD	30%	Current	**$17,990,558**	--	--	--
Scenario 1B (Baseline)	CCAD	40%	Current	**$18,666,050**	--	--	--
Scenario 2	CCAD Europe	30%	Current	**$14,752,908**	$3,237,650	$15,000,000	**5.4 Years**
Scenario 3A	CCAD SWA	30%	Current	**$9,931,944**	$8,058,614	$15,000,000	**2.01 Years**
Scenario 3B	CCAD SWA	40%	Current	**$11,386,462**	$7,279,588	$25,000,000	**4.3 Years**
Scenario 4A	CCAD	30%	25% SWA Reduction	**$15,568,540**	--	--	--
Scenario 4B	CCAD	30%	50% SWA Reduction	**$13,126,569**	--	--	--
Scenario 4C	CCAD	40%	50% SWA Reduction	**$13,716,095**	--	--	--
Scenario 4D	CCAD SWA	30%	50% SWA Reduction	**$9,097,262**	$4,029,307	$15,000,000	**4.2 Years**
Scenario 4E	CCAD SWA	40%	50% SWA Reduction	**$10,076,303**	$3,050,266	$15,000,000	**5.8 Years**

assumed percentage of blades that must be sent back to the OEM for CAT IV repairs. Increasing that percentage to 40 percent increases the annual cost of the network by $675,492 or 3.75 percent.

LOCATIONAL ANALYSIS

Once the baseline cost of the network has been established, the impact of a change in the network or assumption about the network can be determined. Table 4 summarizes a series of alternative scenarios.

The second and third set of scenarios investigates the feasibility of establishing a second repair depot under various assumptions. Scenario 2 looked at a number of different network configurations that added a second repair facility in either Europe or Korea. The best alternative was to locate the facility in Europe. The annual cost of the network decreases to $14,752,908, producing an annual savings of $3,237,650. Assuming it requires a capital investment of $15 million to build the facility, a simple discounted payback calculation will approximate the financial breakeven point and net present value of the alternative. The discounted payback period (assuming a discount rate of 5 percent) is about 5.4 years for Scenario 2.

The third set of scenarios looked at different network configurations that added a second repair facility in Europe, Korea, or SWA. The best alternative was to locate the facility in SWA. In this case, the annual cost decreased to $9,931,944, an annual savings of $8,058,614. Assuming a capital investment of $15 million, the discounted payback period is just slightly over 2 years. In fact, even if we assume that 40 percent

of the blades must be sent to the OEM and the capital investment is $25 million, the discounted payback period is still 4.3 years (see Scenario 3B). It is not surprising that an additional repair facility in SWA is financially viable. The war in SWA is currently the largest source of demand for blade repairs (see Figure 2). Hence, a repair facility located in the region would drastically reduce the total transportation and in-transit costs associated with shipping blades to and from the largest demand facility.

In anticipation of aircraft being pulled out of SWA, the fourth set of scenarios analyzed the impact of reducing the number of aircraft in the region by 25 and 50 percent. The aircraft were redistributed around the world with the demands adjusted accordingly. The overall effect of such reductions on the total annual cost of the Algonquin supply chain network is substantial. For example, compared to the 1A baseline scenario, the effect of a 25 percent SWA reduction (shown under Scenario 4A) is a decrease in total annual cost of about $2,422,018 (13.5 percent). Reducing the number of SWA aircraft by 50 percent decreases the 1A baseline annual cost even more, to $13,126,569, a 27 percent reduction (see Scenario 4B). If the percentage of blades sent back to the OEM is increased to 40 percent, then the 1B baseline cost is reduced a similar 26.5 percent (see Scenario 4C).

An important question is whether an additional repair facility is still warranted in SWA if there were to be a significant redistribution in the number of aircraft from the region. Scenarios 4D and 4E consider the feasibility of an additional repair facility under such conditions. In Scenario 4D, the number of SWA aircraft is reduced by 50 percent with 30 percent of the blades returned to the OEM. The total annual cost of the network is $9,097,262. This is an annual cost reduction of $4,029,307 over the Scenario 4B cost. The discounted payback period of the cost savings is 4.2 years with a $15 million capital investment, and 7.6 years with $25 million.

If 40 percent of the blades must be returned to the OEM (Scenario 4E), the total annual cost of the network is a little higher at $10,076,303. While this is still an annual cost reduction of $3,050,266 over the Scenario 4C cost, the discounted payback period is 5.8 years with a $15 million capital investment, and over 10 years with $25 million. In this case the project is not financially viable at either a $15 or $25 million capital investment.

SUMMARY AND CONCLUSION

The purpose of this article is to present an analytic process used by an Army global supply chain to make a location decision for a critical distribution center. The task is to determine a feasible transportation pattern for shipping items from a set of origins to a set of destinations in a way that minimizes the total transportation cost. Specifically, the article describes the use of commercial off-the-shelf network design software (LogicNet Plus®) to assess the feasibility of locating additional distribution centers in a global supply chain network designed to support the delivery of helicopter parts.

The process involved first establishing a baseline model (scenario 1), which proposed no new distribution facilities and no reallocation of aircraft. Once the baseline

was established, we considered the feasibility of adding an additional repair facility in Europe or Korea (scenario 2). The analysis revealed that the addition of a $15 million facility in Europe would result in an annual savings of about $3.2 million with a discounted payback of 5.4 years. A third set of alternatives (scenario 3) considered the impact of locating the additional $15 million repair facility in Europe, Korea, or SWA. This analysis revealed that the superior alternative would be to locate the additional facility in SWA with an annual cost reduction of about $8.1 million. The discounted payback would be approximately 2 years. The analyses also considered the impact of changes in the percentage of helicopter blades that would be sent to the OEM for repair. Since the war in SWA is currently the largest source of demand for helicopter blade repairs (see Figure 2), this analysis revealed that the location of a repair facility in SWA would dramatically reduce total transportation and in-transit cost associated with shipping blades from the largest demand facility.

To consider the impact of a redistribution of aircraft in the region, we conducted additional analysis (scenarios 4A and 4B) that considered a reduction of aircraft in the region by 25 and 50 percent. The results of the analysis revealed that the reduction of both 25 and 50 percent results in substantial reductions in total annual supply chain cost. The final analysis (scenarios 4D and 4E) considered the feasibility of adding the $15 or $25 million repair facility under the assumption of a 50 percent reduction in aircraft, as well as alternative assumptions about the percentage of blades that would be sent to the OEM for repair. The results suggest that locating a new facility in SWA, while simultaneously reducing the number of aircraft in the region, would not be financially viable.

This study demonstrates the importance of considering all relevant parameters and alternatives when making decisions about supply chain networks. For instance, assumptions about the size of the customer base (e.g., aircraft) and the number of tasks performed (e.g., number of items repaired in existing facilities) can substantially impact the financial implications of location decisions. The results of this study suggest that the validity of distribution location decisions depend on a comprehensive understanding of the make-up, geographical distribution of customers, and all relevant customer service costs. Also, the cost structure of the network must be known with some certainty to estimate the effects of changes to the system. Finally, this study reveals that sound location decisions require that the both the analysts and managers perform a comprehensive investigation that includes a sensitivity analysis with multiple scenarios.

AUTHOR'S NOTE

Please direct all correspondence concerning this article to David Berkowitz, Department of Management and Marketing, BAB 355, University of Alabama in Huntsville, Huntsville, AL 35899; e-mail berkowd@uah.edu; call 256-824-6952; or fax 256-824-6328.

Dr. William R. Killingsworth is Director of the Center for Management and Economic Research at the University of Alabama in Huntsville. He is also Executive Director of the MIT Forum for Supply Chain Innovation. His research focuses on supply chain design and optimization, enterprise software, product life cycle management, lean enterprise, lean manufacturing, six sigma, and new product development. Clients and research sponsors include government and defense organizations and many companies in the automotive, aviation, and aerospace industries.

Dr. David Berkowitz is Chair of the Management and Marketing Department and Associate Professor of Marketing at UAHuntsville. His research has appeared in leading academic journals such as the *Journal of Retailing, Journal of Advertising Research, Journal of Advertising, Defense Acquisition Review Journal,* and the *Journal of Product Innovation Management and Industrial Marketing Management*. At UAHuntsville, Dr. Berkowitz teaches New Product Development, Marketing Emerging Technology, and Marketing Management.

Dr. John E. Burnett is an associate professor of finance at UAHuntsville. He received his Ph.D. in finance from the University of Alabama and his M.A. in mathematics from the Claremont Graduate University. His research interests are in the areas of behavioral finance and investments. His research has appeared in such publications as *Applied Financial Economics, Journal of Financial Research,* and *Quarterly Review of Economics and Finance*.

Dr. James T. "Jim" Simpson is Dean and Distinguished Professor of Marketing in the College of Business at UAHuntsville. In 2004 he received the Academy of Marketing Science National Outstanding Marketing Teacher Award. His research has appeared in leading academic journals such as *Journal of Marketing Research, Journal of Business Research, Journal of Systems and Software,* and *European Journal of Innovation Management*. He has lectured in Russia, China, Taiwan, Romania, France, and England.

AUTHOR **BIOGRAPHY**

REFERENCES

Brown, G., Geoffrion, A. & Bradley, G. (1981). Production and sales planning with limited shared tooling at the key operation. *Management Science, 27*(3), 247–259.

Byrom, J. W., Bennison, D., Hernandez, T. & Hooper, P. (2001). The use of geographical data and information in retail locational planning. *Journal of Targeting, Measurement and Analysis for Marketing, 9*(3), 219–229.

Hernandez, T. & Bennison, D. (2000). The art and science of retail location decisions. *International Journal of Retail & Distribution Management*, *28*(8), 357–367.

Hillier, F. S. & Lieberman, G. J. (2001). *Introduction to Operations Research* (7th ed.). New York: McGraw-Hill.

Hitchcock, F. L. (1941). The distribution of a product from several sources to numerous localities. *Journal of Mathematics and Physics*, *20*, 224–230.

Magnanti, T. L., & Wong, R. T. (1984). Network design and transportation planning: Models and algorithms. *Transportation Science*, *18*(1), 1–55.

Mitropoulos, P., Mitropoulos, I., Giannikos, I. & Sissouras, A. (2006). A biobjective model for the locational planning of hospitals and health centers. *Health Care and Management Science*, *9*(2), 171–179.

ReVelle, C. S., and Eiselt, H. A. (2005). Location analysis: A synthesis and survey. *European Journal of Operational Research*, *165*(1), 1–19.

Srinivasan, V. (1974). A transshipment model for cash management decisions. *Management Science*, *20*(10), 1350–1363.

Stafford, E. F., Tseng, F. T. & Gupta, J. N. D. (2005). Comparative evaluation of MILP flowshop models. *Journal of Operations Research Society*, *56*(1), 88-101.

Stock, J. R. and Lambert, D. (2001). *Strategic Logistics Management* (4th ed.). Boston: McGraw Hill.

Winston, W. L. (1994). *Operations Research: Applications and Algorithms* (3rd ed.). Belmont, CA: Duxbury Press.

Photo courtesy of Northrop Grumman Shipbuilding

REFORMING HOW NAVY SHIPBUILDING CONTRACTS ADJUST FOR MATERIAL-COST RISK

Edward G. Keating, Robert Murphy, John F. Schank, and John Birkler

This article describes how the U.S. Navy structures fixed-price and fixed-price, incentive-fee shipbuilding contracts and how labor- and material-cost indexes can mitigate shipbuilder risk in either type of contract. The Navy frequently uses the Steel Vessel material-cost index, a Bureau of Labor Statistics-derived cost index based on the mix of materials in a typical commercial cargo ship constructed in the 1950s. The Steel Vessel Index has excessive weighting on iron and steel, thereby providing shipbuilders with a mismatch between their actual and the Index-assumed material cost structure. The authors recommend the Navy use a material-cost index with more up-to-date weightings.

The U.S. Navy wants to provide its shipbuilders with appropriate incentive to produce militarily effective vessels at minimum cost to the Navy. Fixed-price contracts provide incentive to a shipbuilder to produce at minimum cost. After contract award, cost savings that the shipbuilder can implement flow directly to the shipbuilder, resulting in higher profit. Conversely, the shipbuilder bears cost overruns, resulting in lower-than-anticipated profits.

Fixed-price contracting becomes problematic, however, when a shipbuilder is forced to bear risk outside of its control. For instance, ship construction requires material inputs such as steel, wire, cable, and a myriad of others. If the global prices of these commodities rise, a fixed-price shipbuilder will have lower profits (or increased losses) external to the shipbuilder's efforts.

Ultimately, the Navy can induce a shipbuilder to agree to any arrangement, including having the shipbuilder bear material-cost risk, by offering the shipbuilder a high enough price. But it is likely to be preferable, at least ex ante, for the Navy to dissipate risk external to its shipbuilder to pay less for the systems the Navy needs.

Conversely, the Navy should not fully immunize a shipbuilder against risks within the shipbuilder's control, e.g., if the shipbuilder's own failures cause a cost overrun. In such a case, the shipbuilder should incur at least a portion of the loss. Of course, it can sometimes be difficult to distinguish problems within a shipbuilder's control from those caused or exacerbated by Navy decisions (e.g., changing requirements) and from those related to external issues (e.g., the rising global price of steel). The Navy uses labor- and material-cost indexes to attempt to correct for several significant cost risks outside its shipbuilders' control. The indexes reflect industry- or economy-wide costs, not the costs of the specific shipbuilder.

HOW THE NAVY USES LABOR- AND MATERIAL-COST INDEXES

In this section of the article, we present illustrative examples of how the Navy uses labor- and material-cost indexes. To illustrate the basic concept, we start with a highly oversimplified example of a fixed-price contract. Subsequently, we turn to an enhanced (though still less complex than reality) example of a contract more in accord with current Navy practices. This latter example is a fixed-price, incentive-fee (FPIF) contract. An FPIF contract is no longer a "pure" fixed-price contract in that it requires the Navy and the shipbuilder to share cost changes from the negotiated level with incentives and disincentives for underruns and overruns (whereas a textbook fixed-price contract would not). The shipbuilder's actual costs are considered in an FPIF contract; they are not in a fixed-price contract.

A VERY SIMPLE EXAMPLE

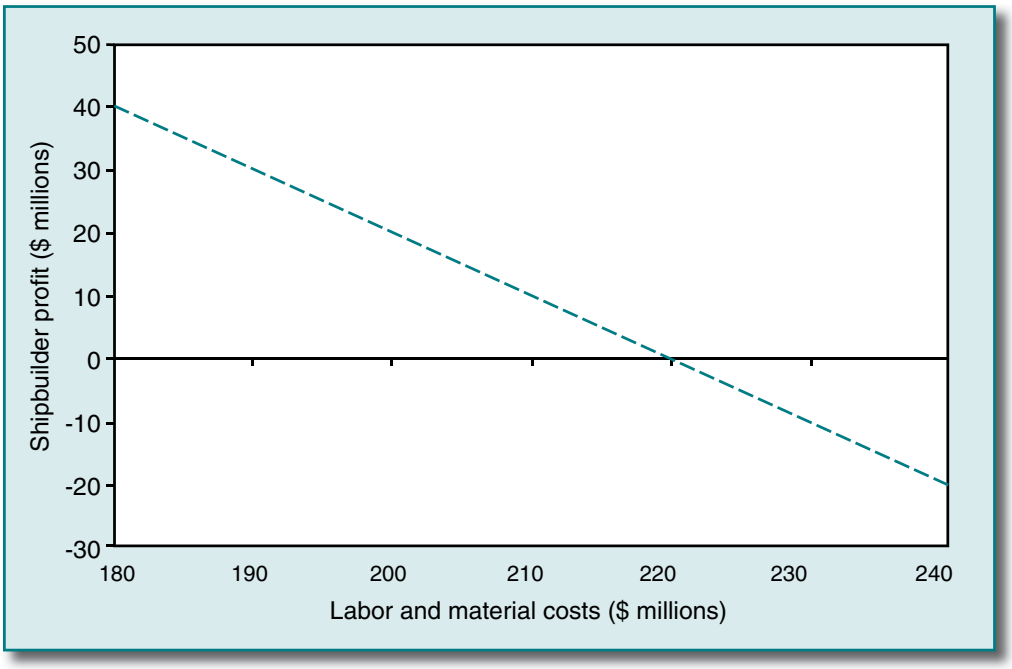
Suppose the Navy signs a fixed-price contract for a $220 million ship on January 1, 2009, with completion scheduled for January 1, 2012. Suppose $100 million of the payment is to cover expected labor costs, another $100 million is to cover expected material costs, and the final $20 million is intended to be contractor profit. Of course, the actual cost the shipbuilder incurs determines the shipbuilder's profit. Figure 1 shows the shipbuilder's profit as a function of the actual labor and material cost of the ship. Increasing costs reduce shipbuilder profits dollar-per-dollar.

Adding material-cost indexes to this fixed-price contract would protect the shipbuilder against exogenous cost risk.

Suppose, during the period 2009–2012, the external labor-cost index designated in the contract goes up 5 percent while the designated material-cost index goes up 20 percent. Then the Navy's actual payment to its shipbuilder would be $245 million ($105 million for labor, $120 million for materials, $20 million in intended or target profits—assuming that the profit level does not increase with the indexes). The shipbuilder's actual profit would then go up or down based on whether its actual cost growth was above or below the indexes'. Obviously, it is of central importance that the cost indexes are agreed on up front.

If, on the other hand, the labor-cost index had risen 5 percent while the material-cost index had fallen 10 percent, the Navy's payment to the shipbuilder would be $215 million ($105 million in labor, $90 million in materials, $20 million for target

FIGURE 1. SHIPBUILDER PROFIT AS A FUNCTION OF LABOR AND MATERIAL COSTS WITH A FIXED-PRICE CONTRACT



profit). Again, actual profit would depend on whether the shipbuilder's total costs had fallen less than or more than the indexes suggested.

Both this example and the one that follows are oversimplified. Both examples assume that all labor is incurred and material purchased on the last day of the contract. If one alternatively assumes that the postulated inflation, labor hours, and material purchases occur uniformly between 2009 and 2012, the average inflation rate would be half as large. In reality, material purchases peak before labor hours incurred so there are two cost-timing distributions for which to account. Actual Navy escalation clauses calculate these effects on actual costs incurred monthly.

A MORE REALISTIC EXAMPLE

The Navy does not generally write shipbuilding contracts that are as simple as the preceding example. Instead, the norm is to use FPIF contracts with "compensation adjustment clauses" or "escalation provisions" to:

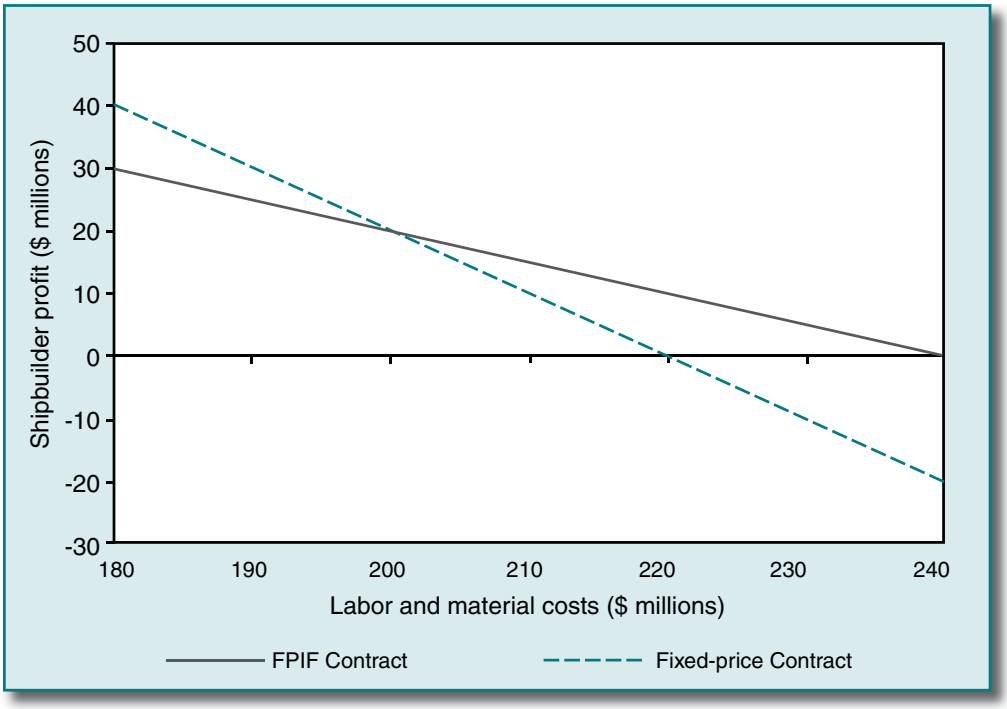
- ensure that the incentive provision operates independently of outside economic forces that impact shipbuilder costs
- keep the shipbuilder from including contingent amounts in its price to cover economic uncertainty associated with external cost pressure.

In this approach, subsequent changes in specified cost indexes result in payments (or refunds) tied to the shipbuilder's actual labor and material costs incurred. Notice that this approach no longer results in a "pure" fixed-price contract; shipbuilders'

actual costs are considered. FPIF contracts actually operate as cost-type incentive contracts within a certain range of costs.

Consider an example similar to the preceding with the Navy signing a contract for a ship on January 1, 2009, with completion scheduled for January 1, 2012. It is anticipated that $100 million will be spent on labor and another $100 million on material. Suppose the Navy also agrees to a 10 percent target profit rate and a sharing ratio of 50/50 for increases or decreases in cost. Figure 2 compares shipbuilder profit under this FPIF contract with the preceding fixed-price case (prior to consideration of cost-index issues). Since this FPIF contract has cost change shared between the Navy and the shipbuilder, the FPIF Contract line is flatter.

FIGURE 2. SHIPBUILDER PROFIT AS A FUNCTION OF LABOR AND MATERIAL COST WITH DIFFERENT CONTRACT STRUCTURES



It would enhance realism to include labor- and material-cost indexes into this contract.

Suppose, during the period 2009-2012, the labor-cost index designated in the contract goes up 5 percent while the designated material-cost index is up 20 percent. We assume base period labor and material costs of $100 million each. If the shipbuilder's actual labor costs were $105 million, the Navy would pay a compensation adjustment of $5 million ((0.05 divided by 1.05) multiplied by $105 million).[1] If actual material costs turned out to be $115 million, the Navy would make a material compensation adjustment of $19.17 million ((0.20 divided by 1.20) multiplied by

$115 million). The "de-escalated base cost" of the ship would be $195.83 million (the actual $105 million plus $115 million less the compensation adjustments of $5 million and $19.17 million). The $4.17 million decrease between the initial base cost and the de-escalated base cost would translate into a $2.08 million increase in profit for the shipbuilder given the assumed 50/50 cost change-sharing ratio. The shipbuilder is rewarded because actual material costs did not rise as rapidly (15 percent) as did the material-cost index (20 percent).

The Navy's actual payment to the shipbuilder would be comprised of $195.83 million in de-escalated base cost, $5 million in labor escalation payments, $19.17 million in material escalation payments, $20 million in target profit, plus $2.08 million in incentive profit, totaling $242.08 million. Shipbuilder profit would be $22.08 million.

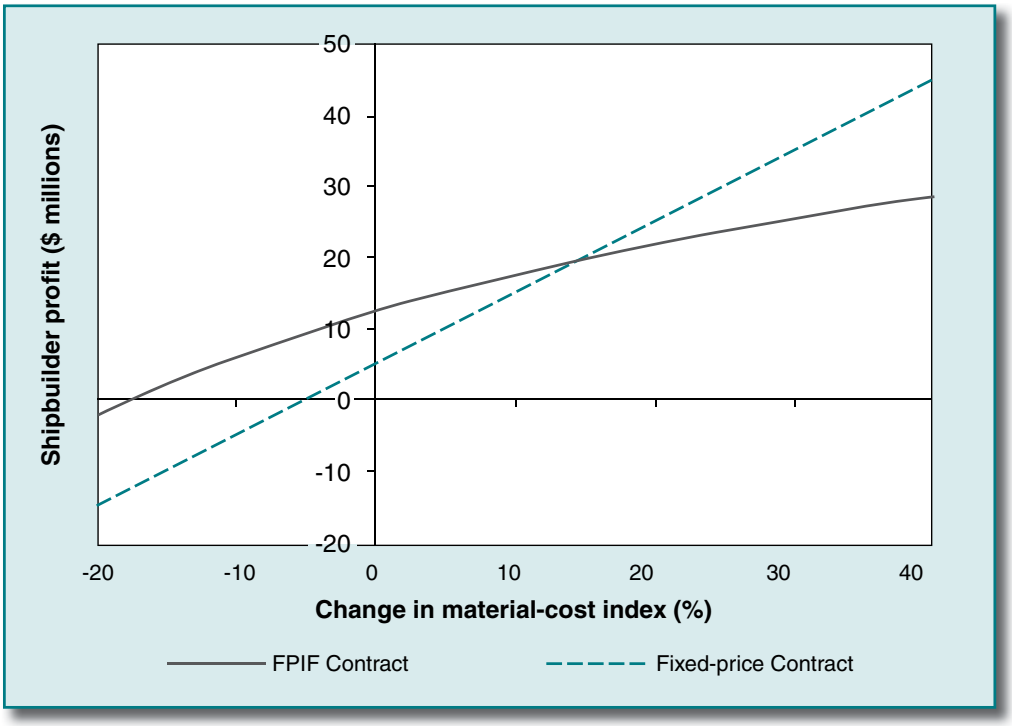
By contrast, holding the shipbuilder's incurred costs the same as above, suppose the labor-cost index had again risen 5 percent while the material-cost index fell 10 percent. The labor compensation adjustment would remain $5 million ((0.05 divided by 1.05) multiplied by $105 million). The material compensation adjustment would now be a reimbursement from the shipbuilder of $12.78 million ((-0.10 divided by 0.90) multiplied by $115 million). The "de-escalated base cost" of the ship would be $227.78 million ($105 million plus $115 million minus $5 million plus $12.78 million). This increase in the de-escalated base cost would result in a $13.89 million profit penalty for the shipbuilder (50 percent of the difference between $227.78 million and $200 million). Then the Navy would pay the shipbuilder $226.11 million ($227.78 million in de-escalated base cost plus $5 million in labor escalation payments less a $12.78 million material de-escalation reimbursement plus $20 million in target profit less a $13.89 million incentive profit penalty). The shipbuilder profit would be $6.11 million.

As in the "Very simple example," we have ignored realistic timing issues, e.g., the fact the median material cost probably precedes the median labor cost and that neither cost is incurred, on average, in 2012. (We explored incorporating such time-phasing. The effect of this enhancement is to roughly halve the realized inflation rate, depending on how one assumes material and labor costs are borne over time. None of the central results of this article changes with such time-phasing.)

Figure 3 summarizes the differential results of these examples, holding fixed that the labor-cost index increased 5 percent while realized shipbuilder costs were $115 million for material and $105 million for labor. Not surprisingly, when the shipbuilder spends more on material than included in the original price while the overall material market has falling prices, the cost disincentive built into the contract reduces the Navy's payment and, therefore, the shipbuilder's profit. (The shipbuilder would have performed very poorly if it paid $115 million for material while material prices were, on average, falling.)

The Fixed-Price contract and FPIF contract lines cross at a 15 percent increase in the material-cost index. We have assumed that the shipbuilder's actual material cost increase was 15 percent or $15 million. If the shipbuilder can keep its actual material cost growth below the index level, its reward is greater in the fixed-price contract in which there is no cost-change sharing with the Navy. Conversely, the shipbuilder's

FIGURE 3. SHIPBUILDER PROFITS ARE GREATER WHEN THE MATERIAL-COST INDEX RISES MORE AND REALIZED COSTS ARE HELD CONSTANT



profit does not diminish as rapidly if its actual material costs increase more than the material-cost index with the FPIF contract's cost-change sharing.

Another way to look at Figure 3 is that, with either type of contract, the shipbuilder is "rooting for" its material cost index to increase without, of course, the shipbuilder's actual material costs increasing commensurably.

If the shipbuilder's skillful management kept ship costs from rising as much as similar costs had in the general economy, greater profits are an appropriate reward. However, if greater profits result from escalation payments calculated by an external price index that does not accurately reflect what the shipbuilder purchases, then greater profit is not warranted. Conversely, it would be unfair to penalize a shipbuilder if an inappropriate cost index declines or increases less than the shipbuilder's actual cost environment.

THE STEEL VESSEL INDEX

A longtime material-cost index in Navy shipbuilding is the "Steel Vessel Index." Based on an estimate by the Maritime Administration of the mix of materials in a typical commercial cargo ship constructed in the 1950s (United States General Accounting Office, 1972), it is a weighted average of three Bureau of Labor Statistics (BLS) producer price indexes (45 percent iron and steel, 40 percent general-purpose machinery

and equipment, and 15 percent electrical machinery and equipment). If, for instance, the iron and steel price index increased 3 percent in a year, the general-purpose machinery index increased 2 percent, and the electrical machinery index fell 1 percent, the Steel Vessel Index would increase 2 percent (0.45*0.03+0.4*0.02-0.15*0.01).

One criticism of the Steel Vessel material-cost index is that it does not accurately cover the materials used in building a modern ship.[2] No modern U.S. Navy ship, for instance, has 45 percent of its material costs in iron and steel. To combat this shortcoming, the DDG-51 and T-AKE programs created their own material-cost indexes, using different weights on the same three underlying BLS indexes (DDG-51: 20 percent iron and steel, 43 percent general-purpose machinery, 37 percent electrical machinery; T-AKE: 10 percent iron and steel, 60 percent general-purpose machinery, 30 percent electrical machinery). In the preceding paragraph's example, whereas the Steel Vessel Index would increase 2 percent, the DDG-51 index would increase 1.09 percent (0.2*0.03+0.43*0.02-0.37*0.01) while the T-AKE index would increase 1.2 percent (0.1*0.03+0.6*0.02-0.3*0.01).

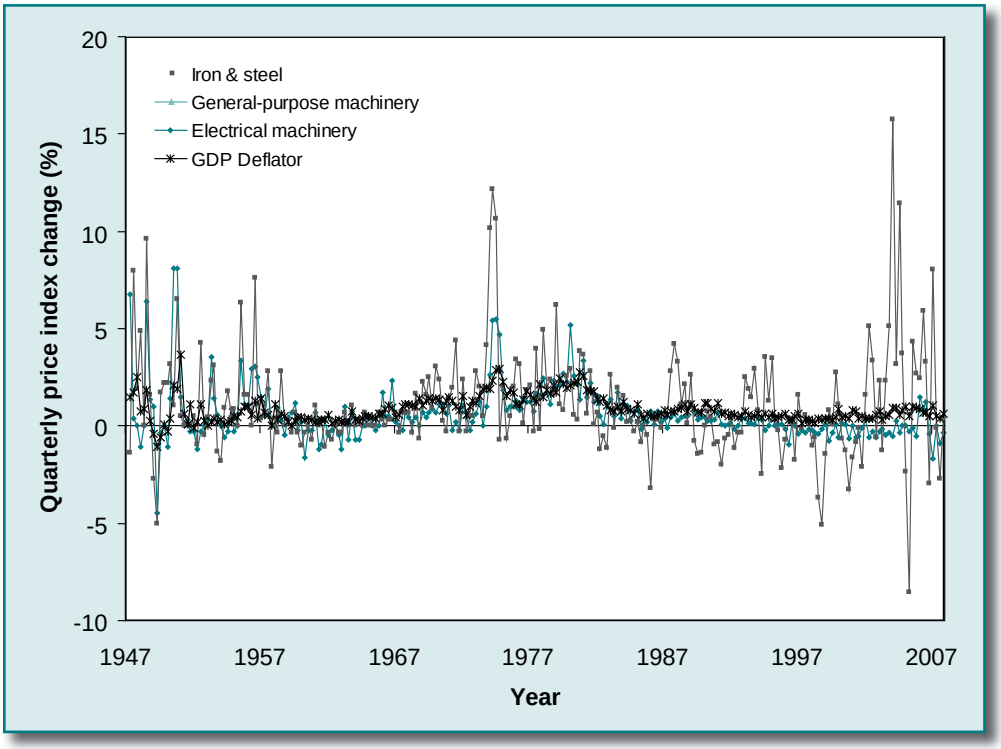
Historically, the BLS iron and steel price index has been much more volatile than the general-purpose machinery or electrical machinery indexes.

There is an additional challenge with any of these indexes: Even if one correctly identified the mix of materials that went into the ship, the materials would be purchased at different stages of ship construction. Steel, for instance, is required early in the construction process. Conversely, combat systems and electrical equipment (perhaps more akin to general-purpose or electrical machinery) are not delivered to the shipyard and consequently do not become incurred costs until much later in construction. Time-phasing the mix of an overall material-cost index could provide greater fidelity. However, it is unlikely that any material-cost index will completely dissipate a shipbuilder's exogenous material-cost risk.

Historically, the BLS iron and steel price index has been much more volatile than the general-purpose machinery or electrical machinery indexes. Figure 4 displays these indexes' quarterly returns (with a positive "return" if the cost-index value went up, negative if it fell) between the second quarter of 1947[3] and the fourth quarter of 2007. We also display the quarterly change in the Bureau of Economic Analysis (BEA) Gross Domestic Product (GDP) price deflator, a measure of overall inflation in the economy.

Naturally, given the Steel Vessel Index's greater relative weighting of the iron and steel price index, it has been more volatile than the DDG-51 or T-AKE indexes. In Figure 5, we plot the standard deviation in the quarterly return and the mean quarterly return for the three ship material-cost indexes and the GDP deflator between the

FIGURE 4. QUARTERLY CHANGES IN DIFFERENT COST INDEXES



Sources: Bureau of Labor Statistics Web site <http://www.bls.gov/data/home.htm> and Bureau of Economic Analysis Web site <http://www.bea.gov/national/nipaweb/Index.asp>

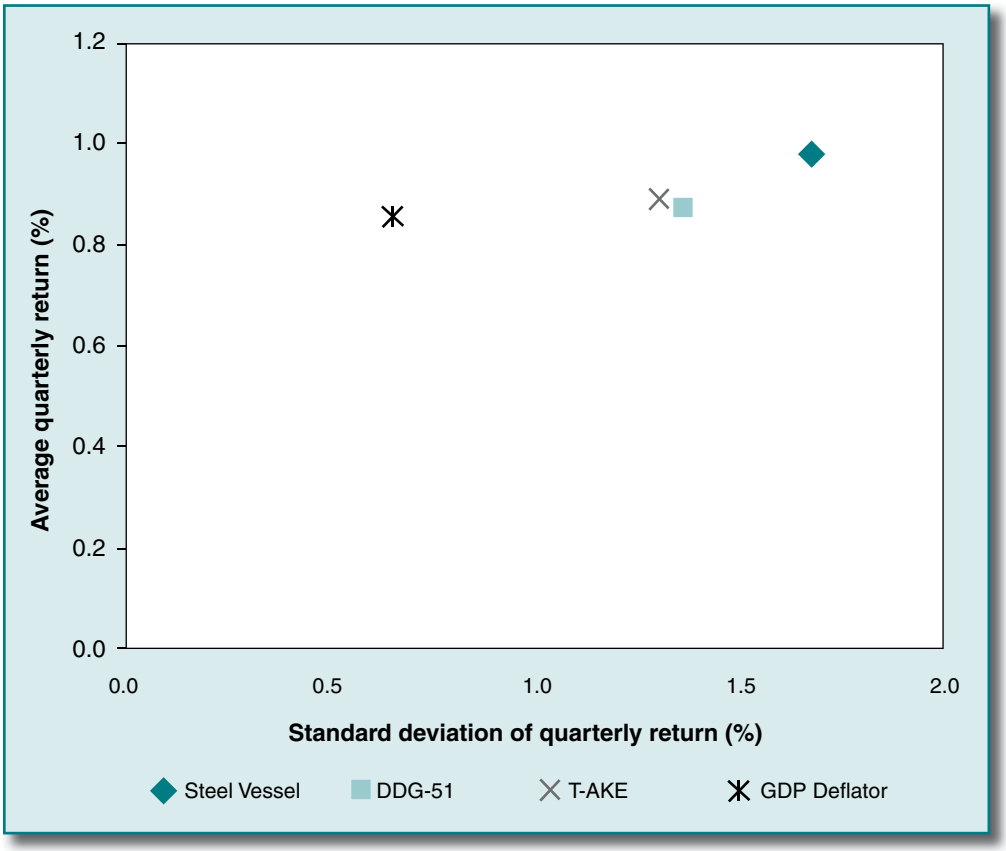
second quarter of 1947 and the fourth quarter of 2007.[4] The Steel Vessel Index had the greatest standard deviation in its quarterly return.

What Figure 5 does not show is how closely correlated any of these indexes is with the actual cost variability a shipbuilder experiences. The best cost index is the one that minimizes a shipbuilder's exogenous risk and therefore minimizes the risk premium that the Navy must pay the shipbuilder. We know, however, that the Steel Vessel Index over-represents iron and steel costs in current naval warship contracts.

The fact that the Steel Vessel Index has had a mean quarterly return greater than the other indexes and the economy-wide inflation rate is not prima facie bad news for the Navy. In a competitive setting, a shipbuilder will submit a lower bid ex ante if it expects super-normal escalation. So the Navy's expected costs are not, in equilibrium, affected by the Index's mean.

What is more problematic is the known mismatch between the Steel Vessel Index's composition and a shipbuilder's material cost structure. The shipbuilder bears a risk, for instance, that the prices of iron and steel may tumble while the shipbuilder's do not. A risk-averse shipbuilder will require a premium to bear this cost structure mismatch-driven risk.

FIGURE 5. QUARTERLY STANDARD DEVIATION AND AVERAGE RETURN OF DIFFERENT MATERIAL-COST INDEXES, SECOND QUARTER 1947 THROUGH FOURTH QUARTER 2007



This mismatch-driven risk could be reduced if the shipbuilder could take a short position on steel futures, i.e., hedge against the risk that steel prices will fall. Currently, however, there is only an embryonic steel-futures market.[5]

Paradoxically, if the shipbuilder locked in its steel input prices through a long-term, fixed-price contract with a steel mill, the shipbuilder's cost structure mismatch-driven risk could be exacerbated, not mitigated. If future steel prices fell, the shipbuilder would receive no advantage on the cost side while receiving reduced revenue from the Navy.

We do not know the "right" material-cost index to use to minimize a shipbuilder's material-cost risk. We do know, however, the Steel Vessel Index is imperfect due to its overrepresentation of iron and steel. As shown in Figure 5, there is little difference between the DDG-51 and T-AKE approaches; their quarterly returns were positively correlated at the 0.985 level between the second quarter of 1947 and the fourth quarter of 2007. (By contrast, the Steel Vessel index had a 0.934 correlation with the DDG-51 index and 0.870 with T-AKE.)

Of the three Navy material-cost indexes, T-AKE (0.657) and DDG-51 (0.639) were more highly correlated with the GDP deflator than was the Steel Vessel Index (0.540). The explanation for the Steel Vessel Index's relative lack of correlation with overall inflation in the economy is that the iron and steel cost index had a much lower correlation (0.363) with the GDP deflator than did the general-purpose machinery (0.634) and electrical machinery (0.605) cost indexes. So a material-cost index that oversamples iron and steel moves away from representation of economy-wide costs.

The foremost argument in favor of the Steel Vessel Index is its familiarity and, consequently, the comfort that some shipbuilders have with the Index. Almost everyone we met in the nautical construction industry knows of the Steel Vessel Index and most have experience with contracts tied to it. The Steel Vessel Index is, perhaps, akin to the Dow Jones Industrial Average in that one would not invent it anew (or at least not with its current weightings), but its fame and tradition keep it in use.[6]

Having shipbuilders being familiar and comfortable with the Index is desirable for the Navy and the government if it implies that shipbuilders can be paid less when the Index is in use. The best material-cost index minimizes the exogenous risk that shipbuilders perceive themselves to face so as to therefore minimize Navy ship acquisition costs. Unless one believes familiarity is extremely important, however, the manifest cost structure mismatch of the Steel Vessel Index suggests that its usage does not minimize the Navy's expected costs.

CONCLUSIONS

We do not think that the Navy should use the Steel Vessel Index to adjust for material cost changes in future shipbuilding contracts. The Steel Vessel Index clearly puts excessive weight on iron and steel relative to the materials actually used in constructing a modern ship. Usage of the Steel Vessel Index does not appropriately mitigate contractor material cost risk. Indeed, from a shipbuilder's perspective, a new risk is created: the risk that the prices of what the shipbuilder actually buys will rise faster than the price of steel.

The shortcomings of the Steel Vessel Index have been known for many years. The DDG-51 and T-AKE programs created their own material-cost indexes with less weight on iron and steel. Their material-cost indexes, which empirically have been highly correlated with one another, are doubtlessly better indexes than the Steel Vessel Index, though they still appear to put too much weight on iron and steel (DDG-51: 20 percent, T-AKE: 10 percent).

We urge the Navy to develop a "Modern Vessel Index" that more appropriately represents the material used in constructing ships. Moving toward a better index would also be an opportunity to explore a time-phased material-cost index, e.g., reflect the fact that shipbuilders typically buy keel steel early in production with on-board electronics procured much later in the construction process. The more accurately a material-cost index captures a shipbuilder's external material cost risk, the less we expect the Navy to have to pay its shipbuilders.

ENDNOTES

1. For expositional simplicity, we are assuming that actual labor costs match the increase in the labor-cost index, allowing us to concentrate on material-cost issues.
2. Indeed, criticism of the Steel Vessel Index pre-dates what we might term "modern" ships. Research in the 1970s (Geismar, 1975) suggested that the Steel Vessel Index was ill-suited to the DD963 Spruance-class destroyer, and the LHA Marine amphibious assault ship, two 1970s-era ship programs. (Both of these ships were very late in delivering, implying that inflation issues proved to be more important than would have been the case had their production been timelier.)
3. Monthly BLS data on these cost indexes are available back to January 1947. However, the BEA GDP deflator data are available only quarterly, so we aggregated the BLS data to the quarter level.
4. None of the three ship material-cost indexes existed in 1947. But we can use BLS data to retrospectively compute how they would have evolved.
5. MacDonald (2008) discusses the London Metal Exchange's launch of a steel-futures contract. By way of background, Anderson (2006) discusses the debate as to the feasibility and desirability of a steel futures market.
6. Discussing an earlier version of this article, Jim Jondrow of the Center for Naval Analyses raised the following analogy to the Navy's continued use of the Steel Vessel Index: Suppose one owned a portfolio that mirrored the National Association of Securities Dealers Automated Quotation System (NASDAQ) Composite Index, but one observed the Dow Jones Industrial Average (or vice versa). On March 10, 2000, the NASDAQ Composite Index closed at an all-time high of 5046 but then fell precipitously, ultimately hitting a bottom of 1114 on October 9, 2002 (http://en.wikipedia.org/wiki/Nasdaq_Composite). Meanwhile, the Dow Jones Industrial Average closed at 9929 on March 10, 2000, and at 7286 on October 9, 2002 (http://finance.yahoo.com/q/hp?s=%5EDJI&a=02&b=10&c=2000&d=09&e=9&f=2002&g=d). The indexes were positively correlated with one another, but the magnitudes of the changes were sharply different.

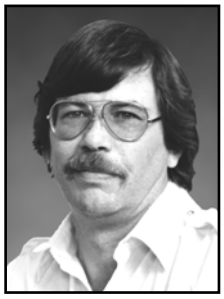
Reforming how Navy Shipbuilding Contracts Adjust for Material-Cost Risk, is derived from a RAND Corporation technical Report TR-520-Navy, entitled "Using the Steel-Vessel Material-Cost Index to Mitigate Shipbuilder Risk," and the RAND Corporation is the copyright holder of the original document.

Dr. Edward G. Keating is a senior economist at RAND specializing in applied and empirical issues in defense economics. He has worked on disparate research projects including aircraft depot-level maintenance, replacement of aging aircraft, optimal contract design, outsourcing and privatization, and DoD working capital fund policies. He received a Ph.D. in economic analysis and policy from Stanford University.

(E-mail address: keating@rand.org)

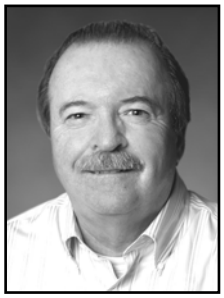
Mr. Robert Murphy retired as a member of the Senior Executive Service after a 33-year career in the U.S. Navy's Nuclear Propulsion program. He finished his career as the Director of Resource Management, responsible for budget, acquisition, and logistics support for the Naval Nuclear Propulsion program. Since retiring from public service, he has been consulting for commercial and government organizations regarding major system acquisitions.

(E-mail address: rmurphy805@aol.com)



Mr. John F. Schank is a senior operations research analyst at RAND. He has been involved in a wide range of research issues including shipbuilding acquisition and industrial base analyses, cost analyses, manpower, personnel and training issues, and logistics. He holds a B.S. in Electrical Engineering from Drexel University and an M.S. in Operations Research from the University of Pennsylvania.

(E-mail address: schank@rand.org)



CAPT John Birkler, USNR (Ret.), is a senior management system scientist at RAND. He is responsible for managing U.S. Navy, U.S. Coast Guard, and UK Ministry of Defence research projects. He holds a B.S. and M.S. in physics and completed the UCLA Executive Program in Management in 1992. After completing his third command tour, he retired from the Navy Reserve with the rank of captain.

(E-mail address: birkler@rand.org)

AUTHOR **BIOGRAPHY**

REFERENCES

Anderson, M. (2006, September/October). Steel in your futures. *Forward Online: Global Perspective from MSCI.* Retrieved March 4, 2007, from http://forward.msci.org/articles/0906steelfutures.cfm

Geismar, D. (1975, September). *Composition of material price indices for naval ship contract escalation.* Naval Postgraduate School master's thesis.

MacDonald, A. (2008, February 25). Will steel futures catch on? *The Wall Street Journal*, *251*(45), C2.

United States Department of Commerce, Bureau of Economic Analysis Web site. (n.d.) Retrieved July 17, 2007, from http://www.bea.gov/national/nipaweb/Index.asp

United States Department of Labor, Bureau of Labor Statistics Web site. (n.d.) Retrieved July 17, 2007, from http://www.bls.gov/data/home.htm

United States General Accounting Office (1972, April). *Feasibility of constructing price indexes for weapon systems.* Report to the Joint Economic Committee Congress of the United States, B-159896. Retrieved June 17, 2007, from http://archive.gao.gov/f0302/096606.pdf

Wikipedia Web site. (n.d.) *Nasdaq composite.* Retrieved July 4, 2007, from http://en.wikipedia.org/wiki/Nasdaq_Composite

Yahoo! Finance Web site. (n.d.) *Dow Jones industrial average historical prices.* Retrieved July 4, 2007, from http://finance.yahoo.com/q/hp?s=%5EDJI&a=02&b=10&c=2000&d=09&e=9&f=2002&g=d&z=66&y=0

Image designed by Jim Elmore

DO TEAM GOALS AFFECT TEAM FOCUS AND PERFORMANCE? RESEARCH STUDY OF DAU'S PROGRAM MANAGEMENT OFFICE COURSE (PMT 352B)

Thomas Robert Edison

Teams can be a significant resource to business leaders and can help lead to greater program successes. This study was conducted on student project teams in 12 classes of a Defense Acquisition University (DAU) executive-level, 6-week program management class in six different locations. The study not only underscores the significance of team focus on performance, but also highlights how team characteristics affect team focus and performance. Significant direct relationships were found in the study's 15 tested hypotheses between work team strategic intent (the team's purpose, objectives, and strategies) and team performance, as measured by team self-assessments and instructor assessments. The results of this study have applications to the successful use of project teams throughout DoD.

What is one of the single most potent tools for program managers—readily available to all? The Department of Defense, as with many other defense industry organizations operating in today's complex, changing, and sometimes chaotic work environments, is becoming increasingly more dependent on *work teams* as a means of leveraging maximum creativity, efficiency, and focus from its acquisition workforce. In today's constrained fiscal environment of limited budgets and manpower, identifying, defining, and understanding the initiatives and strategies that lead to team effectiveness represent a management imperative.

One characteristic that has received significant attention is whether teams with a clear focus and a developed purpose are more effective than those teams that are less focused, with less clear goals or purpose.

The Defense Acquisition University (DAU) has embraced teams, and most of the DAU resident courses are taught with students assigned to student work teams. In particular, in DAU's premier 6-week Program Management Office Course (PMT 352B), teams are used throughout the course to highlight the environment in which a DoD program manager normally interacts with work teams. This article highlights a study conducted on PMT 352B teams to determine if focused teams perform better than those teams that are less focused. Does a team with clear purpose, objectives, and strategies perform more effectively than teams with less clearly defined tenets?

Tomorrow's competitive organizations will be managed and inspired by teams of experts, skilled technicians, and team-appointed leaders.

Warren Bennis (1985) in his book *Leaders, The Strategies for Taking Charge* describes the need for cooperation, communication, and collaboration between individuals in order to achieve greatness—and emphasizes the successful deployment of teams in the last two decades to achieve these same results.

In today's complex and technologically sophisticated society, the most pressing projects require the committed, coordinated, and connected contributions of many talented people. Gone is the myth of the Lone Ranger or a sole champion or larger-than-life hero who can essentially "go it alone." Tomorrow's competitive organizations will be managed and inspired by teams of experts, skilled technicians, and team-appointed leaders. Projects, work efforts, and entire programs will be accomplished by a network of linked, disciplined workers skilled in their own right but connected by their commitment to their team's greater cause, goals, and/or objectives (Bennis & Biederman, 1997).

The Defense Acquisition University and many of its external corporate university partners share the belief that an effective method to enhance product development is through work teams that are focused or intent with the same strategic goals and missions of the corporate leadership. They believe that teams with a significant level of the same strategic focus on the purpose, objectives, and implementing strategies, and that are aligned with the corporate goals and missions, can be an extremely effective tool for enhancing productivity throughout the organization.

For purposes of this study, it was hypothesized that if student team members are aligned in their purpose and objectives to the course goals and learning objectives, then higher levels of student team performance and learning would result. It was further hypothesized that this learning would be more aligned with the learning objectives set forth in the course curriculum and those expressed by the instructors. The team's understanding of and commitment to the purpose, objectives, and strategies of

the course ideally would help the team satisfy its primary reason for enrolling in the course: learning and performing the course's goals and objectives.

Katzenbach and Smith (2003) have accomplished extensive work in the study of teams and their effectiveness. They admitted that no empirical data exist to prove their theories on team effectiveness. This research study provides data to support Katzenbach and Smith's study (2003) and theories on teams: teams can be more effective or perform better if they maintain a Strategic Intent or focus that is understood, and committed to, by all the team members.

PURPOSE OF STUDY

The purpose of this study was to use survey data from PMT 352B student work teams and instructors' surveys to examine the relationship between work team *Strategic Intent* (strategic purpose, objectives, and strategies) and *Team Performance*. The studied work teams were chosen from student work teams attending DAU's Program Management Office Course (PMT 352B). The PMT 352B courses studied were 6-week courses (now reduced to 5 weeks), which teach the concepts and skills necessary to become successful program managers. These courses simulate the conditions and stresses with which senior DoD managers are normally presented in making daily and long-term strategic program management decisions. Team Performance was assessed by surveys administered to the work teams (self-assessment performance) and to the PMT 352B instructors, who were teaching the student work teams (external, instructor assessment).

This research study acquired empirical data from student work team members attending PMT 352B classes. The strategic characteristics of specific PMT 352B student work teams were calculated from information gathered from team surveys. The students attending this technical training course on program management at DAU were generally mature (35 to 60 years of age). The teams' understanding of and commitment to their respective team's strategic management characteristics were measured by surveys administered to the teams in their location of work (the classroom) by the researcher and trained faculty members. The surveys obtained each team member's perceptions of his or her understanding of and commitment to the specific team strategic elements studied in this research—team purpose, objectives, and strategies. These strategic elements helped define the teams' strategic characteristics and were defined in the team survey, so there was an understanding of these variables by the survey respondents. This helped define the strategic elements being studied and the data the researcher was seeking.

Data were collected from each team member on their perception of how similar or linked was their level of understanding of and commitment to the other members of the team's level of understanding of and commitment to the team's purpose, objectives, and strategies. Team similarity was measured both in terms of understanding and commitment to these strategic elements.

The research calculated team data on similarity of team strategic characteristics as measured by understanding and commitment to team purpose, objectives, and

strategies. This research analyzed the relationship or correlation of a team's strategic characteristics (similar understanding of and commitment to team purpose, objectives, and strategies) to the Team's Performance—measured by the team's self-assessment of its performance and by an external assessment by the team's instructor(s).

The larger the correlation (or r value) is, the stronger the relationship. Any correlation above .3 was considered significant and relevant. The study then analyzed the relationship or similarity between a team's self-assessment of its performance, and the instructors' external assessment of the same team's performance. The researcher theorized that the similarity or alignment of a team's purpose, objectives, and strategies was a strong predictor (a direct correlation) of how well the team members worked together, and effectively communicated in making critical choices vital to the successful performance of the team. Team effectiveness in making decisions and accomplishing the course objectives was theorized to be related to the congruence or alignment of each team member's individual understanding or alignment to their team's goals.

This congruence was measured in terms of the member's understanding of and commitment to the other team members' strategic elements of purpose, objectives, and strategies. How congruent or similar the members' strategic characteristics were, the more effective the team should be in accomplishing its purpose, objectives, and strategies. Accomplishing these team strategic elements would make the team perform better, both as determined by the team's own standards and by the instructors' criteria of learning the course objectives. The flow chart depicts the research model, which helped to visually portray the variables (independent and dependent), research questions, hypotheses, and relationships involved in this research study. The next two sections highlight the two key variables studied, which were Strategic Intent and Team Performance.

STRATEGIC INTENT

The Strategic Intent of the team is defined and highlighted in the flow chart as consisting of three team strategic elements: purpose, objectives, and strategies. Strategic Intent is further defined as to how each team member was focused or had similarly aligned understanding of and commitment to the team's strategic elements (purpose, objectives, and strategies), as measured by surveying each team member. The actual measurement of Strategic Intent was then computed by measuring the overall average team scores for Strategic Intent from the individual members' scores on the team survey.

One of the basic reasons for using the term "Strategic Intent" to highlight the strategic thinking or focus of the teams in this study was to use the previous work of Hamel and Prahaland (1989) in this conceptual or research area. Strategic Intent captures the meaning and nature of the characteristics most representative of what exists in teams or other groups that highlight what they think and perceive about their future goals, vision, or purpose.

As discussed by Hamel and Prahaland (p. 64), an organization's Strategic Intent or focus is part of the "dream that energizes a company and is more sophisticated

and more positive than a simple war cry." These two authors highlighted that Strategic Intent implies a sense of organizational direction, discovery, and destiny. They explained that Strategic Intent is more than the implied particular point of view about the long-term market or competitive position that an organization hopes to build over the coming decade or so. It is the stated and vital focus that makes an organization competitive and driven toward a vision, a future direction, or a destiny that consumes its nature and reason for being (Hamel & Prahaland, 1989).

Throughout corporate universities and many defense industries, the belief prevails that teams make organizations more effective.

This research study embraced a similar meaning and value to team Strategic Intent as developed by Hamel and Prahaland—the committed and understood strategic elements of the team that united or focused team actions and decisions as measured by the team's commitment to and understanding of the team's purpose, objectives, and strategies.

It was theorized that adequate controls of the decision-making processes are in place within the focused team, which facilitate it to be more effective and successful as a decision maker in focusing on the team purpose and objectives. Additionally, it was theorized that a more integrated and focused team within the overall organizational structure, would enable or leverage the organization itself to be higher performing in the long term. Properly disciplined, focused, and integrated teams are the ones that become high-performing teams, and they have been considered "the most versatile unit organizations have for meeting both performance and challenges in today's complex world" (Katzenbach & Smith, 2003, p. xiii).

TEAM PERFORMANCE

The concept of Team Performance and how to measure it is critically important to the successful deployment of teams in any environment (Kraft, 1996). Throughout corporate universities and many defense industries, the belief prevails that teams make organizations more effective. However, few research efforts have measured team effectiveness with empirical data. The research cited in this study focused primarily on the manufacturing teams that can be assessed using operational measures such as productivity, efficiency, delivery time, defects, and scrap (Beyerlein, 1995). Some of the challenges presented in this research study on measuring Team Performance were similar to many studies that relied upon self-reported assessments, especially when measuring Team Performance. Team Performance has been studied

extensively, and many techniques exist to measure it. However, measuring Team Performance in the classroom or even in a program office environment is a challenge without using self-reported or self-assessed performance measures or data.

The nature of the data used in this research necessitated that to obtain team characteristics on Strategic Intent, the natural source of the information would be from the team members. The team members were the most reliable source of information on what they thought about the Team Performance and how similar they perceived their beliefs to be regarding team purpose, objectives, and strategies (Strategic Intent). It would be difficult if not impossible to obtain "true" unbiased, objective data on teams' perceptions of their strategic thinking and their performance without using self-reported data.

The effects of self-reported data have been assessed in this research. It was determined that given the nature of the self-reported team member data (aggregated at team level, collected from different sources, locations, and times), the effects of covariance or overlapping data, as highlighted by Podsakoff and Organ (1986), were minimized in this research.

Obviously, the problems of measuring Team Performance are very complex and difficult to pinpoint. The existing performance measurement systems in place in an organization are usually not aligned with new initiatives or changes, such as team development, occurring in today's workplace. In most of these cases, the measurement systems do not adequately reflect the impact on efficiency and effectiveness of the latest initiatives (Beyerlein, 1995). Because of these many difficulties with the lack of an integrated performance measurement system and the complexities of how teams affect organizations, it is difficult, if not impossible, to effectively measure the value of teams with existing databases or performance management systems. Therefore, self-assessment is recognized as one of the more effective ways to measure Team Performance. The other was from the instructors' assessment of team performance.

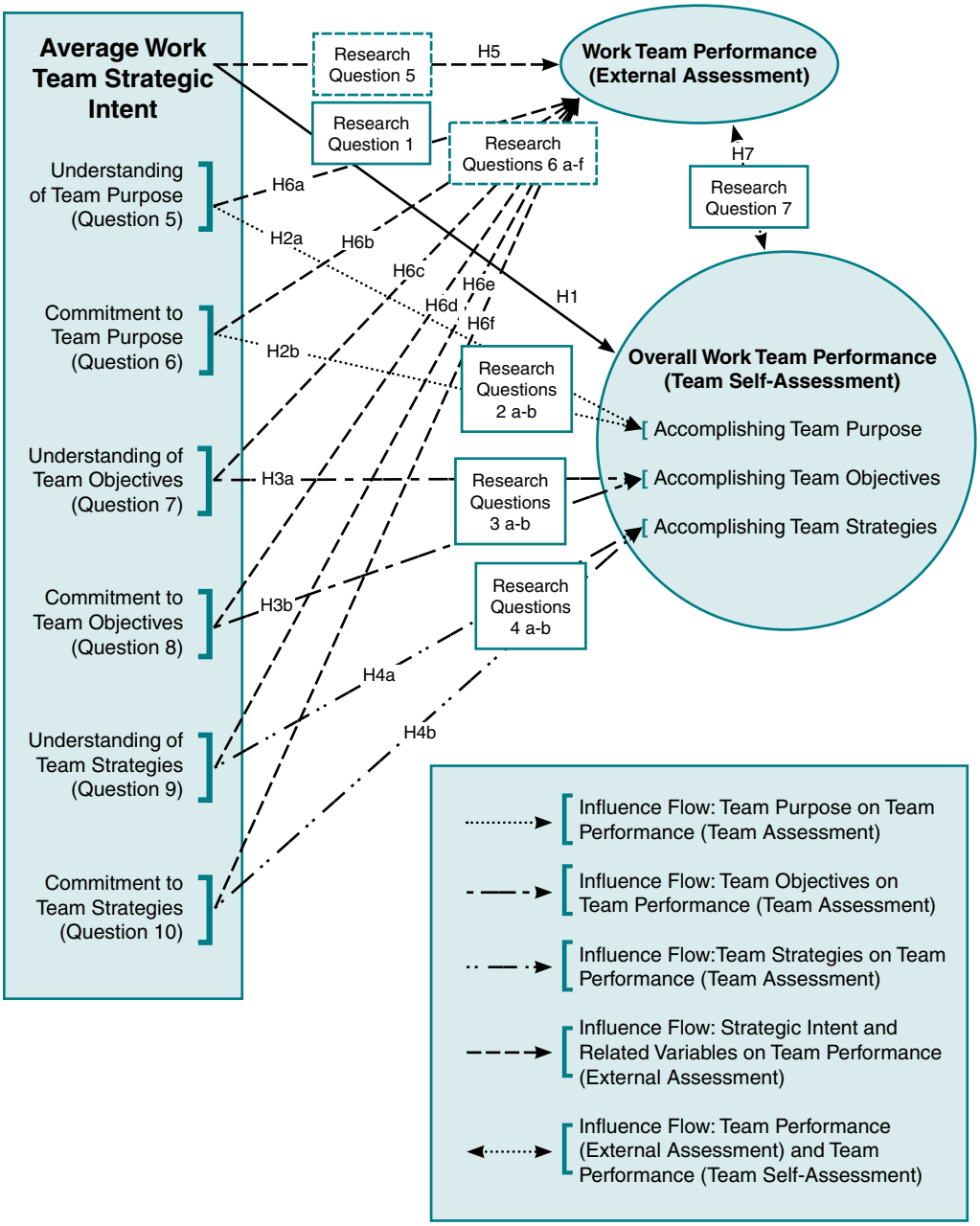
OVERALL RESEARCH SUMMARY AND FINDINGS

The table shown here highlights the relative strength of each of the correlation or relationship tests that was conducted in the study. The italicized entries below identify the original 15 Research Question hypotheses, which were all supported at the 95 percent confidence level, which is considered high in a correlation study. All but the last entry (Question 9 to Instructor Performance) were supported at a 99 percent confidence level (a very low chance of error). All the tests were supported at the 95 percent confidence level.

For this article, the following strength of the relationship or support was used: correlations greater than .7 are considered a strong relationship; from .5 to .699 is considered a moderate relationship; and from .3 to .499 is considered a modest relationship/support. All the relationships in the study were supported at the modest level (.3).

The first entry in the Table highlights the strength of the relationship between overall Team Strategic Intent and Team Performance at .731 (a strong relationship), which underscores the influence that strategic thinking or developing clear and un-

FIGURE 1. DETAILED RESEARCH MODEL WITH HYPOTHESES: WORK TEAM STRATEGIC INTENT AND PERFORMANCE



derstandable strategic elements in a team affects how the team will assess its performance. This is a vital source of information to educators, team and business leaders, and team sponsors/stakeholders. This highlights that a team with a clear set of strategic characteristics of team purpose, objectives, and strategies will more probably develop a strong sense of being a high-performing team. Believing this will empower the team

TABLE 1. TABLE OF RELATIVE STRENGTH OF TESTED VARIABLES

Item	Variables	Pearson's r	p-value	Results
1	Overall Strategic Intent TO Overall Team Performance	.731	.000**	Strongly Supported Hypothesis 1
2	Commitment to Objectives (Question 8) TO Accomplishing Team Objectives (Question 12)	.658	.000**	***Moderately Supported*** Hypothesis 3b
3	Understanding of Objectives (Question 7) TO Accomplishing Team Objectives (Question 12)	.643	.000**	Moderately Supported Hypothesis 3a
4	Commitment to Strategies (Question 10) TO Accomplishing Team Strategies (Question 13)	.640	.000**	Moderately Supported Hypothesis 4b
5	Instructor Performance TO Overall Team Performance	.630	.000**	***Moderately Supported*** Hypothesis 7
6	Understanding of Strategies (Question 9) TO Accomplishing Team Strategies (Question 13)	.625	.000**	Moderately Supported Hypothesis 4a
7	TO Accomplishing Team Purpose (Question 11)	.594	.000**	Moderately Supported Hypothesis 2b
8	Understanding of Purpose (Question 5) TO Accomplishing Team Purpose (Question 11)	.513	.000**	Moderately Supported Hypothesis 2a
9	Commitment to Strategies (Question 10) TO Instructor Performance	.486	.000**	***Modestly Supported*** Hypothesis 6f
10	Understanding of Objectives (Question 7) TO Instructor Performance	.466	.000**	Modestly Supported Hypothesis 6c
11	Overall Strategic Intent TO Instructor Performance	.463	.000**	Modestly Supported Hypothesis 5
12	Commitment to Objective (Question 8) TO Instructor Performance	.405	.002**	Modestly Supported Hypothesis 6d
13	Commitment to Purpose (Question 6) TO Instructor Performance	.352	.007**	Modestly Supported Hypothesis 6b
14	Understanding of Purpose (Question 5) TO Instructor Performance	.349	.008**	Modestly Supported Hypothesis 6a
15	Understanding of Strategies (Question 9) TO Instructor Performance	.330	.012*	Modestly Supported Hypothesis 6e

**Correlation is significant at the .05 level (two-tailed test).*
***Correlation is significant at the .01 level (two-tailed test).*

to greater team results and even more focused performance. This should also produce better results for the organizations that sponsor them. The leader of this team also needs to know that a focused, intent team will believe it will perform well.

The strength of the relationship between Strategic Intent (SI) and Team Performance at .731 (a strong relationship) is compared to the same relationship between Strategic Intent and Instructor-Assessed Performance at .463 (modest relationship/correlation). This indicates that team strategic thinking has a greater relationship to or effect upon Team-Assessed Team Performance than its effect on Instructor-Assessed Team Performance. The strength of team Strategic Intent on the instructors' assessment is significant nonetheless and indicates that team strategic thinking not only affects Team Performance, but also how the team's instructors assessed the team's performance.

Additional correlation tests highlight that when the individual Strategic Intent questions (5–10) are compared to the overall Team-Assessed Team Performance, significant relationships occur. In fact, the results of these tests are similar in strength to the results obtained on the tests between the Strategic Intent questions to their related individual Team-Assessed Team Performance questions (11–13).

In summary, all but one of the tests was significant at .05 level of significance or .95 confidence level. The tests highlighted that in general, strategic intent of the teams was positively correlated or related to both team-assessed team performance and instructor-assessed performance.

ADDITIONAL FINDINGS ON DEMOGRAPHICS DATA

Additional tests were conducted on the measured demographic information and its relationship to overall team Strategic Intent, Team-Assessed Team Performance, and Instructor-Assessed Team Performance. Twelve tests were conducted and only 3 tests were supported at the 95 percent confidence level. Two supported tests related Team Educational Level to Team-Assessed Team Performance and to Instructor-Assessed Team Performance. Other correlation tests indicated a positive relationship between Team Educational Level and overall Team-Assessed Team Performance and Instructor-Assessed Team Performance at a 95 percent confidence level. Educational level can make a difference in Team Performance, both as assessed by the team itself and by the instructors. Although not significant at .05, there is also a positive effect or correlation on overall Team Strategic Intent by team Educational Level. Although not statistically significant, there does appear to be some indication that using teams is an effective learning technique in education, and business leaders employing teams in their organizations who want to enhance strategic implementation of corporate strategic goals and initiatives should be aware that teams with higher educational levels tend to have higher Team Strategic Intent (*correlation of* .239), higher overall Team-Assessed Team Performance (*correlation of* .296), and higher Instructor-Assessed Team Performance (*correlation/modest of* .441). Educational Level has a positive effect/correlation on these three research variables. Education has a rather significant effect on Instructor-Assessed Team Performance (*correlation of* .441).

Team age and years of experience have a negative effect on Team Strategic Intent, on overall Team-Assessed Team Performance, and on Instructor-Assessed Team Performance. The strength of the relationships is low, and the significance levels are high. No relationship was supported at the .05 significance level. Although not supported statistically at .05 significance level, this was of interest to the researcher. Age and experience have negative relationships to all the research variables: Strategic Intent, Team-Assessed Team Performance, and Instructor-Assessed Team Performance.

There is a moderately strong relationship between Team Experience and Team Age (*correlation of* .643). This is logical and passed the common sense test. The results do not affect this research but highlight the strength of the survey data to develop conclusions regarding the survey sample.

CONCLUSIONS

The main conclusions in this research follow:

1. A statistically significant relationship exists between the overall team Strategic Intent and overall Team-Assessed Team Performance. Teams that have high overall team Strategic Intent (team purpose, objectives, and strategies) also have high overall Team-Assessed Team Performance.
2. A statistically significant relationship exists between the individual team Strategic Intent questions (5–10) and overall Team-Assessed Team Performance. Teams that have high results on individual team Strategic Intent questions (5–10) also have high results on overall Team-Assessed Team Performance. More focused teams perform better.
3. A statistically significant relationship exists between the individual team Strategic Intent questions (5–10) and individual Team-Assessed Team Performance questions (11–13). Teams that have high results on individual team Strategic Intent questions (5–10) also have high results on individual Team-Assessed Team Performance questions (11–13).
4. A statistically significant relationship exists between the overall team Strategic Intent and overall Instructor-Assessed Team Performance (Question 4). Teams that have high overall team Strategic Intent (team purpose, objectives, and strategies) also have high Instructor-Assessed Team Performance (Question 4).
5. A statistically significant relationship exists between the individual team Strategic Intent questions (5–10) and individual Instructor-Assessed Team Performance (Question 4). Teams that possessed high scores on each individual's Questions 5–10 dealing with team Strategic Intent also had high Instructor-Assessed Team Performance.
6. A statistically significant relationship exists between the overall Team-Assessed Team Performance (Questions 11–13) and overall Instructor-Assessed Team Performance (Question 4). Teams that have high overall Team-Assessed Team Performance (Questions 11–13) also have high Instructor-Assessed Team Performance (Question 4).

7. A statistically significant relationship exists between the overall Team-Educational Level and overall Instructor-Assessed Team Performance (Question 4). Teams that have high overall Team Educational Level also have high Instructor-Assessed Team Performance (Question 4). There is some indication (supported at .05 significance level) that there is also a relationship between the overall Team Educational Level and *both* overall Team-Assessed Team Performance (Questions 11–13) (supported at .05 significance level) and overall Strategic Intent (Questions 5–10) (not supported at .05 significance level). The more educated the team, the higher the team performance.
8. There is some indication (not supported at .05 significance level) that an indirect or negative relationship also exists between the overall Team Average Age and all of the following: (a) overall team Strategic Intent (Questions 5–10), (b) overall Team-Assessed Team Performance (Questions 11–13), and (c) overall Instructor-Assessed Team Performance (Question 4). The older the team, the lower the team performance.
9. There is some indication (not supported at .05 significance level) that an indirect or negative relationship also exists between the overall Team Average Years Experience and *all* the following: (a) overall team Strategic Intent (Questions 5–10), (b) overall Team-Assessed Team Performance (Questions 11–13), and (c) overall Instructor-Assessed Team Performance (Question 4). The strengths of these relationships and significance levels do not allow for statistical significance of these relationships. The interesting aspect of these studies highlights that with more data and research, age and experience may have statistically significant negative effects on the research variables of overall team Strategic Intent, Team-Assessed Team Performance, and Instructor-Assessed Team Performance.

CONCLUDING STATEMENT

Teams can be a significant resource to business leaders and lead to greater program successes. Using teams can be one of the most potent tools for program managers—readily available to all. Little empirical data exist on what strategic characteristics make teams more effective. Does a work team's success depend on how strategically focused or intent the team is? Do team-developed purpose, objectives, and strategies (strategic intent) have an effect on how well teams perform? This research study hypothesized and proved that work team strategic intent characteristics (team-developed purpose, objectives, and strategies) were directly or positively related to the performance of student work teams.

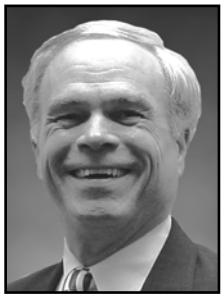
Significant positive correlation relationships were found in all 15 studied hypotheses between work team strategic intent and team performance, as measured by team self-assessments and instructor assessments. Additionally, a positive correlation was found between the team self-assessment of performance and the instructors' assessment of the team performance.

The research provided significant empirical data on the positive correlation relationships between work team strategic intent and work team performance. It

also defined the characteristics that were used to determine the strategic intent of a work team or any work unit. It created empirical support for Katzenbach and Smith's theories from their studies in *The Wisdom of Teams: Creating the High-Performance Organization* (2003) on the success of real teams, based on being committed to a common purpose and performance goals. Additionally, it created a survey to measure the strategic intent of team members and teams in general. Finally, it introduced the study of strategic thinking or use of strategic intent as a method or process for evaluating team performance.

The complexity of team performance and the large number of future potential influences and additional areas of research needed on teams were highlighted in the research. This may help explain why so many organizations using teams in both the public and private sector today are having difficulty as they try to reposition themselves in an ever more turbulent environment, and why teams are often not as effective or successful as possible.

Properly disciplined, focused, and integrated teams are the ones that become high performing teams, and are considered "the most versatile unit organizations have for meeting both performance and challenges in today's complex world" (Katzenbach & Smith, 2003, p. xiii). This study has identified that Strategic Intent or clearly focused team purpose, objectives, and strategies can make teams more high performing and even more versatile and effective in an organization—both in the short- and long-term.



Dr. Thomas R. Edison, currently the Academic Chair for Life Cycle Logistics at Defense Acquisition University West Region, San Diego, CA, has a doctorate from Alliant International University in Strategic Management, a master's degree in Logistics Management from Air Force Institute of Technology, and a master's degree in Education from Chapman University. He is a Certified Professional Logistician by the International Society of Logistics. Dr. Edison has more than 37 years' experience in acquisition and logistics.

(E-mail address: tom.edison@dau.mil)

AUTHOR **BIOGRAPHY**

REFERENCES

Bennis, W. G. (1985). *Leaders: The strategies for taking charge.* New York: Harper and Row.

Bennis, W. G., & Biederman, P. W. (1997). *Organizing genius: The secrets of creative collaboration.* Reading, MA: Addison-Wesley.

Beyerlein, M. (1995). Measuring team performance: The literature. *Work Team Newsletter*, *5*(3), 93–99. Denton, TX: University of North Texas.

Hamel, G., & Prahaland, C. (1989, May-June). Strategic intent. *Harvard Business Review*, *67*(3), 63–76.

Katzenbach, J. R., & Smith, D. K. (2003). *The wisdom of teams: Creating the high-performance organization.* New York: Harper Collins Publishers.

Kraft, R. (1996). *The relationship of team leadership and work team performance.* Unpublished doctoral dissertation, The George Washington University, Washington, DC.

Podsakoff, P. M., & Organ, D. W. (1986, Winter). Self-reports in organizational research: Problems and prospects. *Journal of Management*, *12*(4), 531–542.

We Want to Hear from You!

CALL FOR AUTHORS

We are currently soliciting articles and subject matter experts for the 2009 *Defense Acquisition Review Journal* (*ARJ*) print year. Please see our guidelines for contributors for submission deadlines.

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

- Share your acquisition research results with the Defense Acquisition Workforce.
- Change the way DoD does business.
- Help others avoid pitfalls with *lessons learned* or best practices from your project or program.
- Teach others with a step-by-step tutorial on a process or approach.
- Share new information that your program has uncovered or discovered through the implementation of new initiatives.
- Condense your graduate project into something useful to the Defense Acquisition Workforce.

Enjoy these benefits:

- Earn 25 continuous learning points for publishing in a refereed journal.
- Get promoted or rewarded.
- Become part of a focus group sharing similar interests.
- Become a nationally recognized expert in your field or speciality.
- Be asked to speak at a conference or symposium.

We invite all Defense Acquisition Workforce professionals to submit an article based on research, lessons learned, opinion, or tutorial.

If you are interested, contact the *Defense ARJ* managing editor (DefenseARJ@dau.mil) and provide contact information and a brief description of your article. Please visit the guidelines for authors at http://www.dau.mil/pubs/arq/arqart.asp.

DEFENSE ARJ GUIDELINES FOR CONTRIBUTORS

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

IN GENERAL

We encourage prospective authors to coauthor with others to add depth to their submissions. It is recommended that a mentor be selected who has published before or has expertise in the subject presented in the manuscript.

Authors should become familiar with the construction of previous *Defense ARJ*s and adhere to the use of endnotes versus footnotes, formatting of bibliographies, and the use of designated style guides. *It is also the responsibility of the corresponding author to furnish government agency/employer clearance with each submission*.

SUBMISSIONS

We welcome submissions from anyone involved in the defense acquisition process. Defense acquisition is defined as the conceptualization, initiation, design, development, testing, contracting, production, deployment, logistic support, modification, and disposal of weapons and other systems, supplies, or services needed by the Department of Defense (DoD), or intended for use to support military missions.

RESEARCH ARTICLES

Manuscripts should reflect research or empirically supported experience in one or more of the aforementioned areas of acquisition. Research, lessons learned, or tutorial articles should not exceed 4,500 words. Opinion articles should be limited to 1,500 words.

Research articles are characterized by a systematic inquiry into a subject to discover/revise facts or theories.

MANUSCRIPT SECTIONS

A brief abstract (120-word limit) provides a comprehensive summary of the article and must accompany your submission. Abstracts give readers the opportunity to quickly review an article's content and also allow information services to index and retrieve articles.

The introduction, which should not be labeled, opens the body of the paper and states the problem being studied and the rationale for the research undertaken.

The methods section should include a detailed methodology that clearly describes work performed. Although it is appropriate to refer to previous publications in this section, the author should provide enough information so that the experienced reader need not read earlier works to gain an understanding of the methodology.

The results section should concisely summarize findings of the research and follow the train of thought established in the methods section. This section should not refer to previous publications, but should be devoted solely to the current findings of the author.

The discussion section should emphasize the major findings of the study and its significance. Information presented in the aforementioned sections should not be repeated.

RESEARCH CONSIDERATIONS

Contributors should also consider the following questions in reviewing their research-based articles prior to submission:

- Is the research question significant?
- Are research instruments reliable and valid?
- Are outcomes measured in a way clearly related to the variables under study?
- Does the research design fully and unambiguously test the hypothesis?
- Are needed controls built into the study?

Contributors of research-based submissions are also reminded they should share any materials and methodologies necessary to verify their conclusions.

CRITERIA FOR TUTORIALS

Tutorials should provide special instruction or knowledge relevant to an area of defense acquisition to be of benefit to the Defense Acquisition Workforce.

Topics for submission should rely on or be derived from observation or experiment, rather than theory. The submission should provide knowledge in a particular area for a particular purpose.

OPINION CRITERIA

Opinion articles should reflect judgments based on the special knowledge of the expert and should be based on observable phenomena and presented in a factual manner; that is, submissions should imply detachment. The observation and judgment should not reflect the author's personal feelings or thoughts. Nevertheless, an opinion piece should clearly express a fresh point of view, rather than negatively criticize the view of another previous author.

MANUSCRIPT STYLE

We will require you to recast your last version of the manuscript, especially citations (endnotes instead of footnotes), into the format required in two specific style manuals. The *ARJ* follows the author (date) form of citation. We expect you to use the *Publication Manual of the American Psychological Association* (5th Edition), and the *Chicago Manual of Style* (15th Edition).

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

COPYRIGHT INFORMATION

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

In citing the work of others, it is the contributor's responsibility to obtain permission from a copyright holder if the proposed use exceeds the fair use provisions of the law (see U.S. Government Printing Office, 1994, *Circular 92: Copyright Law of the United States of America*, p. 15, Washington, DC: Author). Contributors will be required to submit a copy of the written permission to the Managing Editor before publication.

COPYRIGHT POLICY

We reserve the right to decline any article that falls into these problem copyright categories:

- The author cannot obtain official permission to use previously copyrighted material in the article.

- The author will not allow DAU to post the article with the rest of the *ARJ* issue on our home page.
- The author requires that unusual copyright notices be posted with the article.
- To publish the article requires copyright payment by the DAU Press.

MANUSCRIPT FORMAT

Pages should be double-spaced and organized in the following order: title page, abstract, body, reference list, author's note (if any), and figures or tables. Figures or tables should not be inserted (or embedded, etc.) into the text, but segregated (one to a page) following the text. If material is submitted on a computer diskette or e-mailed, each figure or table should be saved to a separate, exportable file (i.e., a readable EPS file). For additional information on the preparation of figures or tables, see CBE Scientific Illustration Committee, 1988*, Illustrating Science: Standards for Publication*, Bethesda, MD: Council of Biology Editors, Inc. Please restructure briefing charts and slides to a look similar to those in previous issues of the *ARJ*.

The author (or corresponding author in cases of multiple authorship) should attach to the manuscript a signed cover letter that provides all of the authors' names, mailing and e-mail addresses, telephone and fax numbers. The letter should verify that the submission is an original product of the author; that it has not been published before; and that it is not under consideration by another publication. Details about the manuscript should also be included in this letter: for example, title, word length, a description of the computer application programs, and file names used on enclosed diskettes or in e-mail attachments, etc.

AUTHOR PHOTOS

Please send us a cover letter; biographical sketch for each author (not to exceed 70 words); head and shoulder print(s) or digitized photo(s) (saved at 300 pixels per inch, at least 5 X 7 inches, and as a TIFF or JPEG file); prints of photos will be accepted and returned upon request; one copy of the printed manuscript; and any diskettes. These items should be sturdily packaged and mailed to: Department of Defense, Defense Acquisition University, Attn: DAU Press (*Defense ARJ* Managing Editor), Suite 3, 9820 Belvoir Road, Fort Belvoir, VA 22060-5565.

DEFENSE ARJ PRINT SCHEDULE

2009

The *Defense ARJ* is published in quarterly theme editions. Please consult the DAU home page for current themes being solicited. See print schedule below.

Due Date	**Publication Date**
July 1, 2008	January 2009
November 15, 2008	April 2009
January 2, 2009	July 2009
April 1, 2009	October 2009

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 referees 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 above, or by calling 703-805-3801 (fax: 703-805-2917), or via the Internet at norene.fagan-blanch@dau.mil.

The DAU Home Page can be accessed at: http://www.dau.mil.

Defense Acquisition University Web Site

http://www.dau.mil

Your Online Access to Acquisition Research, Consulting, Information, and Course Offerings

DAU Homepage
- Performance Learning Model
- ACQuire
- DAU Online Resources Tour

I Need Training
- General Information
- Course Schedules
- Apply for a Course
- Pre-Course Information
- Login—Distance Learning Courses
- Browse Distance Learning Courses

Continuous Learning
- Register for Continuous Learning Modules
- Browse Continuous Learning Modules
- Login – Continuous Learning Modules
- Conferences and Symposiums

Knowledge Sharing
- Acquisition Community Connection (ACC)
- AT&L Knowledge Sharing System (AKSS)
- DAU Virtual Library

Performance Support
- Description and Contacts
- Consulting
- Facilitated Decision Making
- Rapid Deployment Training
- Targeted Training
- Ask a Professor (AAP)

Now you can search the DAU Web site and our online publications!

Defense Acquisition Review Journal

ARJ SURVEY

DEFENSE ACQUISITION UNIVERSITY

Please rate this publication based on the following scores:

5 – Exceptional 4 – Great 3 – Good 2 – Fair 1 – Poor

1) How would you rate the overall publication? _____

2) How would you rate the design of the publication? _____

3) Please list all that apply:

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

4) What themes or topics would you like to see covered in future *ARJ*s? _____

5) What topics would you like to see get less coverage in future *ARJ*s? _____

6) How can we improve this publication? Provide any constructive criticism to help us to improve this publication: _____

7) Please specify your organization: _____

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

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

POSTAGE WILL BE PAID BY ADDRESSEE

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

Defense Acquisition Review Journal

ARJ

SUBSCRIPTION

First initial
of last name

Defense ARJ ☐
Quantity _____

Defense AT&L ☐
Quantity _____

☐ **New Subscription**

☐ **Cancellation**

☐ **Change of Address**

Date Form Completed _____

Last Name _____

First Name _____

New Address _____

Old Address _____

Day/Work Phone _____

Signature _____
(Required)

PLEASE MAIL OR FAX TO: 703-805-2917

The Privacy Act and Freedom of Information Act

If you provide us your business address, you may become part of mailing lists we are required to provide to other agencies who request the lists as public information.

If you prefer not to be part of these lists, use your home address. Please do not include your rank, grade, service, or other personal identifiers.

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

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

POSTAGE WILL BE PAID BY ADDRESSEE

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

Insert Cover